

Atulya Nagar
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Intelligent Sustainable Systems

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Intelligent Sustainable Systems

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Preface

The Eighth Edition of the WorldS4 2024—World Conference on Smart Trends in Systems Security and Sustainability will be held during July 23–26, 2024 in a hybrid mode and organized by Global Knowledge Research Foundation and Managed by G R Scholastic LLP. The associated partners were Springer, Springer Nature. The conference will provide a useful and wide platform both for display of the latest research and for exchange of research results and thoughts. The participants of the conference will be from almost every part of the world, with background of either academia or industry, allowing a real multinational multicultural exchange of experiences and ideas.

A great pool of more than 1100 papers were received papers for this conference from across 57 countries among which around 180 papers were accepted with this springer series and were presented through Physical as well as Digital platform Zoom during the 4 days. Due to the overwhelming response, we had to drop many papers in hierarchy of the quality. Total 24 technical sessions were organized in parallel in 4 days along with few Keynotes and Panel Discussions. The conference will be involved in deep discussion and issues which will be intended to solve at global levels. New technologies will be proposed, experiences will be shared and future solutions for enhancement in systems and security will also be discussed. The final papers will be published in four volumes of proceedings by Springer LNNS Series.

Over the years this conference has been organized and conceptualized with collective efforts of a large number of individuals. I would like to thank each of committee members and the reviewers for their excellent work in reviewing the papers. Grateful acknowledgements are extended to the team of Global Knowledge Research Foundation for their valuable efforts and support.

I look forward to welcome you on the 10th Edition of this WorldS4 Conference in 2025.

Liverpool, UK
Windhoek, Namibia
Indore, India
Ahmedabad, India

Atulya Nagar
Dharm Singh Jat
Durgesh Mishra
Amit Joshi

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Dharm Singh Jat received his Master of Engineering and Ph.D. in Computer Science and Engineering from prestigious universities in India. He is a Professor of Computer Science at Namibia University of Science and Technology (NUST). From 1990 to 2014, he was with the College of Technology and Engineering, Maharaṇa Pratap University of Agricultural and Technology—[MPUAT], Udaipur, India. He has guided about eight Ph.D. and 24 master research scholars. He is the author of more than 150 peer-reviewed articles and the author or editor of more than 20 books. His interests span the areas of multimedia communications, wireless technologies, mobile communication systems, edge roof computing and Software Defined Networks, Network security, Internet of things. He has given several Guest Lecturer/ Invited talks at various prestigious conferences. He is a Fellow of The Institution of Engineers (I), Fellow of Computer Society of India, Chartered Engineer (I), Senior Member IEEE and Distinguished ACM Speaker. He also developed experiments based on simulation software for network experiments, research and project work for

undergraduate and postgraduate students. His research in developing video communication platforms for solving QoS issues in video communications and also developed a framework for video transmission over wireless networks for undergraduate and postgraduate students.

Durgesh Mishra has received M.Tech. degree in Computer Science from DAVV, Indore in 1994 and Ph.D. degree in Computer Engineering in 2008. Presently, he has been working as a Campus Director and Director SCSIT, Symbiosis University of Applied Sciences, Indore, India. He was Founder Director, Microsoft Innovation Center at SAIT, Indore, India. He was also a visiting faculty at IIT-Indore, MP, India. He has 33 years of teaching and 15 years of research experience. He completed his Ph.D. under the guidance on Secure Multi-Party Computation for Preserving Privacy. He has published more than 100 papers in refereed international/national journals and conferences including IEEE, ACM conferences. He has organized many such conferences like WOCN, CONSEG and CSIBIG in the capacity of conference General Chair and editor of conference proceedings. His publications are listed in DBLP, Citeseer-x, Elsevier and Scopus. He is a Senior Member of IEEE and held many positions like Chairman IEEE Computer Society Madhya Pradesh Section. Chairman, IEEE MP-Subsection (2011–2012), and Chairman IEEE Computer Society Bombay Chapter (2009–2010). In CSI, Chairman CSI Division IV Communication at National Level (2014–2016). He visited and delivered his invited talk in Taiwan, Bangladesh, Singapore, Nepal, USA, UK and France. He has authored a book on “Database Management Systems”. He has been a consultant to the sales tax and labor department of the government of Madhya Pradesh, India. He has been awarded with “Paper Presenter award at International Level” by CSI. He visited MIT Boston and presented his presentation on Security and Privacy. He also Chaired a panel on “Digital Monozukuri” at “Norbert Winner in the 21st century” at BOSTON. He became a Member of Bureau of Indian Standards (BIS), Government of India for Information Security domain.

Amit Joshi is an entrepreneur and researcher who has completed his graduation (B.Tech.) in Information Technology and M.Tech. in Computer Science and Engineering and completed his research in the areas of Cloud Computing and Cryptography in Medical imaging with a focus on analysis of the current Government Strategies and World forums needs in different sectors on security purposes. He has an experience of around 10 years in academic and industry in prestigious organizations. He is an active member of ACM, IEEE, CSI, AMIE, IACSIT-Singapore, IDES, ACEEE, NPA and many other professional societies. Currently he is the International Chair of InterYIT at International Federation of Information Processing (IFIP, Austria), He has presented and published more than 50 papers in National and International Journals/Conferences of IEEE and ACM. He has also edited more than 20 books which are published by Springer, ACM and other reputed publishers. Apart from this academic involvement he is also associated with the Business and Industry Community across the globe. He is currently the Director of Global Knowledge Research Foundation and major work area is focussed on building and making

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Analysis of Digital Communication Through Facebook for the Construction of an Iconic Brand: Tambo+ 2022



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Abstract The purpose of this research is to analyze digital communication for the construction of an iconic brand, Tambo+ 2022, in Lima, since it belongs to an entity that seeks to implement improvements for the acquisition of new customers and consolidate its position in the market. A qualitative approach was applied, in which 25 publications from the brand's Facebook fanpage were analyzed. Through an observation sheet, the interface, navigation, interactivity, immersion and accessibility and usability were studied. The results showed that the publications do have positive characteristics and facilitate the transmission of the message, mainly through images, which ensure high interactivity. However, improvements in formats are still needed, allowing people with disabilities to interact with publications. In conclusion, there are opportunities for improvement with respect to Tambo+'s digital communication, which must be taken advantage of to transmit messages in accordance with the purpose of brand positioning, so that they lead to the loyalty of a greater number of customers.

Keywords Digital communication · Iconic brand · Tambo · Interactivity · Facebook

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1 Introduction

In early 2020, the COVID-19 pandemic affected much of the world's population, as well as both private and public entities. This highlighted the lack of capacity and speed of some organizations to rethink their communication strategies towards digital media. In many cases, these entities failed to convey an adequate message for the context in which they lived, and some even stopped communicating altogether.

This context accelerated the process of adoption and prioritization of communication through digital means by entities, since most people who were not previously active online users began to interact. This is reflected in studies carried out by We Are Social (2020), which recorded a significant increase in the number of people connected to the Internet, from 321 million in 2019–4,500 million in 2020, and continuing to rise to 4,950 million in 2022. This transformation has drastically changed the way communications are planned. While traditional media was prioritized before, it is now focused on digital media in order to distribute communication, both in terms of branding and performance, which allows connecting with audiences and offering products more effectively. In contrast to traditional media, digital media offers users the possibility of responding instantly, showing interest through comments on publications or expressing their purchase intent through inquiries or direct purchases on websites or e-commerce. However, a lack of feedback or reactions can be interpreted as indifference, while customer discomfort can manifest itself in negative feedback. These comments can lead to a greater reach and the possibility of increasing the number of similar comments.

In the specific case of Peru, both private and public entities needed to expand the reach of their publications, since consumers and the target audience were already generating their own content. In response, Peruvian companies began to look for alternatives to capture the attention of their target audience, including strategic measures to address Internet access gaps in rural areas. According to the National Institute of Statistics and Informatics (2022), 57.4% of Peruvian households have access to the internet, which highlights the importance of choosing strategically among the multiple social media options, such as Facebook, Instagram, TikTok, Twitter, and YouTube [1]. However, according to a report by PeruRetail (2022), only 28% of wineries throughout Peru actively use digital media to manage sales and promote products, mainly through WhatsApp, Facebook, and Instagram. Despite this, many of these new users had a basic knowledge in the use of digital platforms to strengthen their businesses [2]. In Lima, large retailers such as Falabella or Plaza Vea prioritized investment in digital media, strengthening their e-commerce platforms and maintaining a constant presence on social networks. This has proven to be effective, since, according to Ecommerce news (2020), the e-commerce sector has experienced significant growth, cushioning the decline in other sectors such as tourism [3] In this order of ideas, it is important to understand that the challenges that convenience stores such as Tambo+ need to overcome respond to the requirement of correct planning of digital communication. The communicative intention must be oriented towards attracting customers and, with it, their positioning in the market in the long term.

2 Methodology

The following research has a qualitative approach, since it is oriented towards the interpretation of the digital content published by Tambo+ on its social network Facebook. The research is descriptive and aims to detail the most important features of the brand's digital communication. According to Abero et al. (2015), Ecommercenews (2021) highlighted that retail ecommerce cushioned the decline in the tourism sector and grew by more than 250%, mainly supermarkets and department stores [4].

The study reviewed 25 posts from the Tambo+ Facebook fanpage, which were selected from a process from more than 3500 posts. According to Mejia (2000), analyzing between 16 and 25 elements allows us to outline clear findings. One of the main goals on the Facebook platform is to achieve greater interaction between the brand and its audience [5]. Therefore, for the exclusion process, the 25 publications that have a high interaction rate from 2016 to 2022 will be selected, which register more than 134 reactions to the publication, more than 20 comments and 2 shares. These data are determined after analyzing a sample of 25 publications within the Tambo+ fan page. The observation technique and an observation card were used. According to Álvarez (2009), this instrument allows first-hand information to be obtained. To evaluate the digital communication of Tambo+ through Facebook, an observation sheet in Excel was applied [6].

3 Results

When analyzing the 25 publications of the Tambo+ fan page, the following results were obtained:

First, the interface used by Tambo+ 2022 to convey the message through the Tambo+ fan page registered 19 publications were presented in image format, which represents 76%; 4 publications are videos, equivalent to 16%; Finally, 2 publications maintained the mosaic format, which represents 8%. Regarding the analysis of the 25 publications disseminated by Tambo+, it is observed that 92% of them, that is, 23 publications, show a precise message. On the other hand, 8%, equivalent to 2 publications, shows that the format used does not contribute to transmitting the message clearly.

Secondly, the interactivity of Tambo+ 2022 in its digital communication through Facebook is evident, since 100% of the 25 publications analyzed managed to obtain more than 300 reactions. Regarding the reactions seen in the publications on the Tambo+ fanpage, it is observed that 23 publications present the reaction of 'Likes'. In addition, the reaction to 'Me divierte' is found in 15 publications. Likewise, the reaction to 'I love it' is located in 12 publications. It is also observed that the reaction 'It saddens me' is present in 3 publications. Finally, the 'I am amazed' reaction is visualized in 2 publications. It is also noted that 100% of the publications made on the Tambo+ fan page have more than 40 comments. In addition, the 25 publications

analyzed regarding the brand respond to the comments made by its community in their posts. Finally, all the posts shared on the Tambo+ fan page show more than 4 shares each.

Thirdly, the analysis of the communication strategy used by Tambo+ through its fanpage showed that 9 publications have a promotional focus, 8 publications seek to generate affinity and 7 publications have the main objective of promoting interaction. Finally, 1 post is intended to inform. 96% of the publications make it easier for the user to achieve the desired communicational objective, while the remaining 4% do not meet this purpose. As for the thematic axis used in the publications, a clear predominance of the conjunctural approach is observed, since it is present in 11 posts. Likewise, 6 of the publications have a humorous tone, 4 of the publications are focused on the promotion of products or offers. Finally, consumer insight and job postings/stores are represented by 2 posts respectively.

In the analysis of the 25 publications, it is observed that 92% of them present a message consistent with the thematic axis, thus facilitating the fulfillment of the communicational objectives. However, the remaining 8% make it difficult to achieve these objectives. In addition, it is identified that 68% of the publications analyzed have key resources to achieve communication objectives, while the remaining 32% do not present them clearly or do not include them at all. The most used resource in the publications analyzed is the “Call to action”, present in 48% of them, that is, in 13 publications. On the other hand, 30% of the publications do not present any resource that facilitates the fulfillment of the objectives, while 22% include a “Web Link” that allows users to achieve these objectives.

Fourthly, it is observed that 80% of the publications clearly present adjectives or nouns typical of the brand's universe, so they facilitate consumer immersion or involvement. However, the remaining 20% do not include this type of element. The predominant adjective or noun in the publications analyzed is ‘Sobrin@’, present in 18 publications. It is followed by ‘Increasingly closer’, represented in 16 publications. In addition, the terms ‘Tambolovers’ and ‘Tambo is love’ are present in 2 publications respectively.

Fifth, when analyzing the accessibility and usability of Tambo+'s digital communication through Facebook, it was determined that 84% of the publications, that is, 21 posts, do not have audio to reinforce the intention of the publication, mainly because 76% of the publications analyzed are not presented in video format. On the other hand, 16% of the videos analysed do include audio that reinforces the communicational intention. As for subtitles or overprints, it is observed that 64% of the publications analyzed present them, thus facilitating the accessibility of the posts. However, the remaining 36% do not include these elements.

4 Discussion

Valerio et al. (2015) concluded that the image format was the most appropriate to generate greater engagement, while it was specified that the result of the format depended on the published context [7]. In addition, the research of Atarama and Vega, who found that unlike the image format, the audiovisual format allowed it to generate greater interaction from its audience [8]. This is in line with the present research, since the results show that the image format, in 76%, is predominant over the others, since it leads the communicative intention with greater reach to its potential customers. In turn, the format used allowed the message of the publication to be clearly transmitted, finding that 92% did evidence that the format implemented to transmit the message was correct. This means that the image is the right format to give greater visibility to the audience about a message that the brand wants to convey and also with great potential for interaction through social media, but that will ultimately depend on different factors to achieve a positive impact compared to other formats.

Ballesteros (2020) concluded that the most prominent interaction was the 'Like', however, this indicator depended on the thematic axis of the publication, i.e. that the comments or shares maintain superior results [9]. In addition, Garcia (2020) concludes that Facebook is a family platform that allows communities to be generated with a high rate of active participation [10]. This is in line with the results obtained in this research, since it is identified that the publication presents 100% reactions higher than the average of the Tambo+ fan page, likewise, in the results it is identified that the 'Like' reaction predominates in 42%. In addition, those publications that exceed 40 comments per publication stand out in 100%. On the other hand, participation and interaction with potential customers stands out, when the brand responds to the comments made on its publication, while 100% of the participation of Tambo+ in the comments of its audience is evidenced. Finally, the number of shares that are made per publication of the brand is analyzed, while the limit number is established at 4 'shares', therefore, the result obtained showed that, in 100%, the publications did have a high rate of shares. This means that the brand intends to generate interaction through digital communication.

Fernandez and Díaz (2014) linked the content in photographic format with a promotional theme, and also showed that in order to meet the objective it is necessary to have access to the web link [11]. It is also noted that, in other cases, hashtags were added to facilitate the consumption of content in a more organized way. Added to this is the research by Ávila (2017), which concludes that merely informative content does not stand out like events, raffles, coupons or relevant information [12]. In addition, Escobar (2021) concluded that the use of influencers in publications helped the brand generate more trust and achieve its planned goal [13]. This is consistent with the present research, since, in the results, it is evident in 36% that the publications have a promotional objective, in turn, that 96% of the publications did present a clear message to achieve the proposed objective. Likewise, the results agree that the thematic axis with the greatest use in the publications was of a conjunctural nature with 44% of presence. At the same time, it is specified that 92% of the

publications analyzed, with respect to the thematic axis selected for the fulfillment of the objectives set, do respond to this purpose. Finally, 92% do identify that the publication has resources that allow it to meet the objective. In turn, regarding what were the key resources to meet the objective, there was no agreement, since the results indicated with 48% that the main resource was the “call to action”. This means that the conjunctural thematic axis is the one that helps the promotional objective to stand out and achieve its intention, but it must not only have a “call to action” but also a link so that it can achieve its purpose.

Gauthier (2018) concludes that immersion is the transfer of the receiver to the fictional universe, which also reinforces that, thanks to social networks, the receiver begins to bring the elements of said fiction to his reality, creating an inclusivity between both worlds [14]. This is consistent with the present research, since the results show that the brand uses its own nouns or adjectives in 80%, in turn, regarding which were these adjectives or nouns most used in its publications, it was detected that 43% of publications present the word “So-brin@”. This means that the brand will remember it every time it uses different adjectives or nouns of its own when it is used in their daily vocabulary or when interacting with the brand through social networks.

García et al. (2015) conclude that accessibility and usability are important to achieve better interaction, because the inconsistency of the essential elements to achieve this will negatively impact access, employment, and adoption of technologies [15]. The research agrees with this, since the results examine whether the publications have audio to reinforce the intention of the video, so the result reflected in 84% that they did not have it. Likewise, titles or overlays are displayed that reinforce the message and make the content accessible, thus obtaining 64% referring to those that were evidenced during the analysis. At the same time, it can be seen that the publications maintained the same visual structure that identified them, and 84% of them maintain the same structure that allows a quick identification of the brand's content. This means that the publications have average accessibility and usability, since not all publications have sounds, overlays or headlines that reinforce the intention of the content; however, they maintain a visual consistency that will facilitate their identification.

Finally, Majino's (2019) research highlights the importance of social networks to generate and ensure that users recognize brands and also achieve loyalty [16]. In addition, the research of García (2020) highlights that social networks allow the formation of virtual communities that interact constantly [10]. This is consistent with the results, which show a positive interaction, but still to be corrected with respect to the publications of different objectives bypassed the promotional, accessibility and usability, so that people with disabilities can interact with the publications.

5 Conclusions

There is a requirement and acceleration in employing the best practices of digital communication, since the different events forced users to mobilize their acquisition of knowledge and interaction through digital means. The analysis of the Tambo+ brand shows important findings that will allow for improvement opportunities. In relation to the interface, the image format is the most suitable to transmit the messages clearly, this depends on the context in which it is published and also on the message and objective that it is intended to achieve in the user.

Santillán (2006) mentions that the use of language in opinion journalism offers a valuable framework to analyze and improve digital communication, in the Tambo+ brand on Facebook, by applying principles of clarity, persuasion, emotionality, credibility and adaptation to the public, you can strengthen your brand and build a more solid and authentic relationship with your followers [17].

Regarding interactivity, it is evident that the publications shared on the Tambo+ fan page show optimal results in reactions, comments and shares, highlighting in the reactions the element of 'Like', in relation to comments it is visible that the brand does encourage participation, since in each publication it responds to the users who interacted and finally, With the shares, it is clear that they exceed the minimum corresponding to the average of their publications.

In relation to navigation, it was identified that the shared publications have a promotional intention, which seeks to comply with the thematic axis of the conjecture, since it belongs to a sample of high volume of interactions, however, despite the fact that the first two items allow the intention of the publication to be fulfilled, The resource that is most found in the content is the 'call to action', which is rarely accompanied by a link to the website so that the transaction sought by the objective is carried out.

Herrera (2020) concludes that evaluating how social media platforms allow for more direct interaction between diverse audiences and especially their audience, strengthens democratic dialogue. This type of interaction is key to building a brand, as feedback and audience engagement are critical [18].

It is concluded that, in relation to immersion, the brand does present its own adjectives or nouns that allow the participants of its publications to be immersed in the brand's universe. The brand's own word with the most presence in the publications was "Sobrin@", which the brand itself reinforces with the word 'Tío Tambo'.

Finally, regarding accessibility and usability, it is evident that not all the publications made on the fan page are easy to use, since most are published in image format and the few videos do not have overprints or headlines that reinforce the message of the post, however, they do show in most of them the same visual identity that allows the brand's content to be identified more quickly.

References

1. National Institute of Statistics and Informatics (2022) Households with internet connection increase in the second quarter of 2022. INEI: <https://m.inei.gob.pe/prensa/noticias/aumenta-hogares-con-conexion-a-internet-en-el-ii-trimestre-del-2022-13928/>
2. Rojas R (2022) 28% of Peruvian wineries use applications to boost their sales. Tumisoft. <https://www.tumi-soft.com/blog/bodegas-el-28-de-bodegas-utiliza-aplicativos-para-potenciar-sus-ventas>
3. Bravo F (2020) Ecommerce in Peru moved US \$6,000 million in 2020. Ecommerce News.<https://www.ecommerce-news.pe/comercio-electronico/2021/ecommerce-peru-2020.html>
4. Abero L, Berardi L, Capocasale A, Montejo S, Rojas R (2015) Educational research. Opening doors to knowledge. Camus Editions. <https://hdl.handle.net/20.500.12799/4519>
5. Mejía J (2000) Sampling in qualitative research. Soc Res (5):165–180. <https://doi.org/10.15381/is.v4i5.6851>
6. Álvarez-Gayou J (2009) How to do qualitative research. Fundamentals and methodology, Paidós. <http://www.derechoshumanos.unlp.edu.ar/assets/files/documentos/como-hacer-investigacion-cualitativa.pdf>
7. Valerio G, Herrera D, Villanueva F, Herrera N, Rodríguez M (2015) Relationship between publication formats and digital engagement: study of the Facebook pages of Mexican universities. RUSC Univ Knowl Soc J 12(1):50–64. <https://www.redalyc.org/articulo oa?id=78033494006>
8. Atarama T, Vega D (2020) Corporate communication and branded content on Facebook: a study of the official accounts of Peruvian universities. J Commun 19(1):37–53. <https://doi.org/10.26441/rc19.1-2020-a3>
9. Ballesteros C (2020) The frameworks of engagement: Framing and digital engagement in the 2015 Spanish election campaign. OBS Obs*. 14(3):98–119. <https://doi.org/10.15847/obsobs14320201507>
10. García Wong-Kit J (2020) Strategic digital communication for cultural centers: Peruvian Japanese Cultural Center and the Goethe - Instituto Perú. [Master's thesis, National University of Piura].https://pirhua.udep.edu.pe/bitstream/handle/11042/4677/MAE_HUM_GC_001.pdf?sequence=2&isAllowed=y
11. Fernandez G, Diaz J (2014) Children's and young people's thematic channels on Facebook: analysis of the profiles of Disney Channel, Boing and Neox. Commun Man (10):179–194. <https://www.redalyc.org/articulo oa?id=129432541005>
12. Avila Rivas V (2017) The influence of digital marketing on advertising efficiency and its impact on the effectiveness of external communication of university educational services. Case: Technical University of Machala – Ecuador. [PhD Thesis, Universidad Nacional Mayor de San Marcos]. https://cyberentes.unmsm.edu.pe/bitstream/handle/20.500.12672/7166/Avila_rv.pdf?sequence=2&isAllowed=y
13. Escobar Santibáñez P (2021) The digital advertising strategy and its relationship with the positioning of the claro gaming brand. Lima-Year 2019. [Master's thesis, University of San Martín de Porres]. https://repositorio.usmp.edu.pe/bitstream/handle/20.500.12727/9753/ESC_OBAR_SP.pdf?sequence=1&isAllowed=y
14. Gauthier P (2018) Immersion, social networks and transmedia narrative: the inclusive reception modality. Commun Media 27(37):11–23. <https://doi.org/10.5354/0719-1529.2018.46952>
15. García H, Mendoza R, Alvarez F (2015) Design patterns to improve accessibility and use of social apps for older adults. Design patterns to improve accessibility and use of social apps for older adults. Communicate XXII(45):85–94. <https://www.redalyc.org/articulo oa?id=15839609009>
16. Majino Gonzales M (2019) Digital Communication Strategies and their Impact on the Consumer. A proposal for an association of young Peruvians.[Master's thesis, Pontificia Universidad Católica del Perú]. https://tesis.pucp.edu.pe/repositorio/bitstream/handle/20.500.12404/14890/MAJINO_GONZALES_MILAGROS_LIZETTE.pdf?sequence=1&isAllowed=y

17. Santillan R (2006) Language in opinion journalism. Quipus. <https://biblio.flacsoandes.edu.ec/libros/digital/43124.pdf>
18. Herrera M (2020) First part: looks at the journalistic field. Chapter 3: Opinion journalism in the strengthening of democratic processes. Learn Res Resour Cent 63–82. <https://doi.org/10.15332/dt.inv.2020.00535>

Relationship Between Digital Content on Instagram and the Positioning of the Brand ‘Misias Pero Viajeras’ (2022)



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Abstract This research addresses the relationship between Instagram’s digital content and the positioning of the ‘Misias pero viajeras’ brand in the minds of young consumers. The study aimed to determine the relationship between digital content on Instagram and brand positioning among young millennials in Lima during 2022. A quantitative methodology with a correlational approach and non-experimental design was used, using surveys as a data collection instrument. The hypothesis stated the existence of a relationship between digital content on Instagram and brand positioning in the minds of young millennials in Lima in 2022, supported by a Spearman correlation coefficient of 0.699, which indicates a positive correlation. In addition, a significant correlation was found, with a significance value of 0.001 ($p < 0.05$), which confirms the research hypothesis. The sample consisted of 142 respondents. In conclusion, the importance for organizations of having a presence in digital media, developing communication strategies and building loyalty in an online community to achieve a good brand positioning in the market is highlighted.

Keywords Positioning · Digital communication · Social networks · Brand perception · Communication strategies

1 Introduction

The emergence of the Internet has improved the forms of social relations, facilitating the construction of new digital communities and social organizations. This explains why more and more users are deciding to immerse themselves in the digital world in search of new social relationships. If there is a group of people strongly related

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to digital content and its positioning in the market, it is the audience called millennials. Also known as Generation ‘Y’ or the self-taught generation, their age range is between 18 and 35 years old. These users use digital platforms as their main source of information and find in them a space to share information, content and opinions on topics that interest them. They also seek to be aware of the latest news or trends.

Begazo and Fernandez (2015) state that in Peru, millennials are a generation that was born with the internet and digital media present in their lives. Therefore, they use these tools in different areas: communication, education, entertainment, shopping and sources of information through social networks, online channels, digital readings, video blogs and more [1]. A study by Kantar Ibope Media called the Target Group Index (2020) revealed the relationship between millennial consumers and the media, as well as their habits and customs. The result showed that 79% of Peruvians, mostly belonging to Generation Millennials and Generation X, consume five or more media outlets [2].

In Metropolitan Lima, social networks and their digital content are also considered a medium of interest for the millennial generation. Until 2020, Twitter led the list for its immediacy, the ease of linking to the websites of different media outlets and for being a portal where opinions can be issued. Similarly, Facebook and Instagram are platforms where they can find interactive content. In the last year, brands have led on different platforms, especially on Instagram, where you can see trends, videos, reels and photos related to the brands they work with on a daily basis [3].

In this regard, the academic literature collects some background on the subject. First, the brand needs to determine its digital strategy, as it must increase its reach among the target audience. Kotler and Keller (2012) point out that the objective of a brand is to position itself on the chosen social network to be a reference in the consumer’s mind [4]. Ramón and Gutiérrez (2019) argue that digital content on Instagram can quickly go viral, making new users remember the brand [5]. Serrano and Melo (2021) conclude that the content strategy on Instagram influences users, allowing brands to generate impact and sell their services [6].

Secondly, the technical conditions of the platforms where digital content is stored must be optimal, as they facilitate user accessibility and brand recognition. In this regard, Kotler and Keller (2012) state that, due to their visual nature, logos are easy to remember and valuable for identifying products, being associated in memory with the name of the product and the Brand [4]. The logo is the first image that a user associates with the brand and is frequently used in valuable content published on Instagram, such as reels, posts, videos and photos. Likewise, Valera (2020) indicates that the optimization of all a brand’s digital platforms favors user loyalty and allows constant communication with them, which leads, within a certain period, to the creation of a digital community [7].

Third, Chávez (2020) mentions that brand perception is crucial, as it focuses on the ideas that consumers associate with a particular brand or product, which influences their purchase decision, usually determined by emotions [8]. Added to this is the value proposition, i.e., the differentiating factors of a brand that facilitate the purchase decision of the customer or consumer (Castillo, 2016) [9]. These factors drive digital positioning, which seeks to establish the ideal image in the consumer’s

mind through digital skills (Huamán, 2022) [10]. Consequently, according to Díaz and Muñoz (2019), the lack of digital content that adds value for users to identify and become loyal to the brand will cause a company to fail to position itself [11].

Santamaría and Macana affirm that the arrival of digital content and the adaptation to new digital media has caused a change in the traditional concept of opinion leader, giving rise to the concept of influencers. Influencers, thanks to their large number of followers, influence the purchase decision of customers, since users give them an authority status for their extensive knowledge about a particular sector or área [12]. This context has opened up a digital space for Peruvian travel influencers: Daniela Cabrera and Fátima Sotomayor ('Misias pero viajeras'), who in 2016 decided to enter YouTube, Facebook and Instagram and use these platforms to publish videos of their travels, their experiences, tips and reviews for their followers in a fun way. Their digital content is usually shared on their social networks daily and mainly covers tips on how to travel to tourist destinations with a small budget and ideas of what to do in these destinations for free or at a low cost, generating that their audience has a pleasant experience and knows that you do not need a high budget to travel around the world [13].

They discovered a little-served market in Peru and, from there, they began to generate digital content that has positioned them as the travel influencers with the highest engagement in the country (3.85%), during the research stage, they registered 683 thousand followers on Facebook, more than 968 thousand subscribers on their main YouTube channel, more than 941 thousand followers on TikTok and more than 973 thousand followers on Instagram. In this way, the target audience of 'Misias pero viajeras', young millennials, turn to its pages to obtain information on low-cost travel and recommendations of tourist places. Thus, this brand influences the travel decision-making process of young people and has positioned itself as a benchmark in the travel industry in Peru. In this sense, Vásquez, Sánchez, and Bolívar (2018) highlight that "digital pedagogical spaces are in permanent definition and construction, which implies a constant adaptation and evolution of their training elements". This statement applies to the way influencers like 'Misias pero viajeras' have continuously built and adapted their digital content to maintain relevance and engagement with their followers. By creating content that addresses the specific needs and wants of their audience, these influencers have established an educational space where followers can learn about affordable travel and travel planning [14].

Research conducted and published by We Are Social and Hootsuite (2022) [15] shows that the growth of users on social networks continues to rise, with the number of users on social networks being equivalent to 58% of the world's population. In addition, they conclude that the digital platforms with the highest concentration of users are Facebook, YouTube, WhatsApp, Instagram and TikTok, which highlights the importance of digital content creation for the positioning of a brand in the minds of users. According to Hall (2020), the same report reveals that Instagram is the second favorite social network of users between 16 and 64 years old, who consider it the best space to receive news and publish content [15]. Therefore, this research will work with the social network Instagram to identify the relationship between the

digital content shared in this medium and the positioning of the brand ‘Misias pero viajeras’ in the minds of young millennials in Lima.

2 Methodology

The approach considered for this research is quantitative-correlational, since its purpose is to find the degree of relationship between two or more variables of interest. The type of research is basic, since the data required will be obtained by means of a measurement instrument, which in this case will be a survey. The design is non-experimental and the focus of the study is cross-sectional [16].

The population was considered to be the followers of ‘Misias pero viajeras’ who reside in the district of Comas and who are in the age range of 20 to 24 years, which is the age standard that is included in the millennial generation, totaling approximately 2,449 people according to a study published by DIRIS of Lima Norte in 2019. The sample was determined through simple probabilistic sampling, resulting in an adjusted sample size of 142 people. Therefore, the technique used for data collection in this research is the survey [17].

A questionnaire of questions was used to collect the information that included the two study variables. The questionnaire was composed of 23 questions using the Likert scale. Data collection was carried out virtually through the Google Forms platform. The instrument was applied to a sample of 142 young people aged 20 to 24 who reside in the district of Comas and who are followers of the brand ‘Misias pero viajeras’, obtaining the necessary information on the study variables. A pilot test was applied with the aim of measuring the level of reliability, in which 20 people were surveyed. By means of two statistical tests of Cronbach’s alpha, the questionnaires for both variables were validated. In the validation of the first questionnaire for the variable ‘Digital content on Instagram’, a result of 0.865 was obtained, which means that the level of reliability is high. In the validation of the second questionnaire for the variable ‘Positioning’, a result of 0.931 was obtained, which indicates that the level of reliability is high.

3 Results

38% of all respondents consider that the images published on the Instagram of ‘Misias pero viajeras’ are always interesting and novel. Similarly, another 38% consider that such images are almost always interesting and novel. Of the total number of respondents, 41.5% indicate that the videos published on the Instagram account of ‘Misias pero viajeras’ are almost always interesting and novel, followed by 40.1% who consider that the videos are always interesting and novel. Regarding the positioning of the ‘Misias pero viajeras’ brand in the minds of young people, it was determined to be strong. 48.6% and 38% of respondents always and almost always remember

the type of content the brand offers, respectively, while 35.9% and 39.4% always and almost always recognize the attributes the brand offers on its platform. In addition, 46.5% and 37.3% of respondents always and almost always consider the brand as a reference for travel bloggers in Peru.

Regarding the sample of respondents, 42.3% consider that the Instagram account of ‘Misias pero viajeras’ almost always publishes content constantly, followed by 37.3% who consider that the Instagram account of ‘Misias pero viajeras’ always publishes content constantly. Likewise, it is shown that, of the total number of respondents, 31% almost always interact with the content published by ‘Misias pero viajeras’ on their Instagram account, followed by 29.6% who sometimes interact with the content published by ‘Misias pero viajeras’ on their Instagram account.

Likewise, the degree of correlation between digital content on Instagram and the positioning of the brand ‘Misias pero viajeras’ was determined using Spearman’s Rho, whose value is 0.558. This indicates a considerable positive correlation, with a significance value of 0.001. Therefore, digital content on Instagram is related to the positioning of the brand in the minds of young millennials in Lima in 2022. In this way, the null hypothesis is rejected and the alternative hypothesis is accepted.

4 Discussion

The relationship between digital content on Instagram and the positioning of the brand ‘Misias pero viajeras’ in the minds of young millennials in Lima, 2022, was identified. The results obtained showed a direct and positive relationship between the study variables, digital content and brand positioning, as evidenced by Spearman’s coefficient of 0.699, which indicates a moderate positive correlation. These findings coincide with what was stated by Saldaña, Serrano and Melo, who affirm the influence of social networks on tourist destinations and travel [6, 18]. In addition, they point out that Instagram is an effective tool to position a brand in the market, as long as it offers valuable content that attracts the attention of users. Similarly, We Are Social & Hootsuite (2022) reaffirm the importance of using Instagram for brands, revealing that it is the second favorite social network among users aged 16–64, who consider it the best space to receive information and publish content according to their preferences [15]. In this sense, it is concluded that the digital content on Instagram of the brand ‘Misias pero viajeras’ generates a closeness between the creator of the content and the user who receives it.

The relationship between the types of content and the positioning of the ‘Misias pero viajeras’ brand in the minds of young millennials in Lima in 2022 was identified. In this research, it was determined that the degree of correlation has a value of 0.715, indicating a considerable positive correlation and a significance level of 0.001. In other words, the types of content are related to the positioning of the brand ‘Misias pero viajeras’. The content provided to its users is valuable and attractive to them, which explains its constant consumption. Therefore, the null hypothesis is rejected and the alternative hypothesis is accepted, which establishes a relationship between

the types of content and the positioning of the ‘Misias pero viajeras’ brand in the minds of young millennials in Lima in 2022. These results are corroborated by Diaz and Muñoz (2019), who concluded that the positioning of a brand in a certain period of time achieves customer loyalty, which in turn improves content and allows brand growth [11]. Constant interaction is key to good positioning; To achieve valuable content, it is crucial to know the user, from their preferences to the elements that they are not interested in or dislike.

The relationship between the frequency of publications and the positioning of the ‘Misias pero viajeras’ brand in the minds of young millennials in Lima in 2022 was identified. When analyzing the relationship between the frequency of publications and brand positioning, a correlation coefficient of 0.558 was obtained, which indicates a moderate positive correlation. Therefore, the hypothesis that affirms the relationship between this dimension and the positioning variable is accepted. These results coincide with what was stated by Serrano and Melo (2021), who concluded that the content offered by a brand on Instagram must be constantly innovated and updated to generate positioning and stand out on the social network [6]. In addition, Ramón and Gutiérrez (2019) agree that reach on Instagram is linked to the frequency of publications made by entrepreneurs. Consequently, it is concluded that there is a considerable relationship between the frequency of publications and the positioning of the brand ‘Misias pero viajeras’. The frequency with which content is posted on Instagram plays an important role in generating positioning in the public’s mind [5].

The relationship between the response achieved and the positioning of the ‘Misias pero viajeras’ brand in the minds of young millennials in Lima in 2022 was identified. After determining this relationship, a correlation coefficient of 0.309 was obtained, which indicates a low positive correlation with a significance of 0.001. This shows that there is a relationship between both elements, so the hypothesis raised is accepted. These results coincide with the findings of Pérez et al. (2013), who point out that a simple ‘like’ represents a commitment between the user and the publication, which contributes to the user remembering the brand and positioning it in their mind, becoming a loyal user [19]. Likewise, Serrano and Melo (2017) highlight the importance of receiving feedback from users on Instagram posts to develop content that meets their needs, thus favoring brand positioning [6]. Therefore, it is concluded that the response achieved and the positioning of the brand ‘Misias pero viajeras’ are positively related, although at a medium level, suggesting the need to reinforce the interaction with the brand’s followers.

The relationship between the environment and the positioning of the ‘Misias pero viajeras’ brand was identified in the minds of young millennials in Lima in 2022. The results obtained indicate a correlation coefficient of 0.756, which indicates a high significant correlation, with a significance of 0.001, that is, there is a positive and considerable relationship between both elements, which leads to the acceptance of the hypothesis proposed. Valera (2020) supports these results, stating the need to optimize organizations’ digital accounts to promote user loyalty and create a well-positioned digital community [7]. Fajardo and Baena (2021) also agree on the importance of keeping the digital environment up to date in order to attract users to the brand. Consequently, it is concluded that the relationship between the environment

and the positioning of the brand is significant and considerable: as the brand ‘Misias pero viajeras’ operates in an optimal and attractive environment, it will be able to position itself more strongly in the minds of its audience [20].

5 Conclusions

The results support the general hypothesis that there is a relationship between digital content on Instagram and brand positioning ‘Misias pero viajeras’, with a correlation of 0.699, classified as a moderate positive correlation. This indicates a direct and significant relationship between the variables studied. Therefore, it was determined that the digital content on Instagram of the brand ‘Misias pero viajeras’ is of great importance to its consumers. 42.3% and 37.3% of those surveyed consider that the content published on this social network is almost always and always constant, respectively. Videos and reels are the most widely accepted types of content by the public. In addition, 40.8% and 38% of respondents always and almost always find the content published on Instagram visually attractive and valuable.

Regarding the relationship between the dimensions of digital content on Instagram and the positioning of the brand ‘Misias pero viajeras’, it was concluded that it is positive and considerable. The correlation coefficient of 0.715 indicates a high positive relationship. As for the relationship between the frequency of publications and brand positioning, a correlation coefficient of 0.558 was identified, indicating a moderate significant relationship. As for the relationship between the response achieved and brand positioning, a coefficient of 0.309 was identified, indicating a low positive relationship. However, the relationship between environment and positioning was identified with a correlation coefficient of 0.756, which indicates a high significant relationship.

References

1. Begazo J, Fernández W (2015) Peruvian millennials: characteristics and life projections. *J Res Fac Adm Sci, UNMSM* 18:36. <https://revistasinvestigacion.unmsm.edu.pe/index.php/administrativas/article/view/11699/10489>
2. Purisaca Díaz R (2020) The information preference of millennials in multiplatform media, in the context of COVID-19, 2020. [Bachelor’s Thesis, San Martín de Porres University]. <https://hdl.handle.net/20.500.12727/7489>
3. Díaz Castillo G, Laserna Narrea A, Negrete Valle R, Samaná Ubillús F (2020) Factors associated with the digital purchase decision of Millennial consumers in Metropolitan Lima in 2020. [Master’s Thesis, Pontificia Universidad Católica del Perú, CENTRUM]. <https://tesis.pucp.edu.pe/repositorio/bitstream/handle/20.500.12404/20064/Millennials%20de%20Lima%20Metropolitana-DIAZ.pdf?sequence=1&isAllowed=y>
4. Kotler P, Keller K (2012) Marketing management. Pearson. <https://www.montartuempresa.com/wp-content/uploads/2016/01/direccion-de-marketing-14edi-kotler1.pdf>

5. Ramón MP, Gutiérrez MC (2019) The role played by the social network Instagram in the positioning of clothing ventures in Bogotá. [Bachelor's Thesis, College of Higher Studies in Administration]. <https://repository.cesa.edu.co/bitstream/handle/10726/4300/ADM2019-163.pdf?sequence=1&isAllowed=y>
6. Serrano Díaz A, Melo Rodríguez A (2021) Instagram and the positioning of pastry ventures: Yiyi pastry case. [Bachelor's Thesis, College of Higher Studies in Administration]. <https://repository.cesa.edu.co/handle/10726/415>
7. Valera Mendoza A (2020) Digital content strategy to enhance the SEO positioning of the NGO Institute of Watershed Management. [Bachelor's Thesis, University of Piura]. <https://pirhua.udep.edu.pe/handle/11042/4767>
8. Chávez T (2020) Fashion marketing and the perception of branding of the company Fly Boutique, Trujillo 2020. [Bachelor's Thesis, Universidad Privada del Norte]. <https://repositorio.upn.edu.pe/bitstream/handle/11537/28372/Chavez%20Alvarez%20Tatiana%20Atonella.pdf?sequence=1&isAllowed=y>
9. Castillo Martínez M (2016) Value proposition: A graphic design tool. [Bachelor's Thesis, Universidad Piloto de Colombia]. <http://polux.unipiloto.edu.co:8080/00003154.pdf>
10. Huamán Ríos KL (2020) Digital marketing strategies and brand positioning Arujoyas, in Trujillo, 2020. [Bachelor's Thesis, Universidad Privada del Norte]. <https://hdl.handle.net/11537/27792>
11. Díaz Vigo C, Muñoz Luna M (2019) Use of social networks in the brand positioning of a women's boutique in the city of Trujillo in 2019. [Bachelor's Thesis, Universidad Privada del Norte]. [Repository of the Universidad Privada del Norte. http://hdl.handle.net/11537/22340](http://hdl.handle.net/11537/22340)
12. Santamaría E, Meana R (2017) Social networks and the "influencer phenomenon". Reflections from a psychological perspective. *Miscelánea Comillas* 443–449. <https://revistas.comillas.edu/index.php/misclaneacomillas/article/view/8433/8014>
13. Cabrera D, Sotomayor F (2016) Misias pero viajeras [Video]. <https://www.youtube.com/@misiasperoviajeras>
14. Vásquez A, Sánchez L, Bolívar W (2018) Digital pedagogical spaces in permanent definition and construction. An analysis from the formative elements. *Pedagog Knowl* 48:71–82. <https://revistas.pedagogica.edu.co/index.php/PYS/article/view/7374/6011>
15. Hall S (2022) Digital report 2022: The report on digital, social and mobile trends. We Are Social. <https://wearesocial.com/es/blog/2022/01/digital-report-2022-el-informe-sobre-las-tendencias-digitales-redes-sociales-y-mobile/>
16. Hernández R, Fernández C, Baptista P (2014) Research Methodology (6th ed.). McGraw Hill. <https://www.esup.edu.pe/wp-content/uploads/2020/12/2.%20Hernandez,%20Fernandez%20y%20Baptista-Metodolog%C3%A1da%20Investigacion%20Cientifica%206ta%20ed.pdf>
17. Gonzales Saravia T, Quispe Almonacid H (2019) Analysis of the influence of Misias pero Viajeras on the travel decision-making process of millennials in Lima, 2019. [Bachelor's Thesis, César Vallejo University]. https://repositorio.ucv.edu.pe/bitstream/handle/20.500.12692/44559/QUISPE_AH%20-%20SD.pdf?sequence=1&isAllowed=y
18. Saldaña Púcar K (2020) Digital communication strategies used by Lima's millennial micro and macro influencers on Instagram, specialized in the tourism sector [Bachelor's Thesis, Universidad Científica del Sur]. <https://repositorio.cientifica.edu.pe/bitstream/handle/20.500.12805/1277/TB-Salda%C3%B1a%20K.pdf?sequence=1&isAllowed=y>
19. Pérez A, Lloves B, Merino M (2013) The interaction of users on the Facebook profiles of the Spanish press. *Keyword* 16(3):842–872. <https://www.redalyc.org/articulo.oa?id=64930924008>
20. Fajardo Montes C, Baena Gutiérrez C (2021) Instagram: Positioning factor in the luxury fashion industry in Colombia. [Bachelor's thesis, College of Higher Studies in Administration]. <https://repository.cesa.edu.co/handle/10726/4339>

News Coverage of News Related to the Far-Right Collective La Resistencia



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Abstract At the international level, journalistic treatment stands out for detecting what is the orientation of the media in the face of various problems. This research contributes to the journalistic treatment or the theory of the square, in Peru, using the qualitative approach. News related to the far-right group ‘La Resistencia’ is documented through 26 observation sheets. This study reviewed the television sequences found on the YouTube platforms of two news channels. The frequency of appearance of the elements that make up the television news treatment, the audiovisual language, the informative intentionality, and the use of journalistic genres were recorded. As a result, 100% of the files found the appropriate use of audiovisual resources and a permanent use of journalistic genres. However, the intentionality of information is only present in 73% of the files. Therefore, it is concluded that there are informative spaces, in which the time for the contrast of information is minimized and that use narratives that connect with the audience by constructing narratives full of emotions.

Keywords Information treatment · Extreme right · La Resistencia · News · Journalism · Social networks

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1 Introduction

At the international level, the analysis of journalistic treatment allows us to identify the orientation of the media outlet in the face of various problems. First, according to De Frutos and Vicente [1], the media play an important role in the construction of public opinion, so coverage that highlights only negative aspects could influence the audience's perception. For example, in 2018, the International Organization for Migration (IOM) denounced that the limited research in European newspapers on immigration led to a news treatment that reproduced stereotypes [1]. That action reinforced public disapproval of people fleeing their countries because of conflict. Second, García and Zepeda [2] point out that one of the qualities for the construction of information is time, which is not unlimited. Within the time allotted, the journalist must verify the content he receives and evaluate whether it meets the criteria of immediacy, veracity, novel style, precision, brevity and expressive vigor of the news. However, the COVID-19 pandemic in 2020 accentuated the overproduction of information in the real and virtual world. The use of digital tools by people without training or ethics can increase fake news and the management of data at the convenience of public and private entities.

In this regard, several authors documented the journalistic treatment of the Peruvian media. First, Navarrete [3], in his analysis of the news treatment of the América Noticias Edición Central program of the América Televisión channel, uses the concept of 'the civilization of the spectacle' to evidence sensationalism in the news of a murder. Under a semiotic analysis, he concludes that the use of the color red as a background tool in the images, the intimacy of the victims, and the emphasis of both the music and the words 'macabre' and 'horrendous crime'; they construct a narrative of fiction to entertain the public [3]. Second, Montero [4] analyzes a report on Marcelo Odebrecht, CEO of the Odebrecht organization, on the Cuarto Poder program during the crisis of the government of then-President Pedro Pablo Kuczynski (PPK). In this journalistic work, although the CEO's statements are contrasted with archival material, very little time is devoted to the relationship between Brazilian companies and President PPK [4]. Third, Ferro [5] points out that journalists are the recipients of political actors to build the public sphere, which is accentuated in electoral processes. He analyzed the informative articles of the newspapers 'El Comercio' and 'La República' on the candidacy of Ollanta Humala, in the week prior to the second round of the 2011 general elections, and showed that the photographic story, the headline, the journalistic sources, as well as the models depended on the perspective of the journalist and the company [5].

On the other hand, on November 17, 2020, the digital portal of the newspaper Perú21 reported, under the title ‘Fake news spread against protests in Lima’, that the journalistic team had received images of homemade weapons seized during the demonstration against the government of Manuel Merino [6]. The media outlet clarified that the photographs were real, but that they belonged to evidence seized by the Carabineros de Chile, making it clear that it was fake news [6]. However, they were presented as true news during the ‘King with a Beard’ program on the WillaxTv channel, and he attributed them to the demonstrations that took place in Lima [6]. In the same way, on November 17, 2020, the podcast of ‘La Encerrona’ on the YouTube channel of journalist Marco Sifuentes denied and added “The extreme right is the largest manufacturer of fake news in Peru, it has a channel dedicated to that, which is called Willax, whose owners are Mr. and Mrs. Wong, who took 30 million soles from Reactiva (Peru) according to Ojo Público” [7]. On March 9, 2021, the Útero.pe portal titled ‘8 Fake News from Erasmo Wong’s channel (which is already a danger to public health)’, an investigation in which it compiles eight fake news stories spread by said channel, six of them were fake news about vaccines against Covid-19 and the remaining two on political issues [8]. On March 10, 2021, in the opinion column entitled ‘Willax and the ‘fake news’’, by Andrés Calderón’, on the website of the newspaper El Comercio, the author points out the damage of a fake news about the Sinopharm vaccine, broadcast on the Willax TV channel [9]. In it, he clarifies the difference between freedom of the press and malicious intent [9].

For the above, this research is based on the question: What is the informative treatment of the news related to the extreme right-wing collective La Resistencia? In 2022, it was chosen to document the journalistic notes about the collective, which were published on the YouTube platform of the channels ‘Éxito Noticias’ and ‘Willax TV’. This study does not have hypotheses, since it focuses on qualitative methodology, which serves as a guide for the systematization of information [10]. Therefore, it does not start with a hypothesis, since new premises are generated through the data obtained.

For the authors Fernández and Sánchez [11], the theory of framing is present in journalistic treatment, since the media encode and transmit versions of the world, forming frameworks of interpretation, which will generate an opinion through the narrative used. In their study, it was determined that the journalistic sources to construct information about a corruption case came from the police and the prosecutor’s office. Precisely, the preliminary police version was considered conclusive and ended up as a starting point for other reports. Likewise, the journalists interviewed admitted that the journalistic account of the people involved generated expectations in public opinion, since the media constructed archetypes of the characters [11]. It narrates a struggle between good and evil, in which judges and police officers are heroes; and the others are villains. The lawyers claimed that this account made it difficult to believe the alleged innocence of the defendants and formed a judgment in the opinion before the oral trial [11].

Abubakar [12] points out that journalistic treatment is a reference to the concept of framing where, depending on the capacity of the media, certain aspects of a story stand out through the process of selecting, framing, and shaping information. In its study, it determined that journalists considered news about Boko Haram to be in the public interest [12]. This last point is reflected in the choice of name by reporters, Boko Haram is used to call these groups derogatorily and so they were presented in the media [12]. Another case is that of the media, including the BBC, which called the extremist group Da'esh ISIS or Islamic State, a term that its members like, but which is rejected by other Muslims, since it confuses terrorism with their religion [12]. A group of reporters also clarified that the use of words such as 'terrorists' or 'insurgents' to describe them depended on the publisher [12].

In Peru, the author Montero [4] points out that journalistic treatment is the selection of journalistic content according to the public interest (mostly political), which has an impact on public opinion for days or weeks. The study determined that the Sunday program 'Cuarto Poder' marks what will or will not be news by adjusting to the interest of the public [4]. Its content stands out for its novel aspect, its in-depth analysis, interviews with the characters of the week and because it resorts to the search for the counterpart [4]. Likewise, Navarrete [3] mentions that journalistic treatment gains notoriety when the audience interprets the message. Their study determined that sensationalism persists in television journalism and that the program 'América Noticias Edición Central' builds its content with fictional techniques to entertain the public [3].

For the above, the journalistic treatment shapes the content with a certain approach. This action is linked to the framing theory, which transmits a message that is oriented according to the editorial line or the journalist's judgment [13]. Likewise, the media seek interpretations of the problem through the information provided and the information excluded [14]. Within the journalistic treatment, various aspects are developed. Firstly, there are the modes of representation of the news, which are based on the resources of the medium or platforms on which they will be shown, for example, through audiovisual language and testimonies [4]. Television audiovisual language in journalism is used to entertain the public and generate emotions through the use of images, voice-over, editing and post-production [3]. Testimony is a key resource, as it manifests the reality of the facts and offers dynamism to the reports. However, it must be strategically selected to avoid inconsistencies [4]. Secondly, the concept of informative intentionality is developed, which can violate impartiality, as well as the journalist's objective, and which is evidenced in the adoption of a position when transmitting a message [13]. Thirdly, the concept of journalistic genres is developed, which divides content into informative, opinion, and hybrid [15].

2 Methodology

The present research applied the qualitative approach, since it allows recording the data that is produced in relation to an event, phenomenon or problem [16]. Likewise, the flexibility of its design does not have a single process for data analysis and production [17]. The study addressed the phenomenological paradigm, due to the fact that the journalistic treatment of two television sequences was documented, which record interviews with the leader of the far-right collective ‘La Resistencia’ and which are found on the YouTube platform of the Willax TV channels, as well as Éxito Noticias. According to Behar [18], the experiences shared with respect to the topic under investigation focus on the interpretation of the subjects’ meanings. For the research, the content analysis technique was applied, which helped to obtain the data [19]. Likewise, the observation technique was applied, because the study focuses on documenting the information treatment in two television sequences. This is a selective technique in which the interaction of the participants takes place in a certain context, so the observer must be alert to details [20, 21]. In this sense, for data collection, it was decided to use the observation sheet, which was built from the instrument proposed by Bach & Bach [15].

Depending on the objective, the programs ‘Politics’ of the Willax TV channel and ‘Hablemos Claro’ of Éxito Noticias were selected, since in both the leader of the extreme right-wing collective ‘La Resistencia’ was presented. In addition, the media preserved the interviews in their entirety and recorded them on their YouTube platforms, which allows access to said content. In addition, the first media outlet chosen had a history of malpractice. For example, Azorsa [22] mentions that, during the pandemic, Willax TV broadcast news, which was later classified as fake news. For his part, Peves [23] indicates in his thesis that the language of his news program hosts shows sympathy for political figures linked to the right.

Data collection was carried out on the interview sequences with the leader of the far-right collective ‘La Resistencia’, on the September 18, 2021 program, on Willax TV, and on the September 25, 2021, program on Éxito Noticias. The study focused on journalistic treatment (modes of representation of the news, informative intentionality and television journalistic genres). It is necessary to specify that the advertising segments were excluded. For the analysis of the data, descriptive statistics were applied, which allows determining the frequency of appearance of the categories and subcategories involved in the study [24, 25].

3 Results

The journalistic treatment of the interview sequences with the leader of the far-right collective ‘La Resistencia’ in the programs ‘Políticas’ on the Willax TV channel [26] and ‘Hablemos claro’ on Éxito Noticias [27] was analyzed. Through the application

of 26 observation sheets, information was recorded on the modes of representation, informative intentionality and journalistic genre. The general objective of this research is to document the informative treatment of news related to the far-right collective ‘La Resistencia’, which were published on the YouTube platform of the channels ‘Éxito Noticias’ and ‘Willax TV’. The findings are detailed below based on the objectives.

In relation to the first specific objective, the modes of representation of the news involve the ‘audiovisual language’, composed of image, sound and editing, as well as the ‘testimony’, composed of the manifestation of reality and the story of the protagonist or witness. It is observed that in 100% of the sequences analyzed, the resources of audiovisual language are used. Therefore, there is an adequate image, sound and editing that allow the observer to concentrate on the drivers, as well as on the interviewee. In relation to ‘testimony’, it was observed that in 23% of the files reviewed, the ‘manifestation of reality’ is appreciated, that is, events that can be corroborated are referenced. Likewise, in 96% of the observation cards the ‘Story of the protagonist or witnesses’ can be seen. The rest is occupied by a third person, who expresses his opinion on the testimony of the leader of the far-right collective ‘La Resistencia’.

In relation to the second specific objective, the informative intentionality of the news involves ethics (moral commitment of the journalist to himself), responsibility (commitment of the journalist to the community) and veracity (commitment to the search for the truth). It is observed that 73% of the files comply with the three aspects of informative intentionality. On this total, it is necessary to specify that 14 files correspond to the ‘Let’s Talk Clear’ program [27] and one file corresponds to the ‘Policies’ program [26]. The remaining 11 files do not show the aspects of informative intentionality. For example, in the video entitled ‘Demonstration of the group La Resistencia’ [26], starting at minute 6:38, of the second video of the interview, the host of the program indicates that the Institute of Legal Defense (IDL) is favored in defamation lawsuits.

In relation to the third specific objective, the television journalistic genres of the news are informative (characterized by objective language and the account of the facts), the opinionated (composed of the interpretation of the facts and subjectivity) and the hybrid (composed of the chronicle and the mixture of objective content, as well as subjective) [15].

In relation to Table 1, it can be seen that the sequences analyzed involve the three indicators (informative, opinionated, and hybrid). This occurs because during the interview with the leader of the far-right collective ‘La Resistencia’ the interventions of the guest, the host and the panelists concur, as well as the use of resources from the television edition, which include data that reinforces the comments made by the participants of each sequence. Therefore, it can be seen that in the segments in which the informative genre is applied, objective language and a precise account of the facts were rarely used. Likewise, in the segments in which the opinion genre is applied, which includes the interpretation of the facts and the use of subjectivity, tendentious comments are appreciated. Finally, in relation to the hybrid genre, the characteristics of the chronicle and the objective/subjective mixture appear briefly. For example,

Table 1 Television journalistic genres

Indicator	Sub-indicator	Yes you identify (%)	Not identified (%)	Total (%)
Informative	Target language	27 (7)	73 (19)	100 (26 observation sheets)
	Story of the events	35 (9)	65 (17)	
Opinion	Interpretation of the facts	50 (13)	50 (13)	
	Subjectivity	46 (12)	54 (14)	
Hybrid	Chronicle	15 (4)	85 (22)	
	A mixture of objectivity and opinion	35 (9)	65 (17)	

the host, in the video ‘Demonstration of the group La Resistencia’ [26], refers to a journalist from another program and television house. Ironically, she asks him to put her on the list of those who complain on Twitter. For his part, the host, in the video ‘Leader of the La Resistencia collective’, assures that they have links with Fuerza Popular [27] and then asks the interviewee the leader of the far-right collective ‘La Resistencia’ about the reason for the acts of violence by his followers. In that sense, the question is opinionated because it is based on the basis that the aforementioned group is violent.

Table 2 below specifies the segments evaluated.

4 Discussion and Conclusion

In conclusion, the 26 observation sheets show that the channels analyzed do not show problems with the use of audiovisual language. The results show that the effects were not abused, nor was the editing when the guest was interviewed. Therefore, it corroborates the study by Montero [4], who indicates that the editing of television content should not abuse effects because an “agile and simple edition leads to a better understanding of the contents” [4]. In relation to the testimony indicator, 96% of the files show that the camera concentrates on recording the words of the protagonist of the news. Regarding the informative intentionality of the news, 73% of the files show that the sequences comply with the three indicators involved: ethics, truthfulness, and responsibility. Each of these indicators evaluates the journalist who executes the interview. In this regard, Solis [28] mentions that society needs the truth as a value of the journalist in the various areas in which he or she reports. Regarding the use of journalistic genres, it is observed that 100% of the files concur. However, there are differences in the opinionated, informative and hybrid segments, linked to the way

Table 2 List of categories

Token	Fountain	Time analyzed
1	https://www.youtube.com/watch?v=h8atiwuvqL8&list=PLEyCw9_Qczbu-IPxfXZ1tmWi1_HcLcdk2&index=6&t=1317s	24:28–25:28
2		25:28–26:28 min
3		26:28–27:37 min
4	https://www.youtube.com/watch?v=6vX2pucgXCw	06:37–07:37 min
5		07:37–08:37 min
6		08:37–09:37 min
7		09:37–10:37 min
8		10:37–11:37 min
9		11:37–12:37 min
10		12:37–13:37 min
11		13:37–14:37 min
12		14:37–15:45 min
13		16:24–17:21 min
14	https://www.youtube.com/watch?v=uAm0UySItTc&t=135s	00:10–01:10 min
15		01:10–02:10 min
16		02:10–03:10 min
17		03:10–04:10 min
18		04:10–05:10 min
19		05:10–06:10 min
20		06:10–07:10 min
21		07:10–08:10 min
22		08:10–09:10 min
23		09:10–10:10 min
24		10:10–11:10 min
25		11:10–12:10 min
26		12:10–13:10 min

each interviewer approaches the topic and editorial line. It is necessary to clarify that although the interview is a journalistic genre that some authors place in the informative and others in the opinionated [29], it is not exempt from the fundamental principle for its development: objectivity in questions and re-questions.

References

1. Frutos García RA De, Vicente-Mariño M (2019) Refugees, migrants and displaced persons at the southern border. A comparative study of journalistic treatment in seven countries of the European Union. *Stud JIstic Messag* 25(1):147–163. <https://doi.org/10.5209/ESMP.63721>
2. Gómez REG, Orozco JAZ (2021) The journalistic treatment of information vs. the infodemic in pandemic times: contrasts between professional journalism and so-called citizen journalism. *J Soc Sci* 16. <https://doi.org/10.18682/jss.vi16.4441>
3. Navarrete Pinto VM (2020) Analysis of the treatment of television news in the civilization of the spectacle: America News Central Edition Case. <https://hdl.handle.net/20.500.12727/6535>
4. Montero Urbina E (2019) The treatment of information in the journalistic program Cuarto Poder during the political crisis of former President Pedro Pablo Kuczynski, 2018. <https://hdl.handle.net/20.500.12727/5889>
5. Ferro Soriano JI (2019) The Informative Journalistic Discourse in Moments of Electoral Tension: JIstic Treat Natl Circ Newps “El Comercio” and “La República”, on the Candidacy of Ollanta Humala in the Week Prior to the Second Round of the 2011 General Elections (30/05/11–04/06/11).
6. Peru 21 (2020) Fake news spread against protests in Lima. June 05, 2022, from Peru 21 Website: <https://peru21.pe/lima/manuel-merino-marcha-nacional-jose-barba-caballero-rafael-rey-difunden-fake-news-contra-protestas-en-lima-willax-noticia/>
7. Marco Sifuentes (2020) #LaEncerrona Willax’s (and others’) lies about the marches. June 05, 2022, by Marco Sifuentes Website: <https://www.youtube.com/watch?v=4y6MbCNagb4&t=656s>
8. Andy Livise (2021) 8 Fake news from Erasmo Wong’s channel (Which is already a danger to public health). June 05, 2022, Útero.pe Website: <http://uterop.e/2021/03/09/8-fake-news-del-canal-de-erasmo-wong-que-ya-es-un-peligro-para-la-salud-publica/>
9. Andrés Calderón (2021) Willax and ‘fake news’, by Andrés Calderón. June 05, 2022, from El Comercio Website: <https://elcomercio.pe/opinion/columnistas/willax-y-las-fake-news-por-andres-calderon-covid-19-vacunas-noticia/?ref=ecr>
10. Dalle P, Boniolo P, Sautu R, Elbert R (2005) Manual of methodology. Construction of the theoretical framework, formulation of the objectives and choice of methodology. Buenos Aires: CLACSO, Latin American Council of Social Sciences
11. Berlanga-Fernández I, Sánchez-Esparza M (2018) Ethics and treatment of information in journalistic accounts of corruption. *Hist Soc Commun* 23(2):477–488. <https://doi.org/10.5209/HICS.62269>
12. Abubakar AT (2020) News values and the ethical dilemmas of covering violent extremism. *Jlsm Mass Commun Q* 97(1):278–298. <https://doi.org/10.1177/1077699019847258>
13. Arellano Gutiérrez AFdM (2020) The journalistic treatment from the perspective of framing in the newspaper El Comercio. Case: Pulpín Law, December 2014–January 2015. <https://hdl.handle.net/11537/26331>
14. Alvarez E (2022) Mediated and discursive readings of Argentine, American and Mexican academics in the journalistic coverage of presidential candidates. *Communication and Society*, 1–27. <https://doi.org/10.32870/cys.v2022.7828>
15. Bach R, Bach S (2020) Journalistic treatment of covid-19 in the newspaper Correo De Piura, period MAY 2020 National University of Piura. <https://repositorio.unp.edu.pe/bitstream/handle/20.500.12676/3077/COMU-NAV-GUE-2020.pdf?sequence=1&isAllowed=y>
16. Pimienta J, De la Orden Hoz A (2017). Research methodology. Mexico: Pearson
17. Cohen N, Gómez G (2019). Research methodology, for what?: the production of data and designs. Argentina : Theseus
18. Behar D (2008) Research Methodology. Bogotá: Editorial Shalom 2008
19. Rojas B (2014) Qualitative research: fundamentals and praxis. Caracas: FEDUPEL
20. Valles M (1999) Qualitative techniques of social research: methodological reflection and professional practice. Ed Síntesis, Madrid

21. Gómez S (2012) Research methodology. Mexico: Red Tercer Milenio
22. Asorza Villanueva HJ (2021) Fake news in the narrative of Willax TV. Social impact and challenges. <https://repositorio.ulima.edu.pe/handle/20.500.12724/15115>
23. Peves López DA Analysis of the television journalistic coverage of the government of Manuel Merino de Lama. <http://hdl.handle.net/10757/667535>
24. Caballero A (2014) Innovative comprehensive methodology for plans and theses. Cengage Learn, Mexico
25. Hernández R, Fernández C, Baptista, P (2014) Research methodology. Mexico: McGraw-Hill Interamericana
26. Willax Television (2021) *Demonstration of the group “La Resistencia”* [Video archive]. Youtube. <https://youtu.be/h8atiwuvqL8?si=BPZwVi9qvI5LtQwN>
27. Éxito Noticias (2021) *Leader of the collective ‘La Resistencia’ assures that they have no link with Fuerza Popular* [Video archive]. Youtube. <https://youtu.be/uAm0UySItTc?si=0RN0MF2sFnvMSm9B>
28. Solís ANB (2007) Ethics of the journalist. Reunion. Analysis of University Problems, (49):37–42. <https://reencuentro.xoc.uam.mx/index.php/reencuentro/article/view/621>
29. Ochoa CDS (2011) The journalistic interview: genre or tool? (Doctoral dissertation, University of Santiago de Compostela) <https://dialnet.unirioja.es/descarga/tesis/41869.pdf>

Millennial Consumer Perception of North Lima on Crisis Management in ‘The Pura Vida Case’



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Abstract This research was carried out in 2022 and its main objective was to document the perception of the millennial consumer in North Lima about the crisis management applied in ‘The Pura Vida case’. This study was prepared using the qualitative approach. To collect the data from the 25 people, an interview guide was used. The results were systematized for each specific objective. In the first place, it was evident that the company that owns the brand was involved in a communication crisis despite the implementation of various and constant communication strategies. Second, the crisis caused its consumers to be affected and use various social platforms as a means of communication to expose their discomfort. This action caused a negative impact on the corporate image and organizational reputation of the company, the relationship with its audience, and with future potential customers.

Keywords Crisis management · Corporate image · Business crisis · Consumer perception

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1 Introduction

During the last decade, corporate communication has become more relevant for a company's audiences or stakeholders, being essential for the organization. According to Sabina [1], corporate communication only acts in front of the company's audiences, thus meeting their trust. In other words, it is a system that generates interactions and relationships with stakeholders that allow the arrest of possible future problems [2]. Crisis management has the ability to recognize and act on signs of situations that are harmful to the company [3]. Therefore, it is essential to have good management, to resolve or minimize a negative impact, since there are different events that endanger the stability of the organization in the face of a large mass and require the intervention of communications departments [4, 5]. A crisis can cause long-lasting damage to the brand, it can even lead to the loss of profits or its disappearance in the market. In this regard, communication strategies represent support to improve the situation of an organization in a period of crisis [6]. The choice of appropriate spokespersons, the updating of key messages, and the staging of assumptions are preventive measures that companies must implement to face a crisis [4]. This allows for the execution of actions and the provision of timely, accurate, and effective responses in order to restore public trust [7]. Therefore, timely management of a crisis is essential to minimize the impacts.

In the field of organizational reputation, there is also the online crisis, which has a negative impact on a brand, since it extends and registers on the internet the negative or positive judgments made about a company [8]. Because false or confusing information can be spread, entities are forced to monitor all aspects related to the online reputation of their brands. The digital environment and the evolution of the use of social networks have forced companies to pay greater attention to the internet in order to plan better online communication mechanisms [9]. Such management is of vital importance for cases in which comments or interactions between users negatively affect the company. It is necessary to specify that consumer perception is important, since the audience makes decisions and takes actions based on the recommendations or experiences of other consumers. Consumer perception plays an important role in building a corporate image, as it can affect or benefit the company in question [10]. In crisis events, habitual consumer behavior can change and reduce their preference for specific brands. However, a positive consumer perception helps to train and dispose of loyal and growing customers.

This research is based on the question: What is the perception of the millennial consumer of northern Lima about the crisis management applied in 'The Pura Vida case'? Due to the qualitative nature of the study, no hypotheses were raised, as these can be generated during the study process and change as information is collected [11]. Likewise, in order to accurately record the data provided by the interviewees, some concepts from the academic literature have been considered. First, corporate communication is a global procedure of communication between the organization and the various audiences of the company [12]. Therefore, organizational communication

represents a means for feedback among audiences and a space for the official transmission of institutional messages. Likewise, corporate communication has to serve dispersed audiences, where each group has different affinities and seeks information according to its interest [13].

Secondly, crises are events that generate a change that can endanger the image of an organization and that requires an immediate response, which compromises the internal and external balance of a company in the face of its various audiences [6]. Third, crisis management focuses on the production of contingency plans, which allow for an immediate and automatic response in accordance with one's own and existing capacities [3]. There are several types of scenarios; The classification of crises ranges from industrial accidents, environmental problems, strikes, unstable or withdrawn products, internal rumors, leaks to the press, administrative problems or external risks. The correct thing to do is that once they have been diagnosed and reviewed, they should be classified into levels [5]. Likewise, digital platforms are also part of the types of crises and are considered a new instrument for communication, since they have modified the way people interact. Any user who knows how to use digital platforms can spread messages and generate a possible image crisis in companies [8].

Fourth, perception involves the various impressions, information, expectations, attitudes, and feelings accumulated by the subject based on his or her relationship with the organization. Consequently, the perception of a company is based on the information received about it and on the experience after the acquisition of products or services by the individual, who partially interprets positive or negative constructs [10]. In this situation, a positive perception can favor the organization because of its value components and a negative perception can cause irreparable damage. Therefore, this research documents the perception of the millennial consumer of North Lima about the crisis management applied in 'The Pura Vida case'.

2 Methodology

The research is carried out from a qualitative approach, because it is adapted to the objectives of the research, and data analysis is used. According to Polanía et al. [11] "this research is useful to explore aspects that are required of the participation of people, who interact on a daily basis". It is fundamental for interpretation, since its focus of interest is on the description, analysis, and interpretation that guides the understanding of the reality under study [14]. Therefore, under this modality, the information obtained can be accurately analyzed. For the collection of information, the interview was used, this will be applied to the millennial consumers of the brand in order to collect their experiences on 'The Pura Vida case'. This technique is a tool for the collection of data or information from the study subject through verbal interaction with the researcher [15]. It is also necessary to specify that the interview is semi-structured. This type of technique provides greater flexibility, since the questions are planned and can be adapted to the interviewees [16].

For the systematization of the information, the criterion of saturation was applied in the research, since repeated data were detected. For Martínez-Salgado [9], the reduction technique is used when the information collected no longer provides unpublished information for the development of the characteristics and dimensions of the research categories. In addition, data triangulation was also carried out in order to explain and synthetically present the results, since, according to Okuda and Gómez-Restrepo [17], data triangulation includes the use of strategies for the same phenomenon, offering alternatives to visualize a problem from different angles and thus increase the validity and consistency of the findings. Likewise, the instrument selected for the research is an interview guide. According to Taylor and Bogdan [18], the interview guide is a list of general areas with the support of an informant. In addition, a list of topics and subtopics should be composed that should be addressed in the interview [19].

For data collection, the interviewees were asked to sign a letter of consent. Then a date was designated for the participants to carry out the interview and on that established date the selected instrument was applied, thus collecting various perceptions of each of the informants, with the help of the interview guide. Each interview was then transcribed and coded using a matrix. The informants are the subjects, the object of study, or the people who will be part of the research [20]. For this research, which is qualitative in nature, the interview technique was applied to a number of 25 people who are millennial consumers of the brand. Among the criteria used for their selection, it was sought that their age range is between 24 and 36 years old, that they belong to the millennial generation, that they reside in the districts of North Lima, that they are consumers of the ‘Pura Vida’ brand, that they belong to socioeconomic level B and C, that they are active on digital platforms and that they know about ‘The Pura Vida case’.

3 Results

‘The Pura Vida case’, related to the company Gloria S.A., is an outstanding example of the importance of transparency in the advertising and marketing of products. Gloria S.A. was found guilty of committing deceptive acts in the advertising of the product ‘Pura Vida’ [21–23]. The company used the image of a cow and the term ‘milk’ on its packaging and website, however, its composition included non-dairy ingredients such as soy milk, vegetable fat, vegetable fat, minerals, and vitamins. The sanction imposed on Gloria S.A. was ordered by the National Institute for the Defense of Competition and the Protection of Intellectual Property (Indecopi) [21–23]. Through Resolution No. 0273–2018/SDC-INDECOPI, the definitive and immediate cessation of the dissemination of advertising for the product ‘Pura Vida Nutrimax’ was decreed. In addition, it was ordered that the company cover the expenses and costs incurred in the process [21–23]. The Peruvian media emphasized the controversy generated by the misleading advertising of Gloria S.A. and the subsequent sanction imposed by Indecopi, which amounted to 700 Tax Units (UIT), approximately 3 million soles,

in 2018. 'Pura Vida' quickly returned with different packaging and labels, removing the term 'milk' and the image of the cow. They also stated the benefits of the milk mixture. The public's trust in the brand was affected, due to which this research documents, during the year 2022, the perceptions of consumers of 'Pura Vida' about the crisis management implemented by the brand.

The first specific objective was to describe the perception of the millennial consumer of North Lima about the answers provided by the brand in 'The Pura Vida case'. First, the participants agreed that distrust of the brand remains and that the answers provided still generate feelings of concern, fear, frustration, panic, insecurity, and disbelief as a result of labeling that did not declare the real content. They felt mocked and still consider the product to be harmful. Secondly, the interviewees pointed out that the responses to the public by the brand showed inadequate communication management, since they expected the use of misleading advertising to be recognized. Because of this, most consider that it was a management with unfavorable comments, inopportune solutions, and an irresponsible attitude. This procedure was unethical and uncaring with his audience.

The second specific objective sought to identify the perception of the millennial consumer of Lima Norte about the brand's actions in 'The Pura Vida case'. Most of the interviewees indicated that the company used appropriate actions to face the crisis, since they made changes in labeling quickly, replenished products in supermarkets, maintained prices, and issued responses that sparked debate on the adequacy of administrative processes in public management. Likewise, some of the participants pointed out that the management of social networks (Facebook, Twitter, and YouTube) reflected a timely adaptation to changes and the creation of viral content to address the queries of loyal and digitally involved users.

The third specific objective was to determine the perception of the millennial consumer of Lima Norte about the detrimental situation of the brand in 'The Pura Vida case'. First, all the participants agreed that the accusations and the sentence received by the brand represented a risk to the corporate image, since the media recorded the process since its inception in 2017. This immediately caused negative impacts on the company's reputation, sales and supply of the product, which had to be withdrawn until the labels were adapted to the requests of state entities. All this led to an increase in consumer complaints and claims. Secondly, most of the participants pointed out that the impact of the harmful situation was temporary and that, as a result of the crisis, the company Gloria S.A. strengthened its products. Finally, the interviewees mentioned that they continue to consume the product, because its price is cheap, it is part of the family tradition, it represents a custom and it is accessible.

4 Discussion and Conclusion

This research was carried out in 2022, four years after the crisis faced by the company Gloria S.A., in relation to 'The Pura Vida case'. Although there were economic losses and a negative impact on its reputation, the event gradually disappeared from

the media agenda and from the minds of several consumers. In order to document this last aspect, this qualitative study was developed that addresses the perception of the millennial consumer of North Lima on crisis management in 'The Pura Vida case'. Through interviews, consumer ratings were collected, which were selected using criteria such as age, time of consumption of the 'Pura Vida' brand, and their knowledge of the case. In addition, Lima Norte was selected, because it is one of the sectors where commercial movement is very high. It was concluded that the management of the crisis was inadequate, as it was not possible to minimize the negative impact when the accusations emerged. Likewise, after the dissemination of Resolution No. 0273–2018/SDC-INDECOPI in the media in 2018, the debate on the use of misleading advertising and the suitability of administrative management in Peruvian State entities increased.

It is important to remember that consumers' perception of a brand can be influenced by the way it responds to various situations, especially in times of crisis. In the case of the company Gloria S.A., although they provided answers, they failed to generate a positive impression from the beginning of the accusations. This was evidenced in the testimonies of the interviewees, who pointed out that the company provided immediate responses in the media, but did not focus on acknowledging the error. In addition, this procedure represented a lack of concern for the target audience, which increased distrust and decreased sales. For this reason, it is essential that companies manage crises effectively and immediately with assertive, self-critical messages that show the brand's concern for the well-being of its customers.

In relation to the actions established by the brand, it is concluded that the company acted quickly to adapt to the demands of state entities in order to avoid shortages of the product. It also strengthened its presence on digital platforms and sought to get closer to its consumers through different campaigns for social networks. For consumers, this represented an opportunity to clear their doubts. Finally, regarding the detrimental situation, the interviewees mentioned that at the time (2017–2018) it represented a risk to the company's corporate image. However, today, the event has dissipated and no longer has media coverage. Because of this, they feel that the brand has regained its place in the homes of Peruvian families.

This research managed to document the perception of the millennial consumer of North Lima about crisis management in 'The Pura Vida case'. To do this, it synthesized the evaluations of 25 interviewees. Due to its qualitative nature, it represents an approach to a controversial event in which the use of misleading advertising was discussed, but which to date remains a tenuous memory in the minds of consumers. This panorama opens the door to new research, which focuses on the analysis of crisis management under quantitative or mixed approaches. Likewise, it could be studied whether the case was overshadowed by the effects of Covid-19 or if the change in the agenda of the media, which stopped covering 'The Pura Vida case', contributed to its withdrawal from debates on social networks or in the homes of its consumers.

References

1. Civila S (2021) Corporate communication management manual. *Dissertations* 14(1)
2. Bravo PD, Martínez NC, Peralta RP (2020) Corporate communication for customer loyalty. *Immediacy of communication* 15(1)
3. Bailly BA (2017) Simulation as part of crisis management. *Industrial data* 20(2):115–122. Accessed 10 Sept 2021. ISSN: 1560–9146. <https://www.redalyc.org/articulo.oa?id=8165390916>
4. Ariño MÁ, Alcat E (2016) How to manage a crisis well. *IEEM Revista de Negocios* 19(2):78–82
5. Pérez PS, García FG (2010) CRISIS communication as a key element of business communication. *ICONO* 14. *J of Commun Emerg Technol* 8(2):42–56. Accessed 13 Sept 2021. <https://www.redalyc.org/articulo.oa?id=552556586004>
6. Caldevilla Domínguez D (2010) Communicating in crisis situations. *Vivat academia* (105):1–27. Accessed 13 Sept 2021. <https://www.redalyc.org/articulo.oa?id=525753041004>
7. Xifra J (2020) Corporate communication, public relations and reputational risk management in times of Covid-19. *Inf Prof* 29(2):1–18. <https://doi.org/10.3145/epi.2020.mar.20>
8. Martín Herrera I, Micaletto Belda JP (2021) Effects of misinformation on brand image and reaction of three companies in the food sector to a communication crisis: Starbucks, mercadona and burger king
9. Martinez-Salgado C (2011) Sampling in qualitative research. Basic principles and some controversies. *Metropolitan autonomous university*. <https://www.scielosp.org/article/csc/2012.v17n3/613-619#ModalArticles>
10. Pasquel Racines GE, Báez Erazo, VG, Pauker Teneda LM, Apolo Buenaño DE (2016) Perception, intangible assets and stakeholders: a model for corporate image analysis. (Spanish). *Mediterranean J of Commun* 7(1):1–17
11. Polanía C, Cardona F, Castañera G, Vargas I, Calvache O, Abanto W (2020) Quantitative & qualitative research methodology conceptual and practical aspects for application at higher education levels. *Antonio José camacho university institution and césar vallejo university*
12. Capriotti P (2009) Corporate branding. Fundamentals for the strategic management of corporate identity. Santiago. <http://www.analisisdemedios.com/branding/BrandingCorporativo.pdf>. Accessed 2 July 2020
13. Atarama-Rojas T, Vega-Foelsche D (2020) Corporate communication and branded content on facebook: a study of the official accounts of Peruvian universities. *J Commun* 19(1):37–53. <https://doi.org/10.26441/RC19.1-2020-A3>
14. Zerpa K, Yubeira B (2016) The qualitative, its methods in the social sciences. *Organizational Sapienza*, 3(6), 207–230. ISSN: 2443–4256. <https://www.redalyc.org/articulo.oa?id=553056828013>
15. Troncoso-Pantoja C, Amaya-Placencia A (2017) Interview: a practical guide for qualitative data collection in health research. *J Fac Med* 65(2):329–332. <https://www.redalyc.org/articulo.oa?id=576364367022>
16. Díaz-Bravo L, Torruco-García U, Martínez-Hernández M, Varela-Ruiz M (2013) The interview, a flexible and dynamic resource. *Res Med Educ* 2(7):162–167. [https://doi.org/10.1016/S2007-5057\(13\)72706-6](https://doi.org/10.1016/S2007-5057(13)72706-6)
17. Okuda M, Gómez-Restrepo C (2005) Methods in qualitative research: triangulation. *Colombian J of Psychiatry*, XXXIV(1):118–124. <https://www.redalyc.org/articulo.oa?id=80628403009>
18. Taylor S, Bogdan R (2002) Introduction to qualitative research methods. Paidós. <http://mastor.cl/blog/wp-content/uploads/2011/12/Introduccion-a-metodos-cualitativos-de-investigaci%C3%B3n-Taylor-y-Bogdan.-344-pags-pdf.pdf>
19. Penalva C, Alaminos P, Francés F, Santacreu O (2015) Qualitative research—research and analysis techniques with atlas.ti. university of cuenca. https://rua.ua.es/dspace/bitstream/10045/52606/1/INVESTIGACION_CUALITATIVA.pdf
20. Mendieta G (2015) Informants and sampling in qualitative research. *Investigaciones Andina*, 17 (30), 1148–1150. ISSN: 0124–8146. <https://www.redalyc.org/articulo.oa?id=239035878001>

21. Vega Fernandini VL (2021) Report on Resolution No. 0278–2018/SDC-INDECOPI. Pontificia Universidad Católica del Perú. https://tesis.pucp.edu.pe/repositorio/bitstream/handle/20.500.12404/18289/Vega_Fernandini_Informe_sobre%20la_Resoluci%C3%B3n%20No%200278-2018uno.pdf
22. LP Law PE (2024) Gloria and nestlé confirmed for advertising products as if they were milk [read the resolution]. <https://lpderecho.pe/confirman-sancion-gloria-nestle-publicitar-productos-como-fueran-leche-lea-resolucion/>
23. Calligos Ramírez BR, Robles Maldonado IM (2018) The pura vida case. Peruvian university of applied sciences (UPC). <http://hdl.handle.net/10757/624099>

Design of the Additive Winters Model for Forecasting Hospital Stays in Public Health Entities



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Abstract The optimization of resources focused on hospital stays plays a critical role in healthcare efficiency issues. To be exempt from proper hospital resource planning puts a nation's health factor at risk. The Additive Winters forecast model has presented favorable and accurate results in the medical field. In the present research, the Additive Winters model (previous trend analysis) was applied for the double forecast of hospital stays in a public health entity; under an analysis of precision measures, and with a prediction interval of 95%, the forecast model for week 47 and week 48, in this event the values 11 299 and 12 638 stays were predicted with the values MAPE = 6, MAD = 678 and MSD = 649 427, which presents an experimental error for week 47 of 1.46% and for week 48 of 9.23%. To reaffirm the robustness of the model, an analysis of precision measures was conducted, accompanied by residual analysis (Normal probability plot, Histogram, vs fits, and vs order). Similarly, an autocorrelation analysis was performed to reaffirm the model's rigor. The analysis of residuals showed the absence of statistical incidents in both trials. It could be concluded that the Additive Winters model applied in a composite manner presents accurate results in relation to hospital stays, it is important to consider the relevance of the Smoothing Constants analysis to optimize the results.

Keywords Forecast · Winters additive method · Minitab · Hospital stays

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1 Introduction

Forecasting the demand for hospital stays in Peru is a relevant issue that reflects the need to improve the efficiency and quality of health services; the situation related to hospital stays reflects a high level of concern in terms of prolonged hospital stays and their negative effects on the health system. In the same way, obtaining previous data that involves the optimization of the necessary resources are relevant issue in terms of improving health services [1].

1.1 Current Situation

The forecast of hospital stays in Peru and worldwide is of utmost importance for the efficiency and quality of health services. The prolongation of hospital stays and the shortage of hospital resources have become a significant problem, with impacts on the use of beds, the agility of the services provided, the costs associated with medical care, and the risk of adverse events for the patients [2].

1.2 Hospital Stays

Hospital length of stay refers to the period of time a patient spends a set amount of time in the hospital receiving medical care. In the context of hospital management, the length of hospital stays is an important indicator of the efficiency and quality of healthcare services. In the same way, the number of admissions made should be in accordance with the capacity of a center to optimize the expected care and the correct service it provides. A prolonged hospital stay, which is generally considered when it exceeds 9 days of hospitalization of the patient, this phenomenon may be a reflection of inefficiencies in hospital management, impacting on the use of beds, agility of the services provided, and the costs associated with medical care [3].

1.3 Winter's Additive Model

Winter's forecast models, such as Holt-Winters, are fundamental tools in time series forecasting. These models are based on exponential smoothing and are essential for adapting to changing trends and seasonal patterns presented in the data. The application of these models is effective in various contexts, such as sales forecasting, inventory management, and resource planning. In addition, their ability to adjust to changes in trends and seasonal patterns has been highlighted, making them valuable tools for forecasting phenomena with seasonal variations and fluctuating trends [4]. Different

medical uses have focused on the application of the Winters model for different uses, mainly for resource optimization and under epidemiological approaches, such as the case of Chen et al. where Winter and SARIMA forecasting models were applied for the development of a stratified analysis model of the delayed effects and interactions of pollution and meteorological factors in HFRS [5]. Similarly, under a medical approach, this tool has also been used for the prognosis of dispensing amoxicillin and oral prednisolone products obtaining very accurate prognostic values [6]. Under a more particular and specific approach, the research of Lafuente et al. developed a predictive tool to estimate the daily number of intensive care units (ICU) and hospital beds occupied by patients with COVID-19 disease this research showed good performance and accuracy for forecasting the daily number of hospital and ICU beds needed for patients with COVID-19 [7].

2 Methodology

In this research, the hospital stays recorded weekly from the first week of January 2023 to the second week of December 2023 were obtained, the figures were recorded based on the result of the combination of the scheduled sessions and the rescheduled sessions, likewise, weekly canceled sessions were eliminated, as a result, the smoothing constants will be obtained under the SPSS software forecast optimization system, then the sessions carried out were obtained and entered into the Minitab 19 software.

The information obtained was presented in a time series model to be able to analyze the behavior of trends and seasons, for this case, the trend analysis with lower precision measures were the Quadratic Trend Model and Growth Curve Model; both models did not present a trend, by discarding, and under the analysis of the model, the Winters stationary model is applied.

The predicted values were made for weeks 47 and 48, for which the MAPE, MAD, MSD, and experimental error of the trial were analyzed under the actual values obtained for weeks 47 and 48. Two runs were also performed under the additive method because the seasonal pattern remains constant as the data level changes. The model is subjected to a residual analysis (Normal Probability Plot, Versus Fits, Residual Histogram, and Versus Order) to validate the accuracy and purity of the mode.

Finally, a direct analysis of prediction results and accuracy measures was performed in order to generate variants in relation to the Smoothing Constants in the Additive Winter model. Under this analysis, two runs were performed in relation to lower experimental errors obtained for the closest prediction (week 47) and contiguous prediction (week 48).

3 Data Analysis and Results

The first step was to insert the collected data into the software in order to generate a time series and search for the best forecast model to fit the data. This visual analysis follows a weekly data structure, which was grouped into 4 groups of data referring to the month, starting with the first week of January 2023. The grouped data showed clustered seasonality (Fig. 1).

The model goes to the trend evaluation where the two tests with the lowest errors in precision measurements were used: Growth Curve Model and Quadratic Curve Model (See Figs. 2 and 3); in both tests, no trend in the time series was evidenced. Considering that the weekly grouped model presents a trend, the analysis is performed for the application of the Additive Winter model, since the seasonal pattern remains constant as the data level changes. With the support of SPSS software, the smoothing values (level, trend, season) were optimized in order to perform the forecast model for week 47 and week 48, in this event the values 11 299 and 12 638 stays were predicted with the values MAPE = 6, MAD = 678 and MSD = 649 427, which presents an experimental error for week 47 of 1.46% and for week 48 of 9.23% (See Table 1 and Fig. 5).

The residual normality analysis showed in both cases an S-curve distribution with minimal outliers reflecting residual normality. In relation to the histogram of residuals, it does not reflect a high number of outliers in both cases. Finally, the vs fit in both cases reflects randomness and, for the vs order, it shows stationarity under a random order (Fig. 4).

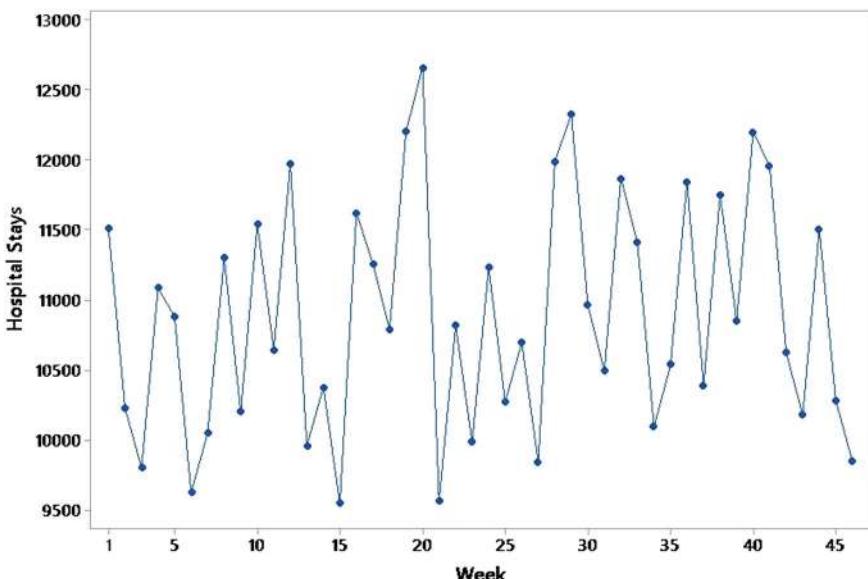


Fig. 1 Time series plot by Minitab software

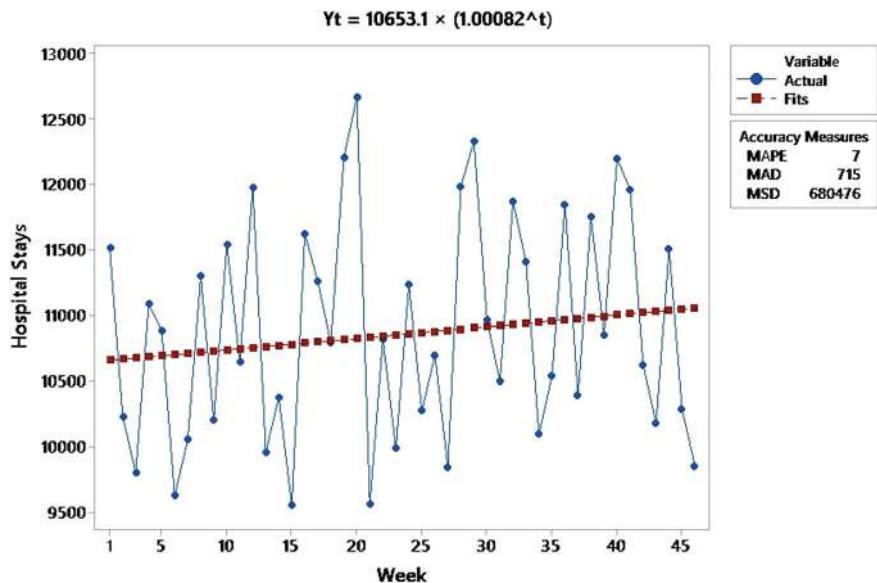


Fig. 2 Trend analysis plot for hospital stays—growth curve model

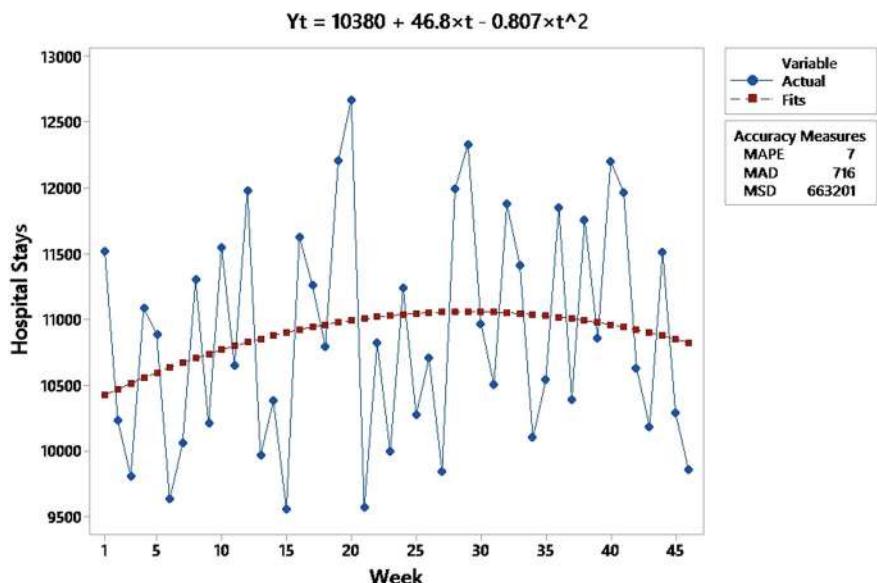
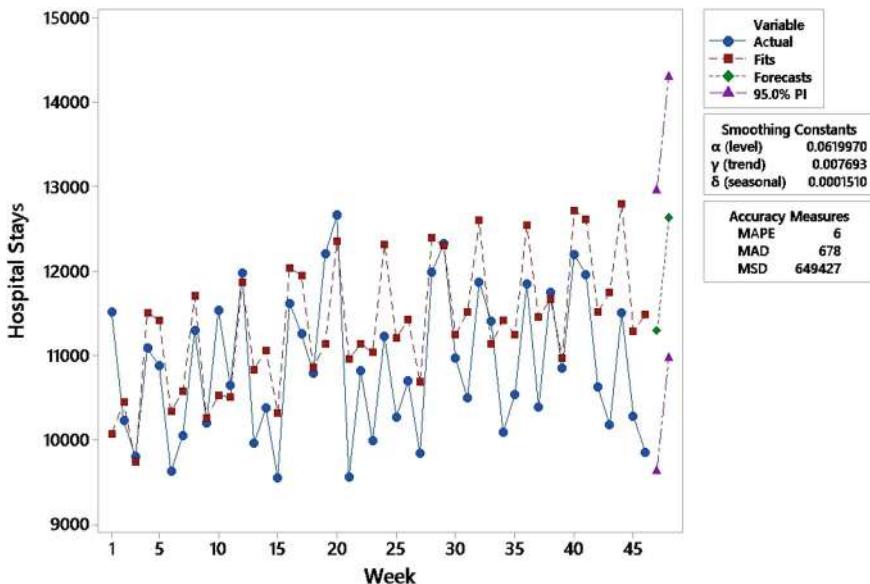


Fig. 3 Trend analysis plot for hospital stays—quadratic curve model

Table 1 Optimal exponential smoothing model parameters (additive winter) SPSS software output

Model			Estimate	SE	t	Sig.
Hospital stays	No transformation	Alpha (level)	0.062	0.057	1,093	0.280
		Gamma (trend)	7,694E-7	0.009	8,786E-5	0.1000
		Delta (season)	0.000	0.130	0.001	0.999

**Fig. 4** Winters' method plot—additive method (Smoothing constants = 0.2, week = 48)

In the ACF graph, the bars are presented within the confidence lines, suggesting that there is no significant autocorrelation in the delay presented. Despite the autocorrelation detected, the fact that the plots do not show autocorrelations at all lags may indicate that the model is already capturing a good part of the data structure, therefore the current model already has a solid foundation (Fig. 6).

4 Discussions and Conclusions

The MAPE, MAD, and MSD values presented accurate values in relation to the forecast model used, similarly, the experimental error for week 47 was 1.46% and for period 48 was 9.23% all forecast values were obtained by 95% PI, this based

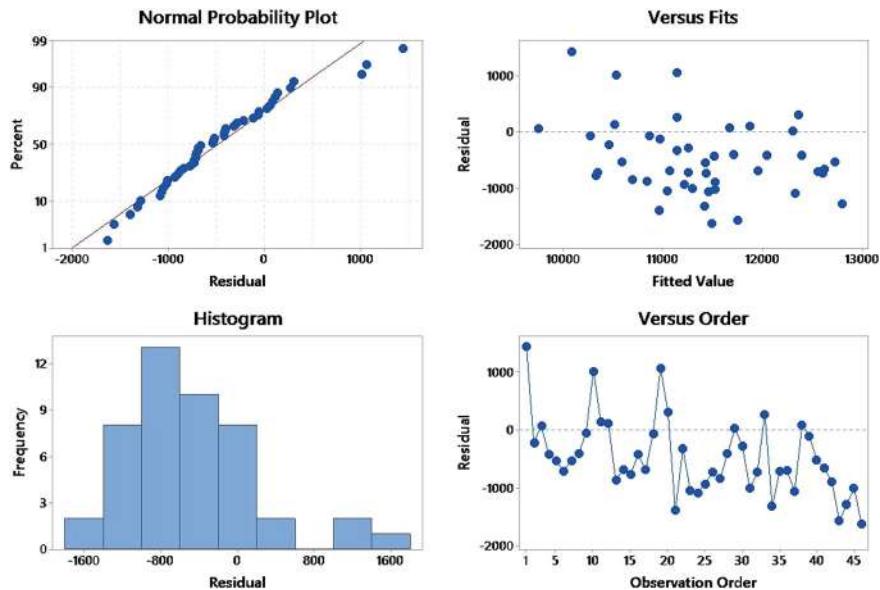


Fig. 5 Residual plot winters additive method (weeks = 47 and 48)

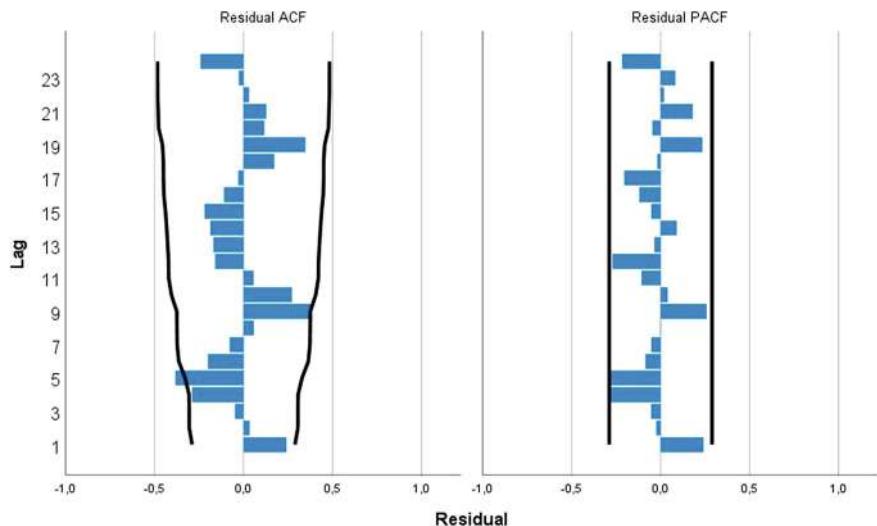


Fig. 6 Residual ACF and residual PACF plots winters additive method

on the actual value obtained, the model is efficient and accurate in relation to the precision measures.

Both residual plots reflected normality based on tails and outliers, the histogram of residuals reflects symmetry in the first forecast and a slight bias in the second value, few outliers were also accurate; the vs. order plot reflects seasonality, finally, the vs. fit has reflected randomness. From the above, it can be stated that the model is very accurate and presents a good level of data fit. The same way applies to autocorrelation analysis.

The Additive Winter method is a model used in the healthcare field with different favorable results. With the help of Minitab software and SPSS, we can obtain very accurate forecasts in order to manage and optimize essential resources for global healthcare. It is important to recognize that the statistical values related to experimental errors were minimal, however, it is appropriate to consider that under these magnitudes, it is important to consider experimental errors less than < 2% to obtain exceptional results.

Trend analysis and optimization of smoothing measures improve the accuracy of the model, it is important to unify the application of different software such as Minitab and SPSS in order to obtain better results in general terms.

5 Restrictions and Advices

The tests performed were limited to 46 values, it is possible to perform an analysis with a higher level of variables in terms of the length of the model, which would increase the number of tests. It is possible to increase the historical value obtained to optimize the levels of accuracy measurements.

A trend evaluation could be performed in case of presenting more historical information; this will serve to adapt a model with lower accuracy measures according to the forecasting model.

It is advisable to perform an implementation analysis of the presented model as a continuous approach in the corresponding health administration, these costs could be evaluated in front of the corresponding authorities for implementation terms.

External factors can interfere with forecast accuracy by altering the values of the time series, these factors such as hospital closures or staff layoffs can modify the randomness of the model abruptly changing the accuracy measures.

References

1. Rafael (2022) Prolonged hospital stay in non-covid patients hospitalized in internal medicine services during the covid-19 pandemic in a level III public hospital. Universidad Peruana Cayetano Heredia, Lima-Peru (Thesis)
2. Asenjo-Alarcón JA (2022) Evolución de pacientes hospitalizados durante la pandemia de COVID-19 en Perú. Revista de la Universidad Industrial de Santander. Salud 54, e337. Epub 22. <https://doi.org/10.18273/saluduis.54.e:22005>
3. Lazarte Gonzales KA (2021) Estancia hospitalaria prolongada y factores asociados en hospitalización de medicina interna de un hospital público peruano
4. Marino MD, Arango A, Lotero L, Jiménez M (2021) Modelos de series temporales para pronóstico de la demanda eléctrica del sector de explotación de minas y canteras en Colombia. Revista EIA 18(35):77–99. Epub. <https://doi.org/10.24050/reia.v18i35.1458>
5. Chen Y, Hou W, Dong J (2023) Time series analyses based on the joint lagged effect analysis of pollution and meteorological factors of hemorrhagic fever with renal syndrome and the construction of prediction model. PLoS Negl Trop Dis 24:17(7):e0010806. <https://doi.org/10.1371/journal.pntd.0010806>. PMID: 37486953; PMCID: PMC10399869
6. Mattsson M, Hong JA, Frazer JS, Frazer GR, Moriarty F (2024) Trends in medication use at the onset of and during the COVID-19 pandemic in the republic of Ireland: an interrupted time series study. Basic Clin Pharmacol Toxicol 134(2):231–240. <https://doi.org/10.1111/bcpt.13958>. Epub 2023 27 PMID: 37903499
7. Lafuente M, López FJ, Mateo PM, Cebrián AC, Asín J, Moler JA, Borque-Fernando Á, Esteban LM, Pérez-Palomares A, Sanz G (2023) A multistate model and its standalone tool to predict hospital and ICU occupancy by patients with COVID-19. Heliyon 9(2):e13545. <https://doi.org/10.1016/j.heliyon.2023.e13545>. Epub 2023 Feb 5. PMID: 36776914; PMCID: PMC9899510

Road Safety Using AI: Safety Index Formulation of Roads by Integrated Road and Road Traffic Violation Control System



Madhu Bala Roy and Abhishek Roy

Abstract The purpose of the paper is to establish a robust safety index for road safety and road traffic violation control systems. While many researchers studied vehicular to vehicular network info system, some focused on CCTV camera based information for the road networks, many created AI based algorithms directed towards road safety and accident reduction systems. Some have also focused on the behavioral aspects and weather conditions all with the help of various information communication technology and Artificial Intelligence based technologies. However, this research has not taken an approach integrating all of the databases in the road safety and traffic violation databases. This research paper suggests taking a much larger approach such as integrating all of the databases such as road accident database, road profile database, integrated traffic management system, integrate existing camera systems, weather information, drivers' license database, road traffic accident database, and traffic violation database. With integration and use of proper artificial intelligence technologies, deep learning technologies, and cloud computing can bring real time road safety data at the fingertips of drivers and travelers. For administration and other concerned departments, it may reduce the burden of accidents and road safety concerns as they will get live data before any mishap happens. Departments will be able to take better decisions for road safety management and also to manage road accidents with minimum casualty. Also, the black spots will be dynamically updated based on real data.

Keywords Road safety system · AI · Traffic control system · Safety index

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1 Introduction

India has one of the busiest road traffics in the world where the roads carry almost 90% of the passenger traffic and 65% of the goods traffic. Upon this, the new registration vehicles are on the rise. With increasing vehicular movement on roads and increasing traffic violations, road accidents have also increased over the years. Safety concerns are of highest importance as accidents not only lead to individual losses but damage to other vehicles and road properties, and sometimes fatal accidents lead to the loss of lives too which has a compounding effect on the relatives, insurance agencies, and other concerned agencies. A smart accident prevention predictive safety index is proposed by integrating road and road traffic violation control system. Based on this the system will predict in real time basis safety index in advance to avoid accidents and damages. The approach taken is the preparation of Apps - Integrated Road Accident Database (IRAD) and Integrated Road Profile Database (IRPD) solution. Embedded deep learning and artificial intelligence will be used for accident prediction. This will help the administration to take preventive measures resulting in lesser accidents. The solution will have a dynamic dashboard with Cloud based analytics which will show various categories of reports—both operational and financial.

Travelers, riders, and drivers can use Safety index for safe travel. It will guide them safest travel option for using the route just like people seek information on the time required to travel in Google Map. Citizens can view the safe routes & choose their journey paths. Two paths can be compared with respect to safety index the way we do it now for searching time required to travel in Google Map. The main stakeholders are Home and Transport departments, beneficiaries in the PWD (Public Works Department) and Rural development, and other road maintaining departments. The road and road traffic safety system will be integrated using emerging technologies like deep learning, artificial intelligence & cloud computing.

2 Requirements and Features of the Road and Road Traffic Violation Control System Leading to Road Safety Index

- (a) Substantial augmentation of contact-less violation detection devices like automatic number plate recognizing cameras with appropriately programmed software with the capability to communicate the same to the offender and transmit it to a centralized server, with retention of clips, as well as to District Traffic Control Rooms- except drunken driving, the other main driving offenses, as well as triple riding, lane changing and fouling and carrying of persons in open commercial vehicles beyond permitted limits can be captured.
- (b) Equipping the prosecution staff on ground with camera-fitted PoS machines with facilities for card swiping, generating e-challan and receipt, e- seizure, and transmission of violations and fines paid to treasury of the State Government through GRIPS.

- (c) Preparation of Apps-**Integrated Road Accident Database (IRAD)** and **Integrated Road Profile Database (IRPD)**—to be used through smartphones/tablets. The Road Profile Database will also be complemented with the installation of cameras at critical road infrastructure spots like bridges and culverts. The integrated road accident database will be achieved by digitizing the joint accident investigation (by police, Transport, and road maintaining authorities). The IRPD will be based on entries made by designated personnel regarding all physical vulnerabilities of road engineering nature—documenting all intersections, unsignalized intersections, uncontrolled junctions, stretches abutting water bodies without crash barriers, stretches with edge drops, occurrence of potholes, stretches with night signage and road marking inadequacies, location of schools/marketplaces/rural haats/residential areas (on highways), etc. This will considerably enhance knowledge of road safety vulnerabilities and inform prosecution plans.
- (d) Adding a dynamic dashboard with Cloud based analytics which shows real time launch of prosecutions and extraction of fines and generates various categories of reports—both operational and financial.
- (e) Incorporating the dashboard with a Google map to be populated with data from two Apps which can be installed in smartphones of officers—Integrated Road Accident database and Road Profile Database. Embedded Artificial Intelligence which could triangulate data from the above two, road traffic volume information from ANPR cameras, and data from Vahaan & the centralized server of cloud to provide the most efficient prosecution tasks which supervisors could plan for their officers.
- (f) Accident Prediction using deep learning & Artificial Intelligence will help the administration to take preventive measures, leading to less accidents.
- (g) Safety index will define safe travel using the route & just like how we view the time required to travel in Google Map, people can see the safe routes among various safety routes suggested in the app & choose their journey path.

However, the project requires the use of emerging technologies like deep learning, artificial intelligence & cloud computing.

It will be a first of its kind in India as no state nor any central government department has a system which triangulates inputs relating to vehicle prosecution by different departments, vehicle flow information, road accidents, and vulnerable road features for broad spectrum and multi-agency governance concerns relating to road safety, tax evasion, and pollution control.

The project will substantially augment fine collection, plug revenue leaks, achieve road safety objectives of safe-drive & save-life campaigns, and be a shining example of e-governance with use of cloud computing, Artificial Intelligence, and Deep learning & Machine learning technology.

2.1 Benefits of the Road and Road Traffic Violation Control System

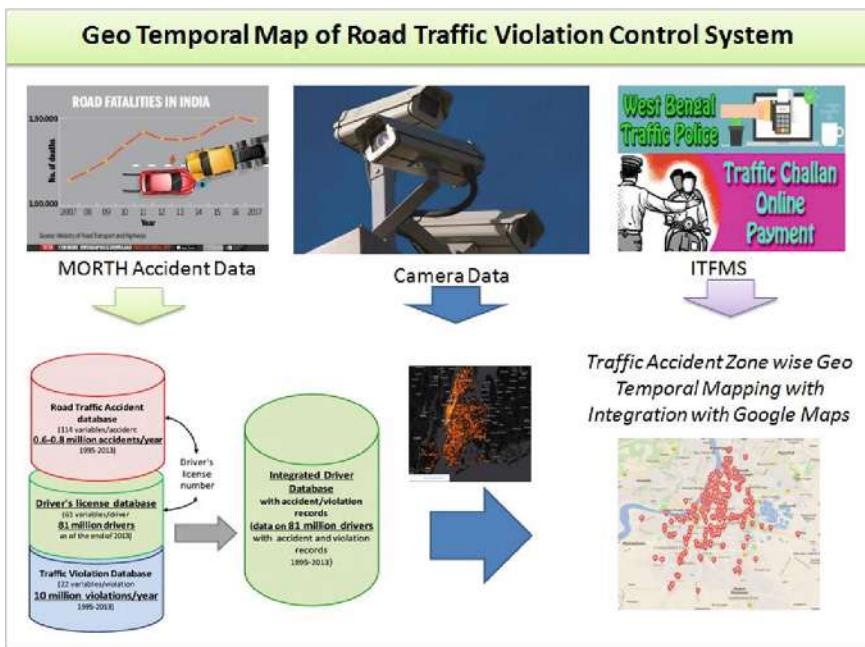
- Check unsafe driving practices: Such as drunken driving, driving without use of helmets/seat belts, over speeding, violation of red lights, driving while talking on mobile phones noncompliance with the installation of speed governors, special conditions in the carriage of school children, triple riding and lane changing, fouling, addition of dangerous extensions like footboard and rooftop seating/ standing capacity, violation of NO Entry and No Parking regulations, etc.
- Check deterioration of roads, overload, and special provisions relating to carriage of inflammable/dangerous substances, absence of rear end conspicuity, restrictions on plying on certain stretches with restrictions on tonnage, number of wheels & specified height/width
- Check evasion of government revenue –plying without CF, misuse of permit conditions, plying of private vehicles for commercial purposes, illegal carriage of minor minerals
- Check violation of pollution norms

2.2 Integrated Databases to Make Roads Safer



By integrating crucial databases like road accident database, road profile database, Mparivahan database (all India vehicle and driver's details in a single platform) and ITFMS/TRIIS, AI (artificial intelligence) and deep learning systems can provide real time information both to the drivers and travelers as well as live reports to the road and traffic departments. This will then lead to traffic awareness before any accident happens.

2.3 Architecture of the Road and Road Traffic Violation System



(Authors framework for the integrated road and traffic violation system)

Various data will be integrated to get real time traffic violation, road accident, and safety index data.

2.4 Vulnerability Assessment of a Road Network

Vulnerability is a core concept in emergency management and raises awareness of the geographic dimension that emergency planners and traffic coordinators must consider.

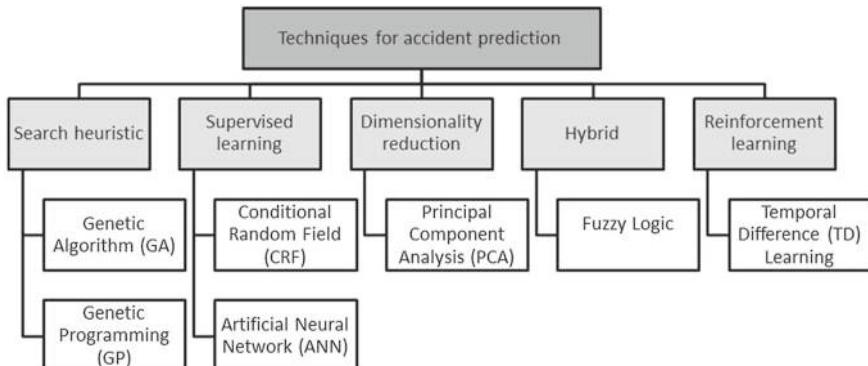
Vulnerability is dependent on not only infrastructure but also on people's behavior. In other words, vulnerability varies across individuals. Accounting for perceptions and course of action from the individual perspective is needed for comprehensive risk assessment.

This difficulty of access is interpreted by the vulnerability ratio depicted: [1].

$$V = T/C$$

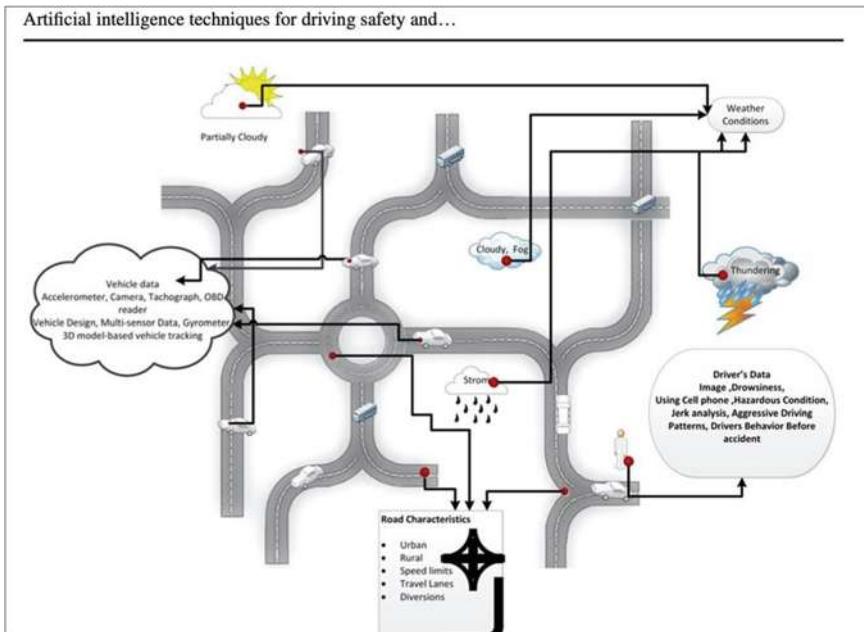
In this equation, the vulnerability ratio represents the difficulty of travel and the potential for traffic congestion for the node of interest (referred to as the anchor node), where T is the total volume of traffic flow and C is the capacity of roads (e.g., number of lanes). When this ratio reaches its maximum, it creates the most difficult scenario for vehicles at the anchor node to relocate and can be used to measure the evacuation vulnerability at this node.

2.5 AI Techniques for Accident Prediction



A set of artificial intelligence tools for accident prediction and road safety analysis [2].

2.6 Data Integration for Pooling Data from All the Sources and Getting Real Time Safety Solutions



Data produced by various traffic system [2]

2.7 Safety Information for People



(Authors visualization for the citizens view of the real time accident probability)

2.8 Real Time Data for the Departments



(Authors visualization on the road safety AI integrated system for the departments)

2.9 Integrated Road and Road Traffic Violation Control System Strategy

- Centralized database for all traffic police authorities across the state.
- Centralized dashboard for entire state and State Police HQ with advanced BI tool and analytics
- Single Integrated Traffic Fine management for E-challan device
- RLVD Camera
- Breath Analyzer
- Speed Gun based challans
- Integration with mParivahan database for fetching vehicle's owner and driver database for generation of challans.

3 Related Works

For vehicular collision avoidance and collision warning, a mobile ad-hoc peer to peer (P2P) networking system was proposed. This system would provide safety related data to the safety systems installed within the vehicles for collision warning and avoidance [3].

From vehicles, communication data accuracy could be achieved. An optical camera communication image processing system is suggested for proactive data collection from autonomous vehicles. With this approach vehicles controlling and warning signals can be transmitted between the vehicles. This system is based on deep learning image processing algorithms [4].

A vehicular trajectory knowledge is proposed for better delivery of vehicular data. According to this mobility data can be first extracted from the historical data then trajectory predictions can be done based on the multiple order Markov chains. Then algorithms can be routed for taking the advantage of predicted vehicular trajectories [5].

An adaptive power control model is suggested to integrate the desired network state and the real current network state by deploying vehicular Cooperative Vehicle Safety System (CVSS). This system can track neighboring vehicles and their movements and thereby detect potential accidents and provide warnings to the drivers [6].

AVANET based traffic safety approach has been proposed for avoiding accidents on roads. The VANET-TSMA proposes using message distribution, congestion control, and traffic management for the overall reduction of road accidents [7].

For a real time road safety assessment a traffic collision evaluation method was proposed using machine learning algorithms. Some of the algorithms such as random forest could achieve 0.85% of the overall accuracy [8].

A method for traffic safety was proposed based on the driver's aggressive driving behaviors along with traffic flow characteristics. The non-negative matrix factorization (NMF) algorithm is applied to get the latent risk factors and get a traffic risk score (TRS) [9].

An aerial remote sensing method using unmanned aerial vehicles (UAVs) is suggested for extracting vehicle speed and trajectory data for getting real time traffic data. Along with the use of a set of algorithms the result shows 95% level of accuracy in speed detection [10].

Google street view (GSV) images along with neural network and computer vision technologies were applied to find out the effects of drivers' visual environment on speed crashes [11].

A near miss event detection system (NMEDS) was designed for road safety using data received from CCTV cameras installed at the roadways. Various algorithms were applied to reconstruct various key points. This would give 3D images and 2D images for safety analysis [11, 12].

4 Limitations and Conclusion

Limited prosecution capacity and voluminous traffic allow violations to remain largely unchecked by manual intervention required with long traffic jams. Physical conduct of prosecution at night/against rogue/speeding vehicles poses safety hazards, accidents, and vulnerability to COVID-19.

The research paper proposes a comprehensive approach to road safety and traffic violation control systems by advocating for the integration of various databases and technologies. By considering multiple sources of information, including road accident data, weather conditions, and driver's license databases, the proposed system aims to provide a holistic solution to road safety challenges. The integration of databases and advanced technologies proposed in the paper can bring significant benefits to both drivers and administrative departments. Real time access to road safety data could help drivers make informed decisions while traveling, while administrative departments could use the data to implement proactive safety measures and reduce the burden of accidents and violations.

The paper emphasizes the use of advanced technologies such as artificial intelligence (AI), deep learning, and cloud computing to analyze and process real time road safety data. By leveraging these technologies, the proposed system has the potential to enhance decision-making processes, improve road safety management, and mitigate accidents and violations more effectively.

One of the limitations is the absence of a supervisory review mechanism. Introducing a mechanism for supervisory review and oversight could enhance accountability, transparency, and quality assurance within the road safety and traffic violation control systems, ensuring that they operate effectively and efficiently. To address this issue, further research could explore strategies for promoting interagency collaboration and information sharing, which are essential for effective road safety management and enforcement of traffic regulations.

Not targeted towards the protection of critical road infrastructure like vulnerable bridges, rural roads, etc. Comes in the way of preparation and documentation of a complete registry of violation profiles of over vehicles registered.

Historical data, aggravated offenses against repeat offenders. Holds up claims of compensation and insurance from tribunals and insurance agencies. Non collation of data hampers reporting obligations to government, courts, tribunals, etc. Knowledge of violations and violators is compartmentalized in silos and not shared across the agencies. Seriously limits control at tactical and strategic levels as prosecution plans are not linked to emerging accident trends across time and space, to load and NO Entry abuse, and road engineering vulnerabilities spread over large areas. No supervisory review mechanism.

The above mentioned problems could be resolved using integrated road safety and traffic violation control systems with the help of AI and deep learning techniques. This will be win-win situation for both the people and the departments managing it.

References

1. Chen X, Li Q (2017) Modeling road network vulnerability for evacuees and first responders in no-notice evacuation. *J Adv Transp* 1–12. <https://doi.org/10.1155/2017/6193127>
2. Halim Z, Kalsoom R, Bashir S, Abbas G (2016) Artificial intelligence techniques for driving safety and vehicle crash prediction. *Artif Intell Rev* 46. <https://doi.org/10.1007/s10462-016-9467-9>
3. Chisalita L, Shahmehri N (2002) A peer-to-peer approach to vehicular communication for the support of traffic safety applications. In: proceedings the IEEE 5th International conference on intelligent transportation systems, pp 336–341. <https://doi.org/10.1109/ITSC.2002.1041239>
4. Do TH, Nguyen NL, Vo HT, Nguyen TB, Khanh NTV (2021) Deep learning based image processing for proactive data collecting system for autonomous vehicle. In 2021 21st ACIS International winter conference on software engineering, artificial intelligence, networking and parallel/distributed computing (SNPD-Winter), pp 253–256. https://doi.org/10.1109/SNPD_Winter52325.2021.00062
5. Zhu Y, Wu Y, Li B (2014) Trajectory improves data delivery in urban vehicular networks. In *IEEE Trans Parallel Distrib Syst* 25(4):1089–1100. <https://doi.org/10.1109/TPDS.2013.118>
6. Zhang F, Tan G, Yu C, Ding N, Song C (2016) Model reference adaptive power control for cooperative vehicle safety systems. *J Inf Sci Eng* 32(2):287–308
7. Kaul A, Altaf I (2022) Vanet-TSMA: A traffic safety management approach for smart road transportation in vehicular ad hoc networks. *Int J Commun Syst* 35(9):e5132
8. Hu Y, Li Y, Huang H, Lee J, Yuan C, Zou G (2021) A high-resolution trajectory data driven method for real-time evaluation of traffic safety. *Accid Anal Prev*. 165. 106503. <https://doi.org/10.1016/j.aap.2021.106503>
9. Zhao X, Yang H, Yao Y, Guo M, Chai, S Research on traffic safety evaluation method based on aggressive driving behaviors and traffic flow characteristics. SSRN: <https://ssrn.com/abstract=4167534> or <https://doi.org/10.2139/ssrn.4167534>
10. Zhang C, Tang Z, Zhang M, Wang B, Hou L (2022) Developing a more reliable aerial photography-based method for acquiring freeway traffic data. *Remote Sensing* 14(9). <https://doi.org/10.3390/rs14092202>
11. Cai Q, Abdel-Aty M, Zheng O, Wu Y (2022) Applying machine learning and google street view to explore effects of drivers, visual environment on traffic safety. *Transp Res Part C: Emerg Technol* vol 135
12. Abdel-Aty M, Wu Y, Zheng O, Yuan J (2022) Using closed-circuit television cameras to analyze traffic safety at intersections based on vehicle key points detection. *Accid Anal Prev* vol 176

Influence of Length Level Growth on Accuracy Measures of the Centered Moving Average Model. A Case Study in Tomography Sessions



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Abstract The shortage of medical personnel represents a significant challenge worldwide, impacting millions of people. In Peru, a study revealed that 43.72% of health facility managers identified the lack of human resources as the main obstacle in healthcare management, compounded by the lack of equipment, drugs, and problems associated with demand. The National Institute of Biomedical Imaging and Bioengineering (NIBIB) has underlined the crucial importance of CT scanners for the diagnosis of serious conditions such as hemorrhages and cancer. However, in Peru, the significant shortage of such equipment results in long waiting periods, with potentially life-threatening consequences if not addressed promptly. The centered moving average model is a tool with favorable results in terms of resource planning. However, it is important to develop the optimization of this model based on correlation of accuracy measures to understand this tool better and make improvements. The test performed showed that the accuracy measures and the length of the centered moving average model present high correlation coefficient with values of 0.924 for the MAPE, 0.888 for MAD and 0.863 for the MSD, all with p-value of 0.000 and a CI of 95%. Negative values of correlation were observed in terms of experimental error and the accuracy measures. Finally, the increase of the accuracy measures themselves presented values similar to the first mentioned relationship.

Keywords Forecast · Pearson correlation · Minitab · Multislice CT

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1 Introduction

The shortage of medical personnel is a global reality that affects millions of people worldwide [1], research by [2, 3] shows consistent evidence that the shortage of medical personnel is a determining factor in health centers [2, 3]. In Peru, according to research by [4] 43.72% of the regional managers of different health facilities indicated that the shortage of human resources is the main problem related to health management. Likewise, in the same study, lack of equipment (21.86%), lack of medicines (10.66%), and problems associated with demand (3.55%) were identified as the main management problems in their own health facilities. These issues are encompassed by the lack of resources, which are complaints generated by the absence of a proper management model and resource optimization [4].

According to the National Institute of Biomedical Imaging and Bioengineering (NIBIB), the CT scanner is one of the most important medical devices because of its capacity to diagnose various life-threatening conditions, such as hemorrhages and cancer variants [5]. In the Peruvian region, the shortage of tomographs is significant, leading to long waiting times for procedures that can be fatal if not addressed promptly [6]. Forecasting is a process by which the future value of one or more variables is estimated [7]. Demand forecasting models have been used as essential tools to anticipate healthcare needs, make informed decisions, and optimize resources. Different studies have obtained favorable results, such as the case of the research by [8] where it is highlighted that different demand forecasting models are effective in terms of probabilistic forecasting accuracy [8], likewise, the research by [9] where, in a hospital setting of psychiatric admissions, forecasting models were relevant in terms of health care planning and hospital resource allocation; these studies lead to recognize the potential of these models in terms of resource allocation and quality improvement for patient care [9].

Among the demand forecasting models, the Moving Average model has shown favorable results in the health field. A clear example is the research by [10] where an accurate value can be obtained for COVID-19 cases in a region using the moving average [10]. Likewise, the research by [11] accurately predicts the peak of the COVID-19 pandemic using this model, allowing for daily risk assessment with a predictive approach [11]. In the two most important scientific databases, there is no statistical study applied within the health field, specifically within the sector of prognosis of MSCT tomography session scheduling, that has shown whether the variability of the length of the centered moving average is significant in terms of the impact of the prognosis and the values of MAPE, MAD, MSD, and E.E. An analysis and discussion of the results would provide a basis for certainty and reinforce the application of the model by considering parameters that reaffirm the model's effectiveness in relation to health approaches.

2 Methodology

The work was carried out in a health institution in the Ica region, Peru; scheduled multislice CT sessions were recorded on a weekly basis, starting from week 1 of October 2022 to week 3 of September 2023. To obtain the value of weekly sessions carried out, the weekly scheduled multislice CT sessions were recorded, the rescheduled cases were increased and the number of sessions canceled due to common causes (patient desists, patient does not attend the scheduled session) were removed; to calculate the number of sessions carried out, the formula was applied:

$$\text{Performed (E)} = \text{Programmed (P)} + \text{Reprogrammed (R)} - \text{Canceled (C)}$$

The data entered into the software is evaluated using the centered moving average method, which centers the moving averages. These data are positioned in the center of the range instead of the end of the range. This method is used to position the moving average data in central positions in relation to time [12].

For the 20 runs performed with length values from level 1 to level 20 (increment), the forecast value was calculated in the initial part. The accuracy measures used are the MAPE, which represents the accuracy of the fitted values within the time series as a percentage, the MAD, which represents the mean absolute deviation of the fitted values in the same units as the collected data, and the MSD for evaluating the effect of outliers [13]. In the final part, the adjusted values are evaluated together with the real values, and in this way, the experimental error of each event (week) is obtained.

Based on the best model selected for the lowest values in relation to the accuracy measures, it is necessary to perform the residual analysis to finalize the validation of the selected model. In this case, the normal probability graphs, the histogram of residuals, and the plots of residuals vs. fits and residuals vs. order were obtained. Finally, the accuracy measures were analyzed using Pearson's correlation to determine the relationship between the increase in the length value and the accuracy measures of the prediction runs obtained from the tomography sessions [14].

3 Data Analysis and Results

The study investigated the effect of increasing the length factor in the centered moving average, obtaining the forecast, the accuracy measures of each trial, and the experimental error of the forecast value in the first twenty variants. None of the trials presented irregularities in relation to the forecast of the centered moving average. As evidence, the value with the lowest experimental error of the forecast is presented with 428 forecast sessions as opposed to the actual value of 412, resulting in an experimental error of 3.88%. Additionally, the MAPE (10.10), MAD (38.69), and MSD (2832.72) values indicate high precision.

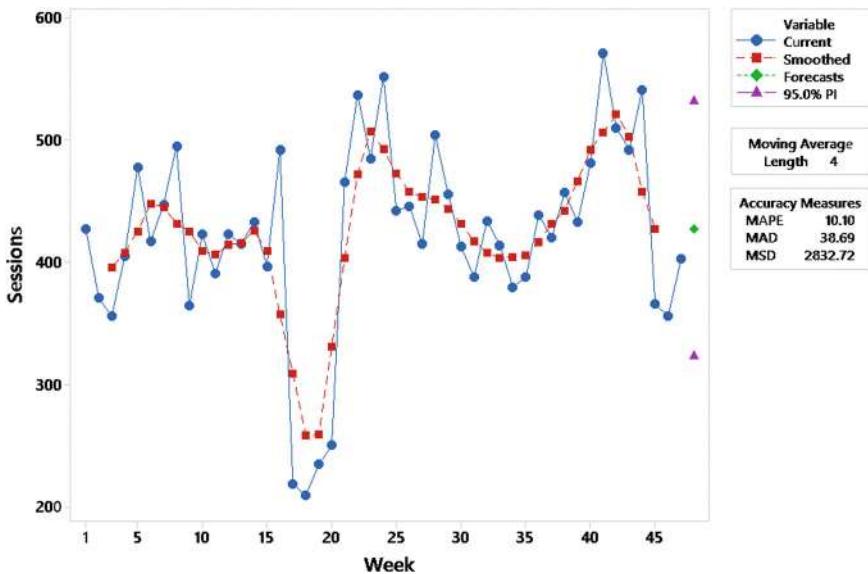


Fig. 1 Centered moving average model with lower accuracy measures (length 4)—value smoothing tomography sessions per week of application

The residual plot shows normality with long tails in the probability plot. The histogram of residuals reflects symmetry, which represents a correct fit of the model. The residuals vs. fit plot reflects randomness in the points, and the residuals vs. order plot show randomness and the absence of trend and cycle. These results indicate that the model is accurate and presents a high level of data fit. The residual plot confirms a correct fit of the selected test (Figs. 1, 2, and 3).

In relation to the 20 events performed, based on the variability of the length, a Pearson Correlation matrix is elaborated based on the values Length, MAPE, MAD, MSD, and Experimental error of the predicted value, in order to visualize if there is a linear relationship between the variables, specifically under the event of the increase of the Length variable in a centered moving average model.

The Pearson correlation coefficient between the accuracy measures and the length of the model is high. This represents a positive relationship: as the accuracy measures increase, the length of the centered moving average also increases. Additionally, the accuracy measures also increase as the length increases.

The initial hypothesis of the project is that the increase in the accuracy measures presents a moderate positive relationship in relation to the increase in the length of the centered moving average. In relation to the MAPE, the correlation is 0.924 for an interval of 0.816 to 0.970 with a p-value of 0.000, which indicates that the Pearson correlation value is statistically significant. Similarly, for the MAD, the correlation value is 0.888 for an interval of 0.734 to 0.955 with a p-value of 0.000. Finally, the MSD presents a correlation value of 0.863 for an interval of 0.680 to 0.955 with a

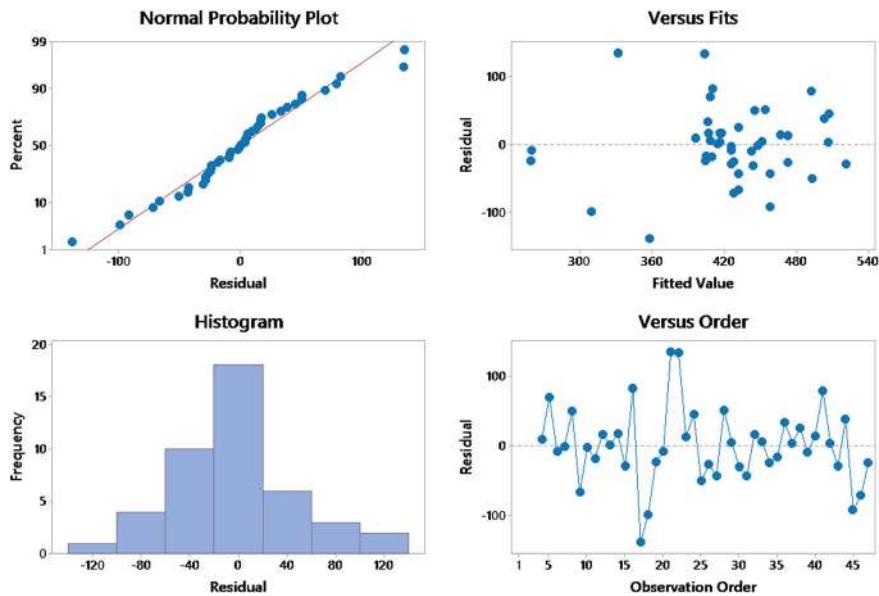


Fig. 2 Graph of residuals—normal probability, verse of fits, histogram, and verse of order

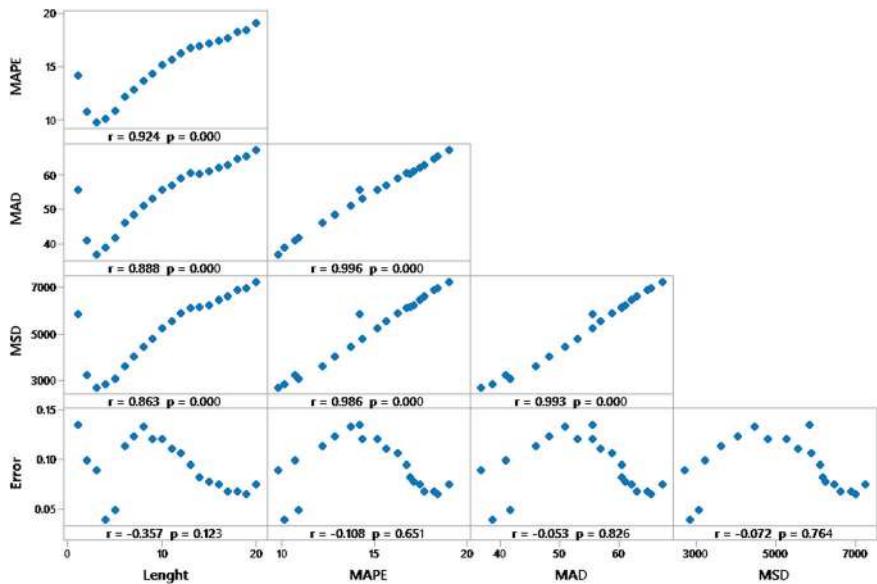


Fig. 3 Pearson correlation matrix—MAPE, MAD, MSD, Error, length

p-value of 0.000. All models were worked with a 95% confidence interval for the p-value.

In the case of the Error (forecast) with the length of the model and the Error with the accuracy measures, in all four scenarios, the correlation is negative. This indicates that as the forecast error increases, the length and the accuracy measures tend to decrease. In all cases, the p-value is greater than 0.05; therefore, there is not enough evidence to conclude that the mentioned correlation is statistically significant [15].

Finally, it is important to note that the accuracy measures are positively correlated with each other. In all variants, the p-value is 0.000, providing sufficient evidence to indicate that the correlation between them is statistically significant. The increase among all of them is as a whole.

4 Discussions and Conclusions

The accuracy measures and model length presented a high Pearson correlation coefficient. This positive relationship indicates that as the length of the moving average model centered for the tomography session forecast model increases, the accuracy measures also increase. At a confidence interval of 95% and a p-value of less than 0.05, this test is statistically significant. In relation to the forecast error, the correlation between the length of the model and the accuracy measures was negative in all four scenarios, with a p-value greater than 0.05. Therefore, as the forecast error increases, the other variables tend to decrease, but this correlation was not statistically significant. The accuracy measures themselves presented a moderate positive correlation, which was statistically significant, indicating that these variables increase together.

The model with the lowest experimental forecast error and the lowest values in the accuracy measures aligned with the conclusions obtained from Pearson's correlation. The accuracy measures increased as the length of the centered moving average increased. The residuals graph showed a correct data fit in relation to the test.

The multislice CT sessions were not differentiated by specific type of application; all multislice CT tomography sessions were included. However, the results support the development of a model that optimizes tomography sessions in a health entity with minimum error values. The model's effectiveness depends on the correlation and the p-value obtained.

5 Restrictions and Advices

The tests performed were limited to 20, it is possible to perform an analysis with a higher level of variables in terms of the length of the model, which would increase the number of tests.

Table 1 Pairwise pearson correlations

Sample 1	Sample 3	Correlation	95% CL for P	P-value
Mape	Length	0.924	(0.816, 0.970)	0.000
Mad	Length	0.888	(0.734, 0.955)	0.000
MSD	Length	0.863	(0.680, 0.945)	0.000
Error	Length	-0.357	(-0.690, 0.102)	0.123
MAD	Mape	0.996	(0.989, 0.998)	0.000
MSD	Mape	0.986	(0.965, 0.995)	0.000
Error	Mape	-0.108	(-0.525, 0.351)	0.651
MSD	Mad	0.993	(0.983, 0.997)	0.000
Error	Mad	-0.053	(-0.484, 0.399)	0.826
Error	MSD	-0.072	(-0.498, 0.383)	0.764

It is possible to increase the historical value obtained to optimize the levels of accuracy measurements.

A trend evaluation could be performed in case of presenting more historical information; this will serve to adapt a model with lower accuracy measures according to the forecasting model.

It is advisable to perform an implementation analysis of the presented model as a continuous approach in the corresponding health administration, these costs could be evaluated in front of the corresponding authorities for implementation terms (Table 1).

References

- United Nations (UN) (2013). Global shortage of health workers expected to keep growing, UN agency warns. Recuperado el 12 de enero de 2024, de <https://news.un.org/en/story/2013/11/455122>
- Oikonomidou E, Anastasiou F, Dervas D, Patri F, Karaklidis D, Moustakas P, Merkouris B (2010) Atención primaria rural en Grecia: trabajar con recursos limitados. Revista internacional de calidad en la atención sanitaria 22(4):333–337. <https://doi.org/10.1093/intqhc/mzq032>
- Ferrinho P, Siziya S, Goma Fy Dussault G (2011) La situación de los recursos humanos para la salud en Zambia: déficit y mala distribución. Recur HumOs Para Salud 9. <https://doi.org/10.1186/1478-4491-9-30>
- Espinoza-Portilla E, Gil-Quevedo W, Agurto-Távara E (2020) Principales problemas en la gestión de establecimientos de salud en el Perú. Rev Cuba Salud Pública 46(4). Recuperado de <https://revsaludpublica.sld.cu/index.php/spu/article/view/2146>
- NIBIB (2022) Tomografía Computarizada (TC) National institute of biomedical imaging and bioengineering. <https://www.nibib.nih.gov/>
- Lujan (2022) Solo hay un resonador magnético operativo por cada 10.000 pacientes con cáncer. La República Data. <https://www.nibib.nih.gov/>
- Fierro Torres CÁ, Castillo Pérez VH, Torres Saucedo CI (2022) Análisis comparativo de modelos tradicionales y modernos para pronóstico de la demanda: enfoques y características.

- RIDE Rev IberoamNa Para Investig Y El Desarro Educ 12(24). <https://doi.org/10.23913/ride.v12i24.1203>
- 8. Rostami-Tabar, B, Browell J, Svetunkov I (2023) Probabilistic forecasting of hourly emergency department arrivals. *Health Syst* pp 1–17. <https://doi.org/10.1080/20476965.2023.2200526>
 - 9. Wolff J, Klimke A, Marschollek M, Kacprowski T (2022) Forecasting admissions in psychiatric hospitals before and during Covid-19: a retrospective study with routine data. *Sci Rep* 12(1):15912. <https://doi.org/10.1038/s41598-022-20190-y>. PMID: 36151267; PMCID: PMC9508170
 - 10. Chaudhry RM, Hanif A, Chaudhary M, Minhas S, Mirza K, Asif T, Kashif M (2020) Coronavirus disease 2019 (COVID-19): Forecast of an emerging urgency in Pakistan. *Cureus*. <https://doi.org/10.7759/cureus.8346>
 - 11. Wang Z, Liu B, Luan J, Lu S, Zhang Z, Ba J (2023) Real-time risk ranking of emerging epidemics based on optimized moving average prediction limit—taking the COVID-19 pandemic as an example. *BMC Public Health* 23(1). <https://doi.org/10.1186/s12889-023-15835-0>
 - 12. Saidi, R, Olivier JC, Machmoum M, Chauveau E (2021) Cascaded centered moving average filters for energy management in multisource power systems with a large number of devices. *Energies* 14(12). <https://doi.org/10.3390/en14123627>
 - 13. Areef M, Rajeswari S, Vani N, Mohan Naidu G (2020) Forecasting of onion prices in Bangalore market: an application of time series models. *Indian J of Agric Econo*
 - 14. Schober P, Schwarte LA (2018) Correlation coefficients: appropriate use and interpretation. *Anesth Analg* 126(5):1763–1768. <https://doi.org/10.1213/ANE.0000000000002864>
 - 15. Dufera AG, Liu T, Xu J (2023) Regression models of Pearson correlation coefficient. *Stat Theory Relat Fields* 7(2):97–106. <https://doi.org/10.1080/24754269.2023.2164970>

Public Space Based on ISO14001:2015 Environmental Management for Higher Education Centers



Juan Carlos Briones Macias , Luis Amando Seis Mendoza , Oswaldo Henry Quimi Bohorquez , Alfredo Javier Plua Marcillo , and Laura Marien Campoverde Tabara

Abstract The present study focuses on the design of a plan for public spaces developed according to the UNE-EN-ISO 14001:2015 standard focused on the quality of life within the public space for students of higher education centers, to be implemented at the Faculty of Architecture and Urban Planning of the University of Guayaquil as a preliminary case study. For the methodological development of the study, the parameters of the ISO 14001 Standard and its derivations are explored regarding the design of healthy spaces that generate the minimum environmental impact in their design and implementation phase, thus forming a plan for public spaces influenced by the interaction and sensory perception of self-learning. The evaluation of environmental aspects was developed, and based on the significant aspects, the program of objectives and goals was generated. In the development of the project, each of the requirements of the standard is responded to. It is concluded that the implementation of the system would improve the urban image of the institution and the environmental awareness of its users; posed as a line of research to be applicable to other higher education educational centers.

Keywords Public space · Environmental management · ISO 14001:2015 standard · Sensory perception · Quality of life

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1 Introduction

Faced with the threat of climate change due to the consumption of non-renewable natural resources and the pollution of air, water, and soil, it is essential to create in people, public institutions, companies, etc. [1]. Both states and civil society join forces to develop strategies regarding environmental responsibility, in order to ensure the satisfaction of the needs of present generations without putting the needs of future generations at risk [2], so much so that 196 states in the United Nations Framework Convention on Climate Change adopted the Paris Agreement and committed to limiting global warming, for which they proposed reducing greenhouse gas emissions as their main strategy [3]. The International Organization for Standardization ISO, for its acronym in English, has developed the ISO 14001:2015 Environmental management system—requirements with guidance for its use [4]. This standard aims to “provide organizations with a framework to protect the environment and respond to changing environmental conditions, in balance with socioeconomic needs” [5].

Organizations with the aim of being more efficient in the consumption of energy resources, water, waste reduction, and management, etc., in addition to complying with current environmental legislation, look for tools that help them satisfactorily manage the environmental impact derived from their operations. The Faculty of Architecture and Urban Planning of the University of Guayaquil (FAU) does not have a management system that reinforces its commitment to environmental protection and helps it improve its environmental performance, therefore, the development of an Environmental Management System at the FAU, which prioritizes protection of the environment and reinforce the image of a public institution that respects the planet. The implementation of an environmental management system based on the ISO 14001:2015 Standard responds to the environmental needs of the FAU. Among the benefits of applying the standard, the specification of the requirements that the organization can use to achieve the objectives stands out expected results within an environmental management system and the flexibility to be applied to any organization that wants to improve its environmental performance [6] and wishes to pursue its environmental responsibilities in an organized manner.

The benefits of public space in the context of a university or higher educational center constitute the expression and evocation of freedom in social expressions, this being an expectant, unfinished space, with poorly defined limits, with a reading of apparent emptiness [7]. Most of these spaces have minimal equipment (a sidewalk, a small square, or a communal space with minimal construction conditions), or in many other cases, they do not have any equipment.

The inclusion of users must be active to employ ingenious strategies to “equip” them: such as using flexible furniture that is positioned depending on climatic comfort [8]. Around these actions, the character of public space is acquired, from the moment they are collectively thought of and enabled, whether through permanent or ephemeral interventions [3]. Its dignity facilitates bonds of solidarity, taking advantage of the channels through which it occurs: communal work, fundraising actions for infrastructure, etc. [9].

Public space is an important element to define a city and the urban condition as such. The definitions that are built around it are as varied as the very images that they tend to evoke in us, from the simplest ones such as the physical relationship of public-empty-open space and private-full-closed space [10], to more complex approaches such as the one that defines it as an area of our social life where public opinion is built.

Public space generates importance in daily life due to its magnitude as a denominator of identification such as that of a student area, business area, or commercial area, being a tool for urban articulation and improving the urban image [11]. Public spaces play an important role in the development of a person's life and their social coexistence, since they are intended to satisfy collective urban needs, allowing enjoyment, well-being, and improvement of the quality of life [12].

2 Material and Methods

2.1 *Environmental Management System*

Environmental management originates from the adhesion of the environmental element in business decision processes, subject to variations in the habitat [3], and is defined as the set of procedures that lead to the comprehensive management of the environmental system, considering it as a strategy. Maintain the organization of human activities that affect the environment [13], to achieve an appropriate quality of life, maintaining the balance between the rational use of resources, environmental conservation, and economic development [14].

The ISO 14001:2015 standard establishes that the objective of an environmental management system is to provide organizations with a reference framework to preserve the environment and respond to changing environmental circumstances, in balance with socioeconomic needs (Spanish Association for Standardization, 2015).

The environmental management system based on this standard is based on the Plan, Do, Check, and Act (PHVA) methodology.

- Plan: Establish environmental objectives and the processes necessary to generate and provide results in accordance with the organization's environmental policy.
- Do: Implement processes as planned.
- Verify: Monitor and measure the processes regarding the environmental policy, including its commitments, environmental objectives, and operational criteria, and report its results.
- Act: Act to continually improve.

Figure 1 shows how the reference framework introduced in ISO 14001:2015 can be integrated into the PHVA model.



Fig. 1 Relationship between the PHVA model and the reference framework in the ISO 14001:2015 standard. *Source* Spanish Association for Standardization, 2015

2.2 Territorial Context

The Faculty of Architecture and Urban Planning of the City of Guayaquil, Ecuador has 62 years of institutional life, it is part of the University of Guayaquil, which is public, is located within the Salvador Allende University citadel in the center of the city, He has two majors to his credit, the Architecture and Urban Planning major and the Interior Design major.

The Faculty of Architecture and Urban Planning of the University of Guayaquil is in the province of Guayas, in the canton of Guayaquil, on the Ciudadela Universitaria campus, on Av. Delta (See Fig. 2).

The proximity of the Faculty to the surroundings of Delta Avenue, an articulated route of the accessibility and public/private transportation system of the faculty around the urban development of the city, has undergone changes in its public space structure since the quality of this space From being perceived as a free access space, it has been privatized despite the urban intervention of the last 3 years; which has led to obtaining a non-permeable design that generates vehicular chaos, which generates the first problematic event through air pollution, excessive noise that does not allow public spaces to serve as places of stay and the concentration of students of higher

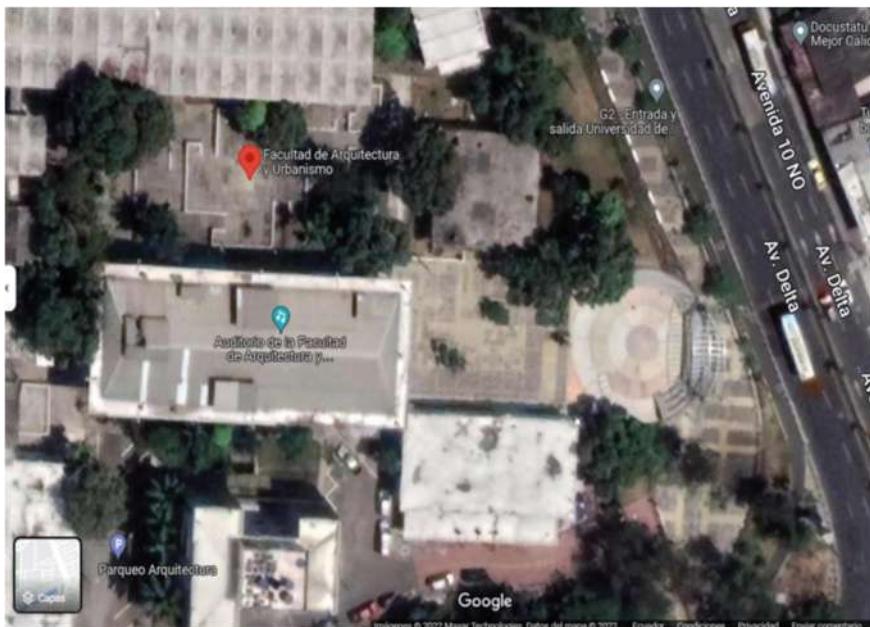


Fig. 2 Geographic location of the faculty of Architecture and urban planning of the University of Guayaquil. *Source* Google Maps, 2022

education is not adequate due to excessive noise and the transition to commercial spaces is obstructed by architectural barriers.

ISO 14001:2015 is an international standard for environmental management systems (EMS). While not designed specifically for the management of public spaces, its principles and framework can be adapted and applied to improve the environmental performance of public spaces.

This is how you can use ISO 14001:2015 for the management of public spaces from the institutional perspective. The environmental analysis of both interior spaces and public spaces is based on the management theory of the company categorized into an institutionality [15] such as the Faculty of Architecture and Urban Planning to align in a strategy that configures the entire structure of public spaces. Achieving a balance between the environment, society, and the economy [16] is considered essential to meeting the needs of the present without compromising the needs of future generations when it comes to meeting their needs. Sustainable development is an objective that is achieved thanks to the balance of the three pillars of sustainability [17].

Establishing a systemic approach to managing the environment can provide the higher institution with sufficient information to build a regulatory framework of guidelines focused on ISO 14001:2015. There are different options that contribute to development through:

- Environmental protection using prevention.
- Mitigation of environmental impacts.
- Mitigate side effects according to own and exogenous environmental conditions.
- Control the way in which public spaces are designed and the services offered such as universal accessibility, interaction, and sensory perception.
- Achieve financial benefits and operations that may result from applying related environmental alternatives that strengthen the institution's positioning in the market.

This standard is not intended to increase the legal requirements of the institution, but rather to propose a regulated design scheme based on an execution, maintenance, and preservation plan. By integrating the principles of ISO 14001:2015 into the management of public spaces, organizations can systematically address and improve their environmental performance while demonstrating a commitment to sustainability and responsible resource management.

2.3 *Methodology*

A mixed methodology was applied with a quantitative and qualitative approach, which allows an approach to the object of study through the theoretical and empirical approaches studied in the drafting of the ISO 14001:2015 Standard, focusing on its focus on quality of life, sensory perception and analysis of public spaces, which will allow first-hand information, moving to an exploratory and descriptive phase with the observation technique to specify relevant details of the public space based on climatic comfort [18], air pollution and auditory as problems encountered in the investigative process.

The use of methods with flexible design, such as the inductive method, allows the researcher to observe spontaneous and real scenarios. As part of this flexible research design, a contextual study analysis was framed using the SWOT method and CAME analysis to exemplify the strengths and weaknesses of the current environmental management system to categorize users weighted from minimum to maximum impact on the space public. From this background, the sample was obtained by categories or groups, where specific strategies will be designed.

In the sampler user's method, we divide the Faculty of Architecture and Urban Planning into three groups of workers are identified: teaching staff, administrative staff, and maintenance staff. Table 1 shows the users that make up the public space structure by categorization or groups.

Table 1 Workers of the faculty of architecture and urban planning

Group	Number of workers
Students	2024
Teachers	91
Administrative	20
Maintenance staff	20
Total	2155

3 Results and Discussion

3.1 Scope of the Management System in ISO 14001:2015

Total quality management is a management system in the institution that results in the improvement of the quality of life, sensory perception, and analysis of public spaces that involves continuous improvement of production and is focused on users. Analyzing the ISO 14001:2015 Standard, the following principles were used [19]: User focus, full user participation; focused on processes; integrated system; strategic and systematic approach; continuous improvement; fact-based decision making, and communications.

Focused on the analysis and study of the ISO 14001:2015 Standard, these relevant aspects in correlation with the standards that measure quality of life can be understood that these five concepts can be framed in sustainable development divided into the synthesis of the quality scheme and perception in public space (See Fig. 3).

The ISO 14001:2015 Standard states that organizations must define three fundamental aspects (Spanish Association for Standardization, 2015):

- a. Stakeholders who are relevant to the environmental management system,
- b. The relevant needs and expectations of these interested parties,
- c. Which of these needs and expectations become legal and other requirements.

For the development of stakeholder identification, stakeholder salience was considered, which is defined as the degree to which managers prioritize the claims of competing stakeholders [20]. Stakeholder prominence is divided into three attributes: power, legitimacy, and urgency. Power is defined as the probability that an interested party within a social relationship is able to carry out its own will despite resistance. Legitimacy is the perception or assumption that an entity's actions are desirable or appropriate within a socially constructed system of norms, values, beliefs, and definitions. Urgency is the degree to which stakeholder complaints require immediate attention. If the stakeholder does not possess any of the three attributes, they cannot be counted as a stakeholder of the project. Table 2 shows the identification and understanding of the needs and expectations of stakeholders.



Fig. 3 Correspondences between the areas and goals of sustainable development with the ISO 14001:2015 Standard. *Source* Zenchanka S, Malchenka S (2018). Lean production and ISO standards as instrument for achieving 2030 Agenda goals

This management system applies to all activities that take place in public spaces within the facilities of the Faculty of Architecture and Urban Planning, in the context of outdoor spaces, and the services provided within the exclusive scope of its functions and powers.

The Faculty of Architecture and Urban Planning of the University of Guayaquil, consistent with the importance of environmental conservation, establishes its environmental policy based on the ISO 14001:2015 Standard, Sect. 5.2 Environmental Policy (Spanish Association for Standardization, 2015).

The Institution is committed to promoting actions that contribute to the continuous improvement of its processes, and compliance with current environmental laws, to control and progressively reduce the environmental impacts derived from its activities.

This commitment is assumed by all personnel who work at FAU, thus contributing to achieving the goals proposed in this field.

Consequently, the FAU establishes its environmental policy in the following points:

- Develop and implement an Environmental Management System in accordance with the ISO 14001:2015 standard.
- Comply with current environmental regulations and legislation.
- Adequately manage the use of the processes' own resources, considering pollution prevention, and effectiveness in the use and disposal of waste.
- Maintain respect for the natural environment in the vicinity where the institution is located.

Table 2 Assessment and classification of environmental impacts in public spaces

		Assessment and classification of environmental aspects			Code	DCA-13-01
					Edition	1
					Page	1
Activity	Environmental aspect	Environmental impact	Assessment			Classification
General operation of interior public space - Plazas	Electrical Energy Consumption	Depletion of resources	VP	VM	VAA	Significant
	Light pollution	Light pollution	2	1	3	Moderate
	Water consumption	Depletion of resources	3	2	5	Significant
	Wastewater discharge	Water pollution	1	1	2	Tolerable
Cleaning activities	Contaminated packaging waste	Collector obstruction	3	2	5	Significant
	Use of chemical substances	Water and soil pollution	3	2	5	Significant
Activities in outdoor public space – Av. Delta	Disused furniture	Obstruction of collectors, positioning that does not allow climatic comfort	2	2	4	Moderate
	Use of PQ: synthetic paints	Resource consumption	2	2	4	Moderate
	Public space and interior spaces	Noise pollution at all hours of the day from traffic	3	3	6	Significant
	RP: paint containers	Collector obstruction	3	2	5	Significant
Gardening activities	Fuel consumption	Depletion of resources	3	2	5	Significant
	GHG emissions	Global warming, air pollution	3	2	5	Significant
	Use of phytosanitary products	Water and soil pollution	3	2	5	Significant
	RP: paint containers	Collector obstruction	3	2	5	Significant

- Establish achievable and measurable environmental objectives with an annual review frequency.
- Communicate the environmental results obtained to the FAU community.
- Raise awareness among FAU users to comply with the criteria of the Environmental Management System.

3.2 Description of the Management System

This section explains how the FAU environmental management system complies with each of the specifications set out in the ISO 14001:2015 Standard.

To comply with this requirement, a SWOT analysis was carried out, which considered the internal and external circumstances concerning the EMS of the Faculty of Architecture and Urban Planning, subsequently, the CAME analysis was carried out, where the strategies to be developed with respect to the findings are presented found (See Fig. 4).

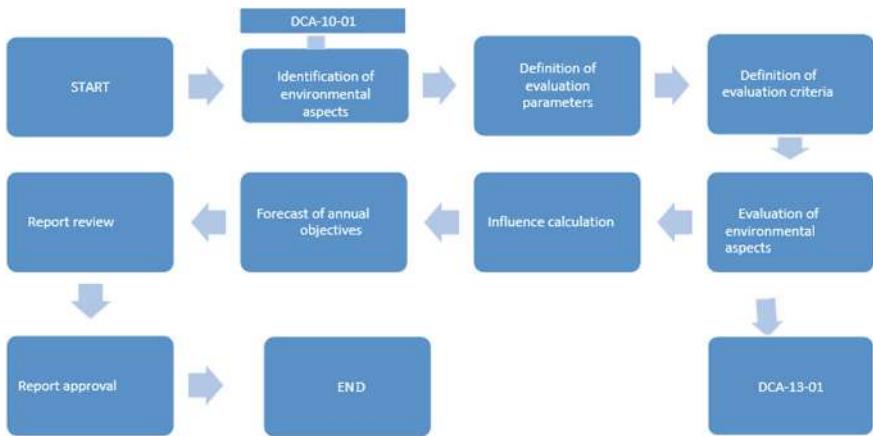


Fig. 4 SGA flow chart. *Source* Own elaboration based on the process flow chart of ISO 14001:2015. Zenchanka S, Malchenka S (2018)

With an environmental management system already framed in systemic processes, the weighting of polluting elements of public space expressed in Table 2 is carried out.

To weigh the impact on public space, 3 assessments are determined, measured in cumulative ranges of: 1–2 Tolerable; 3–4 Moderate; and 5–6 Significant, with respect to the valuations (VP) Value based on the danger of the contaminating element with respect to natural resources; (VM) Value based on the magnitude of the impact on the environment; and (VAA) Cumulative assessment to determine the level of significance of the environmental impact.

3.3 Public Spaces Plan ISO 14001:2015 Standard

As part of the formal urban analysis of the public space, the determination of planning around 3 levels of relationship of the public space with the ISO 14001:2015 Standard is taken as the axis for the public space plan to obtain a plan design route contemplating these 3 resulting strategies (see Fig. 5).

From the assessment and environmental impacts, it was determined that among the acceptable risks are areas in which the physical risk due to infrastructure and services can be improved with conditioning and better disposal of waste.

In the most significant evaluations determined as unacceptable, it is evident that the contamination is active either due to the excessive use of chemicals, noise at all hours of the day due to the layout and location of Delta Avenue near the Faculty of Architecture and urban planning, as well as the quality of the existing furniture which does not have auxiliary architectural or vegetative elements for its good performance. Placing these results as part of the public space plan, the areas of influence or zones

ESPACIO PÚBLICO	NORMA ISO 14001:2015
RELACIÓN ESPACIAL ➔	<ul style="list-style-type: none"> <input type="checkbox"/> El espacio público se relaciona con el medio ambiente y sus beneficios que operan en torno a su ubicación y posicionamiento para obtener confort climático, por su dimensión físico-espacial al ser un espacio accesible por todos y con marcado carácter de centralidad, es decir, fácilmente reconocible para su uso. <input type="checkbox"/> Estrategia 1: Posicionamiento en respuesta al confort climático
RELACIÓN SOCIAL ➔	<ul style="list-style-type: none"> <input type="checkbox"/> El espacio público supone un uso social colectivo, una multifuncionalidad y un dominio público, lo que le hace un factor de centralidad. Su calidad se evalúa en la interacción y los tipos de relaciones sociales que facilita y por su capacidad de estimular la identificación simbólica, la expresión y la integración ambiental. <input type="checkbox"/> Estrategia 2: Campañas de cuidado y uso colectivo.
RELACIÓN TERRITORIAL ➔	<ul style="list-style-type: none"> <input type="checkbox"/> El espacio público con respecto a la Norma ISO 14001:2015 se relacionan territorialmente al definir parcelas de territorio con ponderaciones que determinan la afectación ambiental y establecen módulos espaciales de transición para disminuir el riesgo ambiental. <input type="checkbox"/> Estrategia 3: Zonas de transición y cuidado ambiental.

Fig. 5 Territorial relationship of public space—ISO 14001:2015 Standard. *Source* self-made

of transition and environmental care were determined as proposed in strategy 3 to systematically solve the problem, which is why the corresponding significance is expressed in Fig. 6 to the evaluation of intervention levels being high, medium and low.

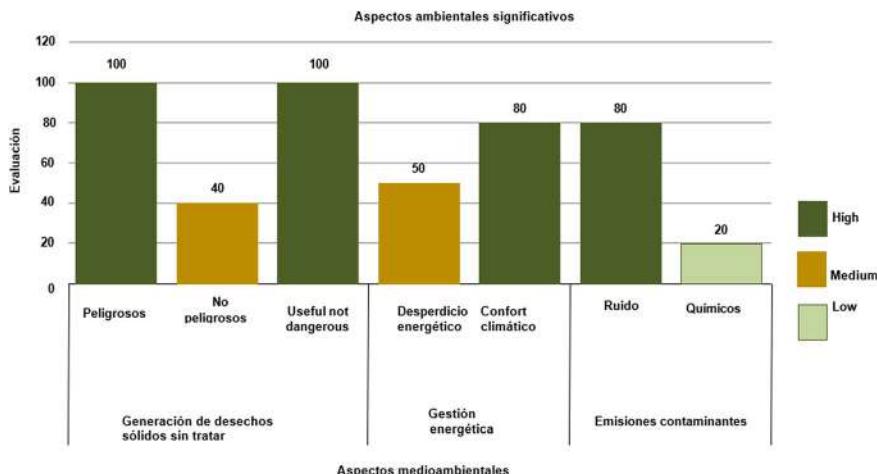


Fig. 6 Evaluation of environmental aspects to intervene. *Source* self-made

3.4 Discussion

The present study is framed in the development of an environmental management system for a public institution of higher education in Ecuador, the Faculty of Architecture and Urban Planning of the University of Guayaquil. The work was prepared following the recommendations of the ISO 14001:2015 standard. Through this work, the institution is given the opportunity to implement an environmental management system that helps to satisfactorily manage the environmental impact derived from its operations; and, consequently, can comply with current legislation, improve its environmental performance, and reinforce its image as a public institution that respects the planet.

In the study, the absence of an environmental management plan, lack of financial resources and the absence of training on environmental issues could be identified as the main weaknesses of the institution. The main threat revolves around the reduction of the universities' budget by the state, while the strength was the commitment of the staff to the institution. Based on this analysis, three strategies were designed that consisted of: the development of a plan for the implementation of an environmental management system, the development and dissemination of environmental campaigns, and the training of personnel.

In identifying the environmental situation of the institution, it was evident that of the 24 requirements established by the ISO 14001:2015 standard, the FAU only meets one requirement, 3 partially meets them and the rest does not meet them. Compliance with the requirements established in the ISO 1400:2015 standard will allow compliance with current legislation and reduce the impact of environmental aspects through the efficient consumption of resources, waste management and controlled use of products harmful to health and environment. Based on this, viable objectives were proposed, focused on reducing the consumption of resources such as water, electricity, paper, ink, the replacement of cleaning products with biodegradable products, and the correct classification and disposal of waste. It was evident that standardization through procedures is key in the environmental management of the institution [21]. The approach to the environmental policy reinforces the commitment of senior management and outlines the guidelines or directives with which the FAU moves towards environmental responsibility.

The correct implementation of the environmental system, and compliance with the stated objectives, will contribute to improving the image of the institution, reducing the economic and social cost, and improving the environmental awareness of its users. For the correct implementation of the system, the timely allocation of resources is important, this being one of the greatest difficulties in public higher education institutions in Ecuador, due to the reduction of the budget for education. Once the EMS is satisfactorily implemented, the FAU will be able to opt for certification in the ISO 1400:2015 standard. It is recommended in the future that senior management include within the annual budget of the FAU, the value of the resources necessary for the implementation and certification of the EMS (Spanish Association for Standardization, 2015). The certification of the FAU in the ISO 1400:2015 standard will

provide a new point of discussion on the implementation of environmental management systems in public higher education institutions in Ecuador and its consequences; This could be the way forward in environmental matters for the rest of the faculties of the University of Guayaquil.

This work was limited by the situation experienced due to COVID 19, since, until June 2022, the largest number of FAU activities were carried out virtually; However, senior management was always willing to collaborate with the development of this research; some activities were carried out on site and others virtually. No information was found regarding the implementation and certification of environmental management systems in public higher education institutions in Ecuador.

The development of this work based on the ISO 1400:2015 standard allowed us to have a clearer vision of what an environmental management system represents, the implications in its implementation, and the contribution it can provide to public higher education organizations, like the FAU.

4 Conclusions

In identifying the current situation of the FAU regarding the requirements of the ISO 14001:2015 standard, it was possible to identify that it only meets one requirement. Three requirements are partially met, and the rest of the requirements are not met. The lack of an environmental management system is evident.

To comply with the requirements of the ISO 14001:2015 standard, an Environmental Management Manual, 7 environmental management procedures and 25 environmental documents were developed.

In the assessment of environmental aspects, it was possible to identify twelve aspects with a significant assessment, eighteen aspects with a moderate assessment and one aspect with a tolerable assessment, all of this confirms the lack of an environmental management program.

Taking into consideration the significant aspects, a program of six objectives was developed, with achievable goals by 2023.

References

1. Duan J, Wang Y, Fan C, Xia B, de Groot R (2018) Perception of urban environmental risks and the effects of urban green infrastructures (UGIs) on human well-being in four public green spaces of Guangzhou. *China Environ Manag* 62(3):500–517. <https://doi.org/10.1007/s00267-018-1068-8>
2. I. Marrero Guillamón, JBM (2008) La producción del espacio público: Fundamentos teóricos y metodológicos para una etnografía de lo urbano. *Diposit Ub Edu* 2(1), 10–20
3. Santiago P (2022) Achieving sustainability in construction through digitally informed decisions. *Structural integrity* 20, 247–269. https://doi.org/10.1007/978-3-030-82430-3_11

4. Zenchanka S, Malchenka S (2018) Lean production and ISO standards as instrument for achieving 2030 Agenda goals. In world sustainability series, pp 459–471, Springer. https://doi.org/10.1007/978-3-319-63007-6_28
5. Zorpas AA (2020) Strategy development in the framework of waste management. *Sci Total Environ* 716. <https://doi.org/10.1016/j.scitotenv.2020.137088>
6. Galati A, Coticchio A, Peiró-Signes Á (2023) Identifying the factors affecting citizens' willingness to participate in urban forest governance: evidence from the municipality of Palermo Italy. *For Policy Econ* 155:103054. <https://doi.org/10.1016/j.forpol.2023.103054>
7. Cole HVS, Lamarca MG, Connolly JJT, Anguelovski I (2017) Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. *J Epidemiol Community Health* 71(11):1118–1121. <https://doi.org/10.1136/jech-2017-209201>
8. Balakin VV, Aleksikov SV, Azarov VN (2023) Ensuring the quality of atmospheric air on main streets and in residential buildings by means of planning and landscaping. *Gigiena i Sanitariya* 102(7):639–647. <https://doi.org/10.47470/0016-9900-2023-102-7-639-647>
9. Lowe M, Boulange C, Giles-Corti B (2014) Urban design and health: progress to date and future challenges. *Health Promot J Austr* 25(1):14–18. <https://doi.org/10.1071/HE13072>
10. Adibhesami MA, Karimi H, Sharifi A, Sepehri B, Bazazzadeh H, Berardi U (2023) Optimization of urban-scale sustainable energy strategies to improve citizens' health. *Energies* 16(1):119. <https://doi.org/10.3390/en16010119>
11. Paül i Agustí D, Guerrero Lladós M (2022) The influence of public spaces on emotional states. *J of Urban Design* 27(1):73–90. <https://doi.org/10.1080/13574809.2021.1960155>
12. Anderson PML, Avlonitis G, Ernston H (2014) Ecological outcomes of civic and expert-led urban greening projects using indigenous plant species in Cape Town, South Africa. *Landsct Urban Plan* 127:104–113. <https://doi.org/10.1016/j.landurbplan.2014.03.007>
13. Costanzo V, Evola G, Marletta L (2021) Urban heat stress and mitigation solutions: an engineering perspective. *Urban heat stress and mitigation solutions: an engineering perspective*, pp 1–412. <https://doi.org/10.1201/9781003045922>
14. Nassar DM, Elsayed, HG (2018) From informal settlements to sustainable communities. *Alexandria Engin J* 57(4):2367–2376. <https://doi.org/10.1016/j.aej.2017.09.004>
15. Awasthi A, Omrani H, Gerber P (2018) Investigating ideal solution based multicriteria decision making techniques for sustainability evaluation of urban mobility projects. *Transp Res Part A: Policy Pract* 116:247–259. <https://doi.org/10.1016/j.tra.2018.06.007>
16. Sandhu M, Dann MR (2023) Life-Cycle analysis for upgrading residential buildings to optimize energy consumption. *Lect Notes Civ Eng* 247:619–629. https://doi.org/10.1007/978-981-19-0968-9_50
17. Oliveira V (2021) The town-plan as built heritage. *Heritage* 4(3):1049–1061. <https://doi.org/10.3390/HERITAGE4030058>
18. Revich BA (2023) The significance of green spaces for protecting
19. Ruževičius J (2008) The study of quality certification system of Lithuania [lietuvių kokybės sertifikavimo sistemos analizė]. *Eng Econ* 2(57):78–84
20. Aapaoja A, Haapasalo H (2014) A framework for stakeholder identification and classification in construction projects. *Open J Bus Manag* 02(01):43–55. <https://doi.org/10.4236/OJBM.2014.21007>
21. Malikova TS, Agadullina AK, Tuktarova IF (2022) Integrated management system as a tool for sustainable development of the organization SOCAR. *Proceedings* 2022:62. <https://doi.org/10.5510/OGP2022SI200765>

Scene and Aerial Image Classification Based on Advanced Deep Learning Technique



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Abstract Classifying scenes and aerial imagery is a critical component in applications such as land-use analysis, land cover mapping, and remote sensing technologies. Numerous existing models leverage Convolutional Neural Networks for classification, but they often involve intricate designs with a vast number of parameters, necessitating extensive computational power and prolonged training periods. This paper introduces a refined strategy employing a pre-trained EfficientNet B0 framework. Modification of parameters and layers through careful fine-tuning has resulted in notable enhancements in the model's classification precision. The superiority of EfficientNet B0 over comparative CNN architectures was confirmed by testing with three disparate datasets, particularly within the sphere of remote sensing imagery. The EfficientNet B0's superior performance is credited to its optimal structure that strikes a balance between model complexity and efficiency. Effective fine-tuning coupled with judicious computational resource allocation yields substantial accuracy in categorization. Moreover, its adaptability to assimilate remote sensing data exemplifies its widespread applicability. This study accentuates the significance of refining prevailing deep learning models to cater to specified objectives. Tailoring pre-trained models such as EfficientNet B0 enables marked advancements in classification precision, circumventing the necessity for intricate systems or significant

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computational demands. This methodology is promising for elevating both the proficiency and impact of scene and aerial image classification across a range of fields, with particular implications for remote sensing endeavors.

Keywords UCM · SIRI WHU · RSSCN7 · Efficient-Net B0 · CNN · Neural networks · Deep neural networks

1 Introduction

Remote sensing, especially by satellite and aerial imagery, has become an important tool across a number of domains including agriculture, environmental monitoring, urban planning, and disaster management. Among these, image classification also plays a pivotal role in extracting meaningful information from raw imagery [1].

Deep learning, especially CNNs have established remarkable success in various image classification tasks. However, training CNNs from scratch on remote sensing datasets often requires high computational resources and labeled data, which may not always be available or feasible to acquire [2].

Transfer learning offers a convincing solution to these challenges by leveraging pre-trained models trained on larger datasets like ImageNet, and fine-tuning them on target tasks with limited labeled data. EfficientNet, a family of CNN architectures, has gained importance for its superior performance and computational efficiency across a number of image classification tasks [3].

This research is about the investigation of the effectiveness of transfer learning using the EfficientNet B0 for remote sensing image classification [4]. EfficientNet B0, the smallest variant in the EfficientNet family, strikes an optimal balance between size of the model and its performance, making it particularly suitable for resource-constrained environments typical in remote sensing applications [5].

In 2019 EfficientNet models came into existence, these models are trained on the largest dataset that is ImageNet. There are multiple variants of EfficientNet, starting from B0 to B7 [6]. In this research, we have proposed a model to utilize a pre-trained EfficientNet B0 model to achieve high classification accuracy, especially for remote sensing datasets [7].

The structure of the article is as; Section II contains related work; Section III is the methodology and the details of remote sensing datasets we have used for experimentation. Section IV is about the results and analysis. Section V is the conclusion.

2 Related Work

Remote sensing images using CNN. It could be divided into three categories; either a fully trained model can be used or a model can be fine-tuned as per the proposed problem other than that model can also be implemented from scratch. [8] According to the latest research, a pre-trained model that is tuned according to our desired problem is considered to be the best performing model.

Transfer learning is a type of technique where knowledge from other problems can also be used to solve the problem. Rather than working on a problem from scratch every time, it is transferring knowledge learned from one domain or task (source domain/task) to another domain or task (target domain/task), typically by reusing or adapting pre-trained models, representations, or knowledge [9].

There are multiple CNN models available [10]; It consists of several convolutional layers followed by subsampling layers and fully connected layers. LeNet-5 was primarily used for handwritten digit recognition tasks [11]. AlexNet was introduced by Alex Krizhevsky et al., AlexNet was the breakthrough CNN model that won the ImageNet Large Scale Visual Recognition Challenge in 2012. It consists of several convolutional layers followed by max-pooling layers and fully connected layers. AlexNet popularized the use of deep CNNs for image classification tasks [12]. There are two different types of VGG, model (VGG16, VGG19) developed by the Visual Geometry Group at the University of Oxford, VGGnet is characterized by its simplicity and uniform architecture. It consists of a series of convolutional layers with small filter sizes (3×3) and max-pooling layers. VGG16 and VGG19 refer to specific variants with 16 and 19 layers, respectively [13].

Google Net also known as Inception model was introduced by Google researchers, Google Net features the Inception module, which consists of parallel convolutional pathways with different filter sizes [14]. This architecture aims to capture features at multiple scales efficiently while reducing computational complexity.

ResNet has multiple variants; ResNet50, ResNet101, ResNet152 [15]. ResNet model is also known as Residual Network. The concept of residual learning was introduced to address the vanishing gradient problem in very deep neural networks. It utilizes skip connections to learn residual functions, allowing for the training of extremely deep networks with improved performance [16].

Inception-v3: A variant of the Inception architecture, Inception-v3 incorporates additional optimizations such as factorized convolutions and batch normalization. It achieves improved performance compared to earlier versions of Inception [16].

DenseNet introduces very deep connections between layers, where each layer receives feature maps from all preceding layers. This architecture encourages feature reuse, improves gradient flow, and reduces the number of parameters compared to traditional architectures [17]. MobileNet (MobileNetV1, MobileNetV2, MobileNetV3) was designed for mobile and embedded devices. MobileNet utilizes depth wise separable convolutions to reduce computational complexity while maintaining performance [18]. MobileNetV2 and V3 further improve efficiency and accuracy through techniques such as inverted residuals and neural architecture

search [19]. Moving towards the advanced research, there are a few studies available on EfficientNet that is a new advancement in the field of deep neural networks [18]. The EfficientNet architecture is based on a compound scaling method that uniformly scales the network width, depth, and resolution with a set of fixed scaling coefficients. This approach ensures that the model's performance improves consistently as resources (computational power, memory) increase [20]. EfficientNet with different variants (EfficientNetB0, EfficientNetB1, EfficientNetB2, etc.): EfficientNet introduces a compound scaling method to balance model depth, width, and resolution for optimal performance. It achieves state-of-the-art accuracy with significantly fewer parameters compared to other models [21].

3 Methods and Tools

EfficientNet is the latest deep learning model in the area of deep learning particularly for image classification tasks. To perform experimentation and increase the performance of remote sensing satellite image datasets we have used a pre-trained EfficientNet B0 as a base model that was previously trained on ImageNet dataset. We have replaced the final three layers of pre-trained EfficientNet B0 model and fine-tuned the hyper parameters to increase efficiency as shown in Fig. 1. EfficientNet B0 has basically 7 blocks, each block has different no of layers the detailed layer graph of our model is shown in Table 1. The detailed pictorial representation of methodology used for experimentation is explained in Fig. 2

3.1 Dataset Details

3.1.1 Msrc V2

MSRC (Microsoft Research Cambridge) dataset is a popular benchmark dataset for semantic image segmentation. It was created by the Microsoft Research Cambridge team and contains images from outdoor scenes, focusing on various objects and regions in the images [22]. Each image in the dataset is manually labeled with pixel-wise annotations, providing ground truth labels for semantic segmentation tasks. Some of the common labels are; Sky, Tree, Building, Road, Grass, Car, Sign Symbol,



Fig. 1 Block diagram for the process of transfer learning

Table 1 Layer graph of EfficientNet B0 with resolution of images

Layer type	Output size
Input layer	Input image size
Convolutional layers	(224, 224, 3)
Efficient block 1	(112, 112, 16)
Efficient block 2	(56, 56, 24)
Efficient block 3	(28, 28, 40)
Efficient block 4	(14, 14, 80)
Efficient block 5	(7, 7, 112)
Efficient block 6	(7, 7, 192)
Efficient block 7	(7, 7, 320)
Average pooling layer	(1, 1, 320)
Fully connected layer	Num of classes
SoftMax layer	
Classification layer	Output

Pedestrian, Fence, Bicyclist, Pole, Sidewalk, Unlabeled. Figure 2 shows some of the images of MSRC dataset. Figure 3 shows some of the images of MSRC dataset.

3.1.2 UCM

The UCM dataset has been widely used in remote sensing research, particularly for evaluating the performance of machine learning and deep learning models for land-use classification tasks. It serves as a standard benchmark dataset for assessing the accuracy and generalization capability of classification algorithms across different land-use categories [23]. Some of the common labels are; Agricultural land, Forest land, Residential land, Commercial land, and Industrial.

land, River, Lake, Medium residential, Dense residential, Highway, Freeway, Overpass, Parking lot, Tennis court, Swimming pool, Runway, Airport, Baseball diamond, Intersection, Harbor, Sparse residential. Figure 4 shows some of the images of UCM dataset.

3.1.3 SIRI WHU

The ‘SIRI WHU’ dataset comprises 2,400 images obtained through remote sensing, accurately classified into 12 distinct scene categories. Each class encompasses 200 images, all captured with a resolution of 2 m and sized at 200×200 pixels [23]. These images were sourced via Google Earth by the Intelligent Data Extraction and Remote Sensing (RS IDEA) group affiliated with Wuhan University.

The dataset offers a diverse representation of land-use types prevalent in urban settings, with the following categories included: Water, River, Residential, Park,

Fig. 2 Flow chart explaining layers of EfficientNet B0 with image pixel values

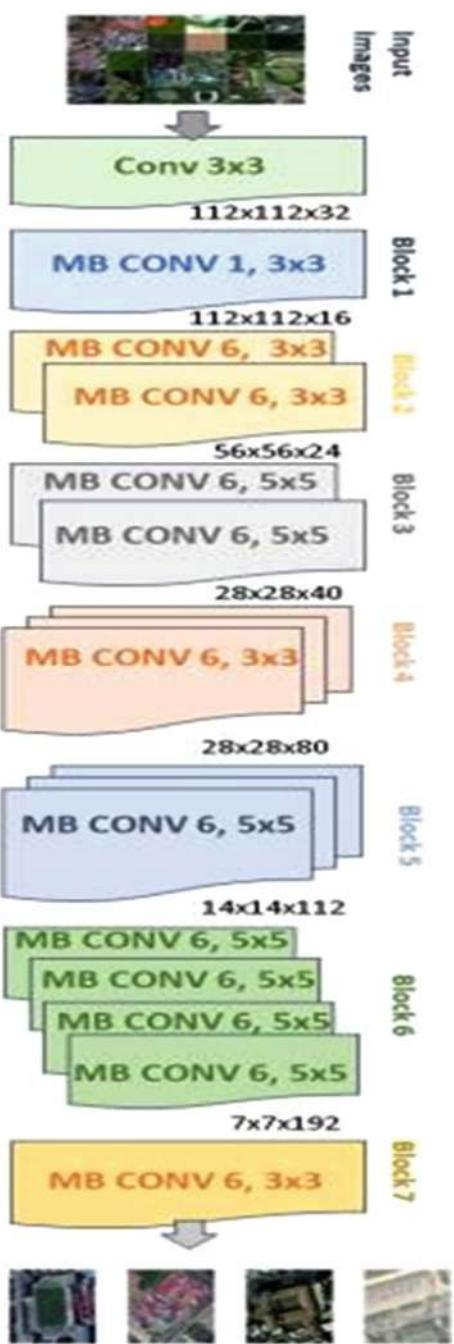




Fig. 3 MSRC dataset with image details

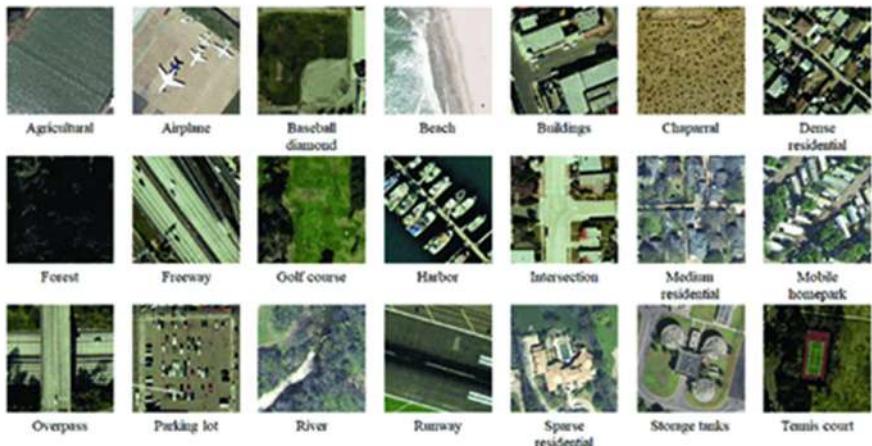


Fig. 4 UCM dataset with image details

Pond, Overpass, Meadow, Industrial, Idle Land, Harbor, Commercial, and Agriculture. Sample images corresponding to each class are provided for reference in Fig. 5

While the dataset has been extensively utilized in various research methodologies, it is noteworthy that its scope primarily focuses on urban regions within China. Consequently, there may be limited diversity and challenges presented by the dataset due to this geographical emphasis. The details of all the three above mentioned datasets is explained in Table 2.

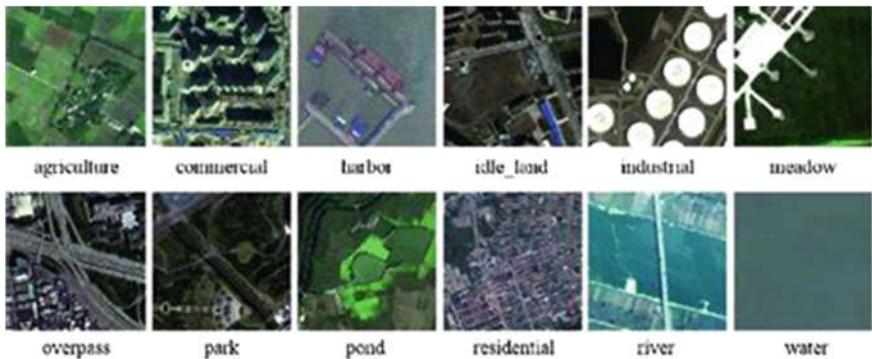


Fig. 5 SIRI WHU dataset with image details

Table 2 Classification accuracy of UCM, MSRC V2, and SIRI WHU satellite image sets using EfficientNet B0

Datasets	Accuracy
UCM	87.68%
MSRC V2	89.78%
SIRI WHU satellite	89.44%

4 Experimentation and Results

4.1 Experimentation

To perform the desired experimentation HP Pavilion gaming Laptop with AMD Ryzen 7 4800 H Radeon Graphics processor was used. 64-bit Windows 10 as Operating System 256 GB Primary Memory. MATLAB was used as a platform. Pre-trained EfficientNet B0 model was used for the classification of remote images. To increase the performance accuracy of pre-trained model, the desired tweaking in the layers and tuning parameters and hyper parameters was performed. For this, we have used the ImageNet weights of initial layers whereas the final 3 layers were removed and new three; fully connected, SoftMax, and classification layers were added.

The model was trained for only 30 epochs. Learning rate is the most important factor so piece wise learning rate scheduler was used for better accuracy. The 70:30 training testing ratio was used for experimentation. SGDM as an optimizer. Hyper parameters like weight and bias learning rate were trained as 20, initial learning rate as 0.0001 and 0.1 as drop rate.

Table 3 Comparison of classification accuracies of MSRC V2 dataset with different techniques published in literature

MSRC V2	
[24]	76.9%
[25]	79.0%
[26]	85.09%
[27]	86.01%
Proposed Method	89.78%

4.2 Results

The main idea behind conducting this research is the find out how effective are these latest deep network model like EfficientNet B0 particularly on remote sensing datasets. The results are shown in Table 3. We can see that MSRC V2 dataset achieved highest accuracy of 89.78%, whereas UCM dataset has the lowest accuracy of 87.68%.

As we all know, lower the loss better the model unless the trained model is over fitted for training data. The main objective of these deep network models is to reduce the loss function by training the hyper parameters and adjusting weights by back propagation a shown in Figs. 6, 7 and 8.

The accuracy curve shows that the learning parameters are all adjusted and fixed with the training data. The better the accuracy the better the results. Then the model is fed with test data. The blue line shows the performance of training images and black line shows the performance of validation data.

We call a model as over fitted model if it performs good for training data but not up to the mark for validation data. We can see from the above.

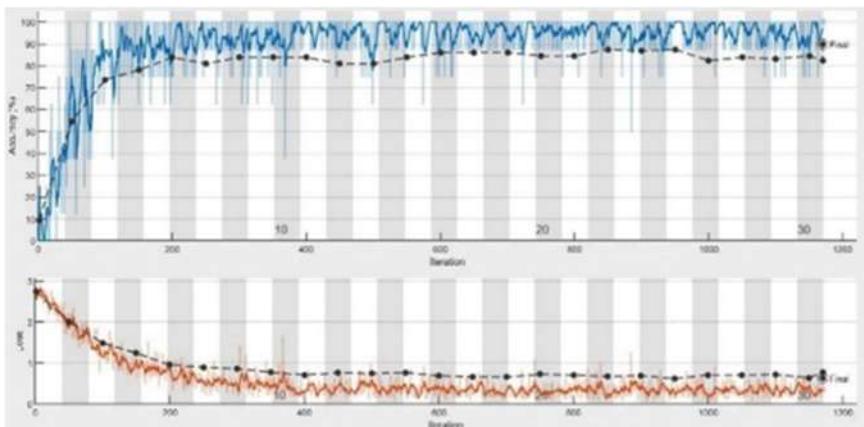


Fig. 6 Training and Loss process of MSRC V2 dataset

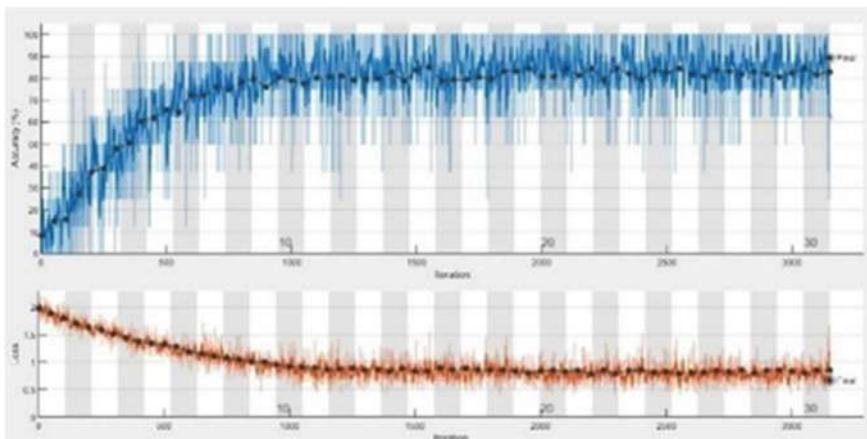


Fig. 7 Training and loss Process of SIRI WHU image dataset

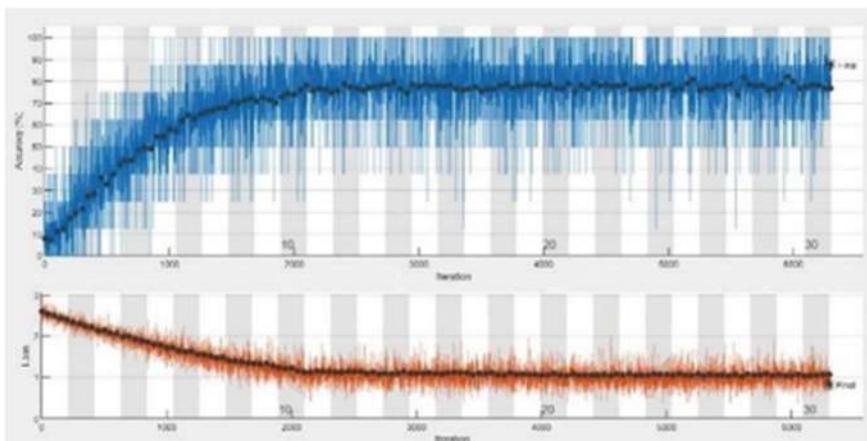


Fig. 8 Training and Loss Process of UCM Dataset

Figure 8 that training and validation curves are moving in the same pattern so the proposed model is not over fitted for training data as well.

The results are validated by comparing them with existing literature. Table 3 explains some of the results published in the literature using the same MSRC V2 dataset, whereas Table 4 explains the validation of results of UCM and SIRI WHU datasets. It is clear that these new CNN-based approaches like EfficientNet are performing better than the existing techniques.

Table 4 Comparison of classification accuracies of UCM and SIRI WHU dataset with published techniques [6]

UCM	
Alex net	79.76%
VGG 19	81.19%
VGG 16	83.81%
Proposed model	87.68%
SIRI WHU	
Alex net	86.52
VGG 19	87.60
VGG 16	88.04
Proposed Model	89.44%

5 Conclusion and Future Work

This research proposed an EfficientNet B0 model as a best suited model that outperforms for remote sensing images. We have used a pre-trained model trained for ImageNet dataset. The weights of this pre-trained network were used and by adjusting parameters and hyper parameters and adjusting the final layers, we were able to achieve quite good accuracy.

We have trained the model for only 30 epochs; hence we can say that with very few computation resources and very little time we achieved a remarkable accuracy of 89.78%. In future, we can achieve even better results especially for remote sensing images that have a high demand for areas like land use land cover.

References

- Pang B (2022) Classification of images using EfficientNet CNN model with convolutional block attention module (CBAM) and spatial group-wise enhance module (SGE). In: International conference on image, signal processing, and pattern recognition (ISPP 2022), 12247. SPIE, pp 34–41
- Chai J, Nan Y, Guo R, Lin Y, Liu Y (2022). Recognition method of landslide remote sensing image based on EfficientNet. In: 2022 IEEE 2nd International conference on electronic technology, communication and information (ICETCI). IEEE, pp 1224–1228
- Guo X, Hou B, Ren B, Ren Z, Jiao L (2021) Network pruning for remote sensing images classification based on interpretable CNNs. IEEE Trans Geosci Remote Sens 60:1–15
- Chaganti R, Ravi V, Pham TD (2022) Image-based malware representation approach with EfficientNet convolutional neural networks for effective malware classification. J Inf Secur Appl 69:103306
- Jain, DK, Li Y, Er MJ, Xin Q, Gupta D, Shankar K (2021) Enabling unmanned aerial vehicle borne secure communication with classification framework for industry 5.0. IEEE Trans Ind Inform 18(8):5477–5484
- Thirumaladevi S, Swamy KV, Sailaja M (2022) Multilayer feature fusion using covariance for remote sensing scene classification. Acta IMEKO 11(1):1–8

7. Ramos R, Martins B (2022) Using neural encoder-decoder models with continuous outputs for remote sensing image captioning. *IEEE Access* 10:24852–24863
8. Yang L, Lu B, Zhou Q, Su P (2024) Unsupervised domain adaptation via feature transfer learning based on elastic embedding. *Int J Mach Learn Cybern* 1–14
9. Ma Y, Chen S, Ermon S, Lobell DB (2024) Transfer learning in environmental remote sensing. *Remote Sens Environ* 301:113924
10. Mehmood M, Shahzad A, Zafar B, Shabbir A, Ali N (2022) Remote sensing image classification: a comprehensive review and applications. *Math Probl Eng* 2022:1–24
11. Firat H, Asker ME, Bayindir Mİ, Hanbay D (2022) Spatial-spectral classification of hyperspectral remote sensing images using 3D CNN based LeNet-5 architecture. *Infrared Phys Technol* 127:104470
12. Zhou Y, Wang M (2020) Remote sensing image classification based on AlexNet network model. In: *frontier computing: theory, technologies and applications (FC 2019)* 8. Springer, Singapore, pp 913–918
13. Zhu F, Li J, Zhu B, Li H, Liu G (2023) Uav remote sensing image stitching via improved vgg16 siamese feature extraction network. *Expert Syst Appl* 229:120525
14. Eftekhari A, Yang G (2023) Machine learning approaches for crop identification from remote sensing imagery: a review. In: *Proceedings of the 14th International conference on soft computing and pattern recognition (SoCPaR 2022)* vol 648. Springer Nature, p 325
15. Reddy KVVK (2023) ResNet is a novel method for more accurate segmentation and classification of remote sensing images as compared to KNN. *J Surv Fish Sci* 10(1S):2883–2893
16. Adegun AA, Viriri S, Tapamo JR (2023) Review of deep learning methods for remote sensing satellite images classification: experimental survey and comparative analysis. *J Big Data* 10(1):93
17. Guoxiang LI, Guo'en XIA, Liming BAI, Wenbin MA (2023) Remote sensing image classification based on DenseNet feature hashing. *Remote Sens Nat Resour* 35(1)
18. Thapa A, Horanont T, Neupane B, Aryal J (2023) Deep learning for remote sensing image scene classification: a review and meta-analysis. *Remote Sensing* 15(19):4804
19. Yang H, Wang S, Chen Y, Yan Z, Cheng Y, Wang T, Wei R (2023) Improving power transmission tower state recognition in remote sensing images using cooperative Adaboost-MobileNet. *Remote Sensing Letters* 14(2):124–134
20. Kwak T, Kim Y (2023) Semi-Supervised Land Cover Classification of Remote Sensing Imagery Using CycleGAN and EfficientNet. *KSCE J Civ Eng* 27(4):1760–1773
21. Xiao J, Aggarwal AK, Rage UK, Katiyar V, Avtar R (2023) Deep learning-based spatiotemporal fusion of unmanned aerial vehicle and satellite reflectance images for crop monitoring. *IEEE Access*
22. Le C, Pham L, Nvn N, Nguyen T, Trang LH (2023) A robust and low complexity deep learning model for remote sensing image classification. In: *Proceedings of the 2023 8th International conference on intelligent information technology*, pp 177–184
23. Alem A, Kumar S (2022) End-to-End convolutional neural network feature extraction for remote sensed images classification. *Appl Artif Intell* 36(1):2137650
24. Bappy JH, Roy-Chowdhury AK (2016) CNN based region proposals for efficient object detection. In: *2016 IEEE International conference on image processing (ICIP)*. IEEE, pp 3658–3662
25. Jiang J, Tu Z (2009). Efficient scale space auto-context for image segmentation and labeling. In: *2009 IEEE conference on computer vision and pattern recognition*. IEEE, pp 1810–1817
26. Ahmed A, Jalal A, Kim K (2019). Region and decision tree-based segmentations for Multi-objects detection and classification in outdoor scenes. In: *2019 International conference on frontiers of information technology (FIT)*. IEEE, pp 209–2095

27. Rafique AA, Jalal A, Kim K (2020) Statistical multi-objects segmentation for indoor/outdoor scene detection and classification via depth images. In: 2020 17th International Bhurban conference on applied sciences and technology (IBCAST). IEEE, pp 271–276
28. Rao DS, Koteswari S, Sindhuri KB, Chand SR, Appikonda M, Sivarambabu PV (2024) A comprehensive analysis of state-of-the-art transfer learning models for remote sensing scene classification. *Int J Intell Syst Appl Eng* 12(1):596–602
29. Cheng X, Lei H (2022) Remote sensing scene image classification based on mmsCNN–HMM with stacking ensemble model. *Remote Sensing* 14(17):4423

‘e-Midwife’—Empowering Mothers with Smart, Personalized Support



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Abstract The creation and assessment of the “e-Midwife” smartphone application, which aims to offer complete support for expectant and new mothers, is presented in this research paper. In order to address different aspects of maternal health, such as early intervention for skin conditions, personalized exercise recommendations, emotional support through a chatbot, and stress-relieving gaming with music suggestions, the application makes use of cutting edge technology, including image processing and machine learning techniques. Convolutional neural networks (CNNs) are used in the study to detect and predict skin conditions; machine learning models are used to identify the risk level of mothers; and an extensive questionnaire is used to evaluate participants’ emotional well-being. The application’s efficacy in enhancing maternal care outcomes for all pregnancies is evidenced by the results, which highlight how technology has the potential to completely transform maternal healthcare.

Keywords Maternal health · Mobile application · Convolutional neural networks

1 Introduction

In the journey of pregnancy and early motherhood, women navigate through a transformative landscape marked by both profound joy and significant challenges. This pivotal period demands comprehensive care and support, addressing not just the physical but also the emotional and psychological well-being of mothers-to-be and new

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mothers. Recent statistics illuminate a concerning gap in maternal care: According to the World Health Organization, approximately 6,700 infant fatalities occur daily, representing 47% of all child deaths under the age of five, primarily due to inadequate maternal care. This stark reality underscores the critical need for timely maternal care, which significantly benefits children's health [1].

The national statistics from the Family Health Bureau of the Ministry of Health in Sri Lanka further emphasize the dwindling engagement of pregnant mothers with clinic services and postnatal home visits by Public Health Midwives, alongside a noticeable reduction in teenage pregnancy registration. Amidst this backdrop, the development of "e-Midwife," a mobile application offering smart personalized support, emerges as a beacon of innovation aimed at bridging the care gap. The "e-Midwife" project is distinguished by its multifaceted approach, addressing key areas through four innovative components: Early intervention for skin conditions, personalized exercise recommendations, emotional support via a chatbot, and stress-relieving gaming with music suggestions. These components are underpinned by alarming statistics [2]. Employing advanced machine learning and image processing technologies, including Inception ResNet V2 for skin condition detection, Support Vector Machine stress relief gaming, CatBoost for exercise suggestions functionality, and Natural Language Processing for emotional support chatbot functionality, "e-Midwife" stands as a testament to the potential of technology in revolutionizing maternal care.

2 Literature Review

The integration of technology in maternal care has opened new avenues for enhancing health outcomes for both mothers and their babies. The importance of early detection and management of skin conditions during pregnancy cannot be overstated, given the potential impacts on maternal and fetal health. Pregnancy induces various physiological changes affecting multiple organ systems, including the endocrine, vascular, metabolic, and immune systems in expectant women. These alterations give rise to numerous cutaneous changes, which can manifest as either physiological or pathological conditions [3]. Physiological changes in the skin during pregnancy primarily involve modifications in skin pigmentation and laxity, primarily influenced by elevated hormone levels [4]. Studies such as AlDera et al. [5] presented a framework for the identification of various skin disorders, including acne, cherry angioma, melanoma, and psoriasis, by analyzing images of affected areas. The framework employed the Otsu technique for the segmentation of images and leveraged Gabor filters, Entropy, and Sobel operators for the extraction of features from skin image datasets, specifically DermNet NZ and Atlas Dermatologico. The study then proceeded to classify these conditions using Support Vector Machine (SVM), Random Forest (RF), and K-Nearest Neighbors (KNN) algorithms, achieving classification accuracies of 90.7%, 84.2%, and 67.1%, respectively.

The research conducted by Prrottasha, Md. Sazzadul Islam et al. [6] on datasets of skin diseases brought to light several important findings. The study demonstrated that applying fine-tuning techniques to Convolutional Neural Networks (CNNs) significantly enhances model accuracy beyond what is achievable through mere transfer learning. It was found that the Adam optimizer not only expedited classification tasks but, when used in conjunction with Inception ResNet v2, consistently delivered superior accuracy. Interestingly, despite having fewer parameters, MobileNet v2's performance was on par with that of Inception ResNet v2. The comparison between Adam and Rmsprop optimizers revealed negligible differences in accuracy, although ResNet-50 exhibited tendencies towards overfitting [7]. Maternal depression and anxiety are significant public health concerns that play an important role in the health and well-being of mothers and children [8]. The latest study has demonstrated the effectiveness of machine learning (ML) algorithms in predicting mental health problems, specifically postpartum depression and anxiety in pregnant mothers. Among several algorithms, Gradient Boosting (GB) and Random Forest (RF) have been identified as leaders, with accuracy rates of 83.3% and 83.2% for depression, and 82.9% and 81.3% for anxiety. The Naïve Bayes (NB) and GB models outperformed other models, with MCC values of 0.63 and 0.59 for depression, and 0.74 and 0.73 for anxiety, respectively. An evaluation of feature importance identified key predictors of these disorders, such as pregnancy stress, family and social support, financial issues, and income levels [9]. In another study, six machine learning models (SVM, RF, Naïve Bayes, L2-regularized LR, XGBoost, and Decision Tree) were used to predict PPD. We used tenfold cross validation to evaluate each model's performance based on the area under the receiver-operator curve (AUC). They used R 3.4.3 (R Foundation for Statistical Computing, Vienna, Austria) for all machine learning and statistical analyses [10]. The role of physical activity in ensuring the health and well-being of pregnant women has been extensively studied.

The research conducted by Ahmed and Kashem focuses on utilizing IoT technology to monitor and predict the risk levels of pregnant women in Bangladesh. By analyzing health data and various risk factors, the system is capable of identifying different levels of risk intensity. A modified Decision Tree Algorithm was implemented to enhance the accuracy of classification and prediction tasks, achieving notable results in the process [11].

Despite this, there has been limited research attention directed towards predicting maternal health risks. Raza et al. (2022) proposed the utilization of the DT-BiLTCN feature extraction technique, which combines BiLTM and TCN, for subsequent training of machine learning models. They then applied LR, DTC, SVM, and ETC to anticipate pregnancy-related risks to maternal health. Their investigation revealed that diastolic and systolic blood pressure, heart rate, and gestational age emerged as the most influential predictors of health risks during pregnancy [12]. The systematic study by BMC Pregnancy and Childbirth emphasizes the crucial role of social support for the mental health of expectant and new mothers. It reveals that organized peer support significantly benefits their well-being amidst challenges like sadness, stress, and loneliness. The study emphasizes the need for accessible, competent support systems for mothers during pregnancy and postpartum, addressing emotional distress

and improving mental health outcomes, despite challenges like remote location, stigma, and knowledge gaps.

These disparities create a strong case for digital interventions, especially when using chatbots powered by artificial intelligence (AI) to close the gap and provide moms in need with fast, individualized care [13, 14].

AI-driven chatbots have filled gaps in healthcare, particularly in maternity support. They offer personalized, easily accessible help using machine learning algorithms and natural language processing. Research by Fitzpatrick et al. (2017) showed chatbots significantly reduced users' depression symptoms, proving their efficacy in emotional support [15]. Additionally, Miner et al. (2020) found that a significant portion of users reported feeling at ease and comfortable conversing with chatbots, suggesting that chatbots could improve patient satisfaction and engagement [16]. By using LSTM models, chatbots are better able to comprehend the sentiment and context of discussions, which enables them to provide sophisticated emotional support. Gao et al. (2019), who discovered that LSTM-based chatbots outperformed conventional models in identifying and reacting to emotional distress cues, lend support to this [17]. AI chatbots have provided personalized support for isolated mothers, but their generalizability is limited due to methodological limitations, such as reliance on specific machine learning algorithms without thorough validation across diverse datasets, particularly in pregnant women.

3 Methodology

The research uses image processing and machine learning to create four key components for maternal health and well-being: early skin condition intervention, personalized exercise suggestions, emotional support via a chatbot, and stress relief gaming levels with music recommendations (Fig. 1).

3.1 *Early Intervention for Skin Conditions and Skin-Related Diseases by Skin Condition Detection and Prediction*

A. The methodology employed in this study involved the evaluation of the proposed method using two publicly available datasets: dermnet and private images sourced from dermatologists. These datasets comprised approximately 5000 images categorized into six classes: Petechiae, Maculopapular, Herpes HPV, PUPP Hives, Melanoma, and Discoid. The data were partitioned into training, testing, and validation sets at a ratio of 70:20:10, respectively, based on empirical studies demonstrating optimal performance [18]. We used data preprocessing techniques, specifically dilation and Contrast Limited Adaptive Histogram Equalization (CLAHE), to address class imbalance and improve the quality of the training data as shown in Fig. 2.

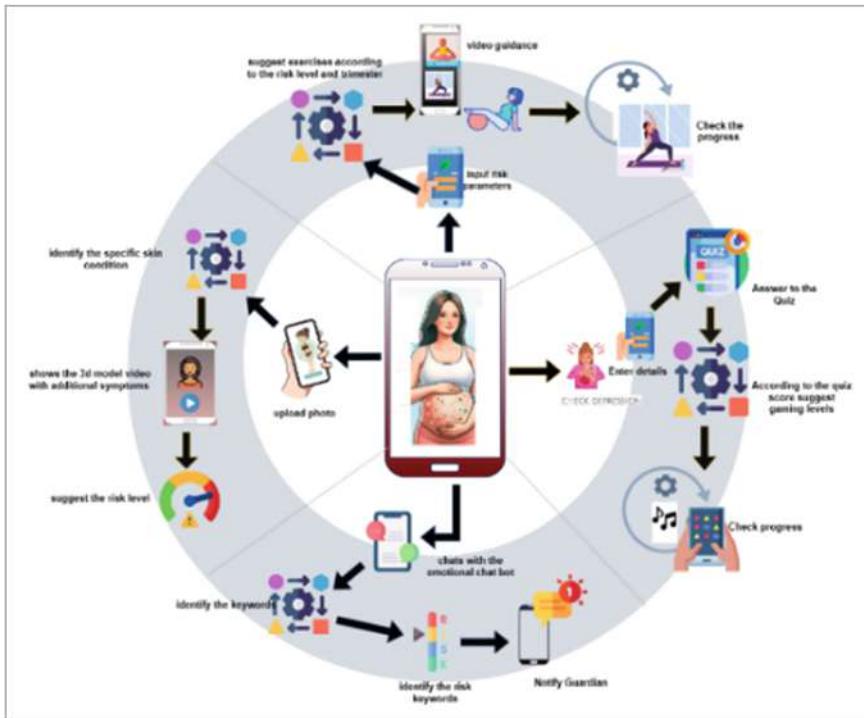


Fig. 1 System architecture

A common image processing technique known as CLAHE was used to enhance contrast and quality, while dilation, a morphological operation, was used to brighten and enlarge images [19].

Furthermore, to mitigate data imbalance and overfitting issues, reshaping-based augmentation and other augmentation techniques were implemented. Specifically, four augmentation techniques were utilized: rotation within a range of 90 degrees, shearing within a range of 0.3, horizontal flipping, and vertical flipping [20]. These techniques aimed to increase the diversity and volume of images within the datasets. In the development of convolutional neural network (CNN) architectures, we experimented with various backbones, including MobileNet V2, VGG16, and Inception ResNet V2, to explore their efficacy in classifying skin conditions accurately.

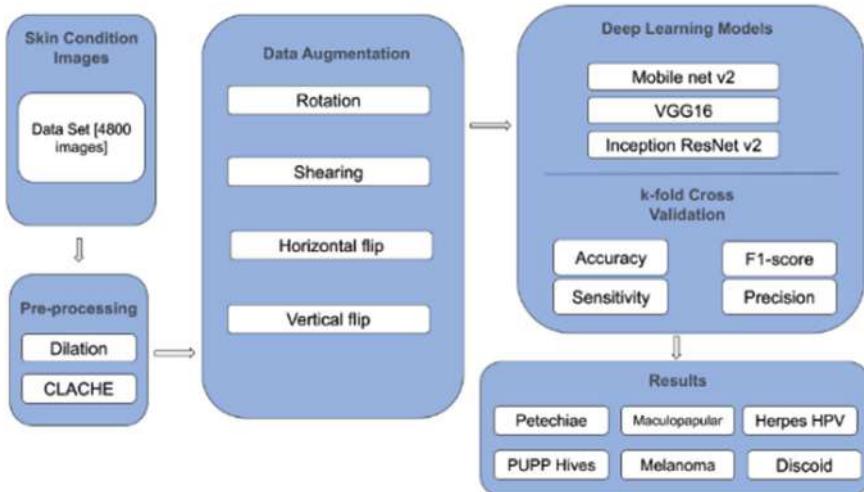


Fig. 2 Process view

3.2 Maternal Risk Level Identification and Exercise Suggestions

In this study, we aim to assess maternal health risk using machine learning techniques, specifically focusing on parameters including heart rate, age, temperature, blood sugar levels, systolic, and diastolic blood pressure. We employed four different machine learning architectures: Decision Tree, CatBoost Classifier, Random Forest, and XGBoost, to predict maternal health risk based on these parameters [21]. We collected a dataset containing information on maternal health parameters including heart rate, age, temperature, blood sugar levels, and systolic and diastolic blood pressure. The dataset was preprocessed to handle missing values and ensure consistency across features.

No feature encoding techniques such as One-Hot Encoder or Label Encoder were applied, as CatBoost Classifier, one of our chosen models, can handle both categorical and numerical features without the need for explicit encoding. Additionally, the symmetric weighted quantile sketch (SWQS) algorithm was utilized to automatically handle missing values in the dataset, reducing overfitting and improving overall model performance [22]. Four machine learning architectures were explored for maternal health risk prediction: Decision Tree, CatBoost Classifier, SWQS, Random Forest, and XGBoost. Decision Tree is a simple model based on feature values, while CatBoost Classifier efficiently handles categorical and numerical features. Each model was trained on a preprocessed dataset with and without hyperparameter optimization. Hyperparameter optimization techniques such as grid search or random search were employed to fine-tune model parameters and improve performance.

where applicable. The performance of each model was evaluated using appropriate evaluation metrics such as accuracy, precision, recall, and F1-score.

3.3 Stress Relief Gaming Levels with Music Suggestions

The begins with the administration of a comprehensive quiz to pregnant and post-partum women, encompassing questions related to their emotional well-being, experiences during pregnancy, and overall mental health. This quiz is designed to assess the participants' level of stress, depression, and other relevant factors, providing a foundational understanding of their mental state [23]. By leveraging machine learning algorithms and integrating the Edinburgh Postnatal Depression Scale (EPDS), the application provides personalized music recommendations and interactive game levels for stress relief and emotional support. The collection of data through a comprehensive quiz administered to pregnant women, covering aspects of their emotional well-being, experiences during pregnancy, and overall mental health. This initial step was crucial for evaluating participants' levels of stress, depression, and other emotional states. To predict the mental health status of participants effectively, we utilized Python for its robustness in data science and machine learning tasks. The choice of algorithms was critical for the success of the e-Midwife application. We choose a variety of machine learning algorithms to predict the most suitable gaming levels for users, aiming to support pregnant and postpartum women's mental health through personalized interactive experiences. Specifically, we utilized Decision Tree (DT), Random Forest (RF), K-Nearest Neighbors (KNN), Support Vector Machines (SVM), and a Voting Classifier, each optimized through hyperparameter tuning via Randomized Search CV to enhance model performance. These algorithms were chosen for their diverse strengths in classification tasks, from DT's simplicity and interpretability to RF's robustness against overfitting, KNN's effectiveness in capturing complex patterns, and SVM's proficiency in high-dimensional spaces. The Voting Classifier, leveraging a soft voting mechanism, integrated predictions from DT, RF, SVM, and KNN, providing a consensus-based approach to accurately predict gaming levels tailored to individual emotional states. The algorithms were trained on a data set, evaluating their effectiveness in predicting postpartum depression and anxiety levels, with a focus on their ability to provide personalized mental health recommendations.

3.4 Emotional Support and Risk Key Word Identification Chatbot for Mothers

In this study, we're presenting an advanced chatbot developed to assist and keep an eye on the safety and mental well-being of pregnant and new moms. With the

aid of an extensive dataset including more than 3,000 entries, every record includes conversational starters in addition to related risk keywords, their weights (ranging from 0 to 10), and risk categories classified by subject matter experts. These levels go from high risk, which denotes an urgent need for medical attention, to low risk, which denotes no urgent worry. The intelligence foundation of the chatbot is based on a deep learning model that uses neural networks with Long Short-Term Memory (LSTM) layers that are tuned to process the complexity of human language. This enables accurate evaluations of users' physical and emotional states based on their interactions. To enable efficient learning and prediction, the model's development technique features extensive text preprocessing, tokenization, and sequence padding to standardize input data. Its architecture makes use of the Sequential API from Keras, with bidirectional LSTM layers to fully understand user inputs, an embedding layer for word vector processing, and SpatialDropout1D to prevent overfitting. Each stimulus is classified by a sequence of dense layers that lead to a SoftMax activation function based on the predetermined risk levels. When the system recognizes a high-risk situation, it immediately sends out a Twilio SMS alert to a pre-verified family member, urging them to take immediate action. The chatbot's conversational capabilities are improved by this smooth interface with Google Bard API, enabling natural, ongoing exchanges that may precisely capture emotional subtleties and risky behaviors. The research indicates to provide mothers with a responsive and caring environment throughout this crucial period of life by mutually integrating modern AI technologies with healthcare insights. This project demonstrates the huge potential of AI for transforming maternal care and support.

4 Results and Discussion

The study assesses Inception ResNet-v2, VGG16, and Mo-bileNetV2 models for early skin condition intervention, revealing that increasing epochs from 50 to 100 enhances performance and prevents overfitting (Table 1).

The Inception ResNet-v2 architecture achieved the highest accuracy of 98.8%, demonstrating its effectiveness in accurately identifying skin conditions and related diseases. To address class imbalance issues in medical image datasets, the dilation

Table 1 Performance in CNN architecture

Performance	CNN architectures		
	Inception resnet V2	VGG16	MobileNetV2
Accuracy	98.08%	95.05%	92.20%
Precision	96.02%	96.12%	93.15%
F1 score	98.18%	94.25%	91.24%
Sensitivity	97.10%	97.98%	97.59%
Loss	0.60	0.89	0.92

method was employed as part of preprocessing techniques. By employing dilation, we aimed to enhance the representation of minority classes within the dataset, thereby improving the overall performance and robustness of the models.

The tuning of hyperparameters in the decision tree classifier, which included criteria like gini and entropy, as well as parameters like min_sample_split [2–5] and min_sample_leaf [1–4], resulted in a considerable increase in model accuracy to 78%. This improvement also significantly increased the model's robustness and ability to generalize across datasets when compared to the default settings. In XGBoost, hyperparameter optimization used max_depth [3, 5, 7], learning_rate [0.1, 0.01, 0.001], and subsample [0.5, 0.7, 1], resulting in an 88% accuracy. Furthermore, using the CatBoost classifier with improved hyperparameters such as iterations [500, 1000], learning_rate [0.15, 0.2], and depth [8, 10, 12], gave an accuracy of 89%. These findings emphasize the efficiency of hyperparameter modifying in improving model performance across different machine learning algorithms (Fig. 3 and Table 2).

The CatBoost classifier demonstrated the highest accuracy of 89% after hyperparameter optimization, outperforming other models. This highlights the effectiveness of hyperparameter modification in improving model performance across various machine learning algorithms. The CatBoost classifier was chosen as the preferred model for predicting maternal health risk. The application's efficiency was evaluated using Decision Tree, Random Forest, K-Nearest Neighbors, Support Vector Machines, and a Voting Classifier for their predictive abilities in healthcare contexts (Table 3).

The study shows machine learning can provide personalized mental health support to postpartum mothers, with SVM showing the best accuracy. The Voting Classifiers aggregation method showed equal prediction capability across conditions.

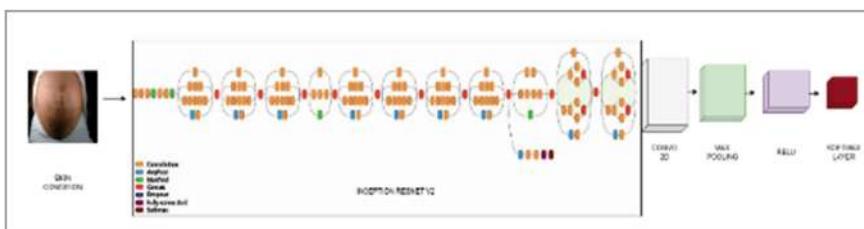


Fig. 3 Inception Resnet-v2 architecture diagram

Table 2 Hyperparameter optimization

Model	With hyperparameter optimization (%)	w/o Hyperparameter optimization (%)
Decision tree	78	72
Catboost classifier	89	87
Random forest	—	83
XGBoost	88	87

Table 3 Accuracy evolution of the models

Model	Accuracy
Decision tree (DT)	0.8395
Random forest (RF)	0.8444
K-Nearest neighbors (KNN)	0.8378
Support vector machines (SVM)	0.8490
Voting classifier	0.8411

This suggests the potential for digital health interventions in mental health care. An Embedding layer, a Spatial Dropout layer, a Bidirectional LSTM layer, Dense layers with dropout for regularization, and a Dense output layer designed for multi-class classification made up the model architecture. Given the temporal dependencies present in the data, this structure was essential in helping the model learn intricate sequential patterns within the dataset. Over the course of 20 training epochs, the model's performance improved progressively. The model's training accuracy was 51.08% at first, but by the last epoch, it had greatly increased to 99.14%. Accordingly, validation accuracy increased from 84.33% to an astounding 97.86%. These measures showed how resilient the model was and how effectively it could generalize outside of the training set.

A final test accuracy of 97.86% demonstrates the LSTM model's superior performance over traditional algorithms in handling sequential data complexity. We also investigated the performance of Random Forest and Decision Tree models for comparison, and the results showed accuracies of 92.40% and 89.50%, respectively. The comparison, which is summed up in the table below, demonstrates how much better LSTM is at capturing temporal dependencies in the data (Table 4).

The model's learning trajectory is explained by its training and validation performance over epochs, demonstrating a steady increase in accuracy and a reduction in loss, indicating its efficacy and suitability for the task in Fig. 4.

The classification report provides detailed information on the model's precision, recall, and F1-score for each class, confirming its balanced performance and its efficacy in various dataset scenarios in Fig. 5.

The LSTM model's exceptional performance in sequential data processing and complex temporal relationships tasks makes it an attractive option for practitioners and academics in related fields, as it offers advantages over conventional machine learning techniques.

Table 4 Accuracy evaluation of the models

Model	Accuracy (%)
LSTM	97.86
Decision tree	89.50
Random forest	92.40

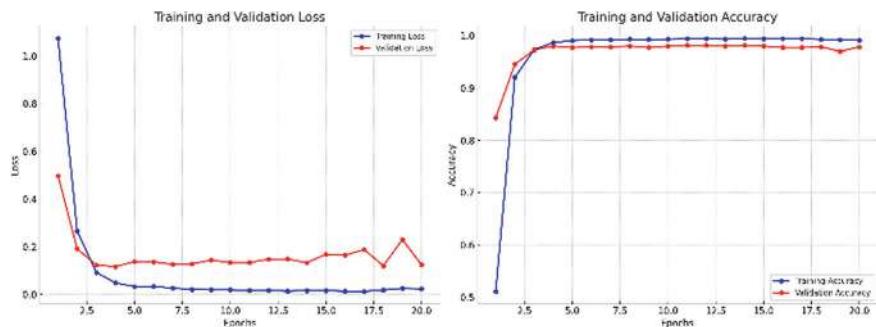


Fig. 4 Validation performance

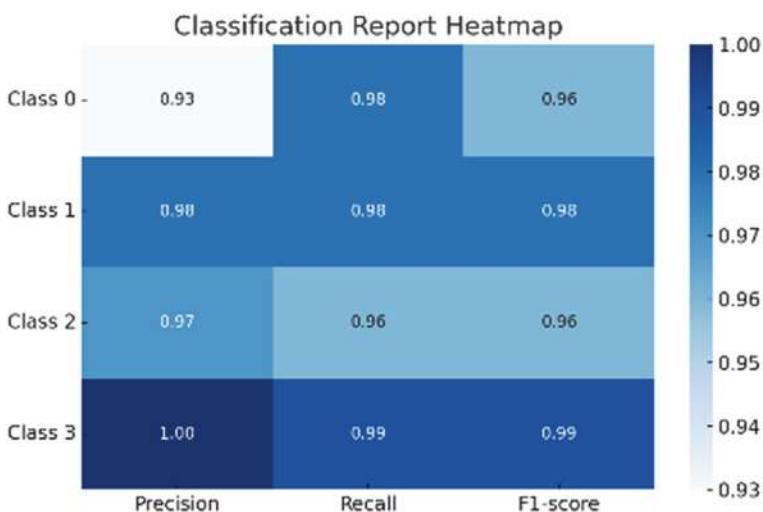


Fig. 5 Classification heat map

5 Conclusion

To sum up, the “e-Midwife” smartphone application, which provides customized support to pregnant women and new mothers, is a noteworthy development in the field of maternal health. The application offers early skin condition intervention, individualized exercise recommendations, emotional support, and stress-relieving gaming with music suggestions through the integration of image processing and machine learning techniques. The application’s effectiveness in enhancing maternal health outcomes is demonstrated by the evaluation, underscoring the significance of technology in augmenting healthcare delivery. For maternal care practices to continue to innovate and improve, research and development in this area must continue.

References

1. Ramalingam GD, Sampath SK, Amirtham JP (2021) Challenges facing during pregnancy and measures to overcome. *Global Women's Health*
2. Kanotra S, Angelo DD, Brian M (2000) Challenges faced by new mothers in the early post-partum period: an analysis of comment data from the 2000 pregnancy Risk Assess Monit Syst
3. Karen Pomeranz M (2012) Fitzpatrick's dermatology in general medicine. Skin changes and diseases in pregnancy
4. Ambros-Rudolph C (2011) Dermatoses of pregnancy—clues to diagnosis, fetal risk and therapy, In *Annals of dermatology*
5. Sah AK, Bhushal S, Amatya S, Mainali M, Shakya S (2019) Dermatological diseases classification using image processing and deep neural network. In International conference on computing, communication, and intelligent systems (ICCCIS)
6. Protasha MSI, Mahjabin Farin S, Bulbul Ahmed M, Zihadur Rahman M, Kabir Hossain ABM, Shamim Kaiser M(2023) Deep learning-based skin disease detection using convolutional neural networks (CNN). In the fourth industrial revolution and beyond
7. Sokolov A, James Chidester (2023) Predicting maternal health risk by utilizing different machine learning ClassifiersFazla RabbiNiamat Ullah Ibne Hossain. In proceedings of the American society for engineering management
8. Qasrawi R, Amro M, VicunaPolo S, Abu Al-Halawa D, Agha H, Abu Seir R, Hoteit M, Hoteit R, Allehdan S, Behzad N, Bookari K, AlKhafaf M, Al-Sabbah H, Badran E, Tayyem R (2022) Machine learning techniques for predicting depression and anxiety in pregnant and postpartum women during the COVID-19 pandemic: a cross-sectional regional study. F1000Res. 11:390. <https://doi.org/10.12688/f1000research.110090.1>. PMID: 36111217; PMCID: PMC9445566
9. Huang Y, Alverna S, Kim SJ, Maki P, Dai Y, Bernabé BP (2023) Predicting prenatal depression and assessing model bias using machine learning models. medRxiv [Preprint]. 2023.07.17.23292587. <https://doi.org/10.1101/2023.07.17.23292587>. PMID: 37503225; PMCID: PMC10371186
10. Wang, Shuoqia et al (2024) Using electronic health records and machine learning to predict postpartum depression. Ebooks.iospress.nl, IOS Press, 2019, ebooks.iospress.nl/volume/article/52116
11. Ahmed M, Kashem M (2021) IoT based risk level prediction model for maternal health care in the context Of Bangladesh. <https://doi.org/10.1109/STI50764.2020.9350320>
12. Raza A, Hafeez S, Munir K, Almutairi M, Rustam F, Ashraf I (2022) Ensemble learning-based feature engineering to analyze maternal health during pregnancy and health risk prediction. PLOS ONE. 17. <https://doi.org/10.1371/journal.pone.0276525>
13. Al-Mutawtah M et al (2023) Women's experiences of social support during pregnancy: a qualitative systematic review. BMC Pregnancy Childbirth 23(1). <https://doi.org/10.1186/s12884-023-06089-0>
14. McLeish J, Redshaw M (2017) Mothers' accounts of the impact on emotional wellbeing of organised peer support in pregnancy and Early parenthood: a qualitative study. BMC Pregnancy Childbirth 17(1):13. <https://doi.org/10.1186/s12884-017-1220-0>, <https://doi.org/10.1186/s12884-017-1220-0>
15. Fitzpatrick KK et al (2017) Delivering cognitive behavior therapy to young adults with symptoms of depression and anxiety using a fully automated conversational agent (Woebot): a randomized controlled trial. JMIR Mental Health 4(2):e19. [mental.jmir.org/2017/2/e19/](https://doi.org/10.2196/mental.7785), <https://doi.org/10.2196/mental.7785>
16. Miner Adam S et al (2020) Chatbots in the fight against the COVID-19 pandemic. Npj Digit Med 3(1):1–4. www.nature.com/articles/s41746-020-0280-0. <https://doi.org/10.1038/s41746-020-0280-0>
17. Neural approaches to conversational AI question answering, Task-oriented dialogues and social Chatbots. Ar5iv, ar5iv.labs.arxiv.org/html/1809.08267. Accessed 21 Mar 2024

18. Radhika V, Chandana BS (2023) MSCDNet-based multi-class classification of skin cancer using dermoscopy images. PeerJ Comput Sci 29(9):e1520. <https://doi.org/10.7717/peerj-cs.1520.PMID:37705664;PMCID:PMC10495937>
19. Ghezal M, Simon JJ, Escoubas L, Atteia F, Nguyen T (2023) The impact of using morphological operators with enhancement technique. pp 1–6. <https://doi.org/10.1109/MAPR59823.2023.10289049>
20. Hao R, Namdar K, Liu L, Haider MA, Khalvati F (2021) A comprehensive study of data augmentation strategies for prostate cancer detection in diffusion-weighted mri using convolutional neural networks. J Digit Imaging 34(4):862–876. <https://doi.org/10.1007/s10278-021-00478-7>. Epub 2021 Jul 12. PMID: 34254200; PMCID: PMC8455796
21. Gaillard, Romy, et al (2011) Maternal Age during pregnancy is associated with third trimester blood pressure level: the generation R study. American J Hypertens 24(9):1046–1053. <https://doi.org/10.1038/ajh.2011.95>
22. Dhananjay B, Sivaraman J (2021) Analysis and classification of heart rate using CatBoost feature ranking model. Biomed Signal Process Control (68):102610. <https://doi.org/10.1016/j.bspc.2021.102610>
23. Calculating clinically significant change in postnatal depression studies using the Edinburgh postnatal depression scale. J of Affect Disord 78(3):269–272, Mar 2004. [https://doi.org/10.1016/s0165-0327\(02\)00313-0](https://doi.org/10.1016/s0165-0327(02)00313-0). Accessed 2 Mar 2019

Securing the Chain: A Comprehensive Review of Blockchain Security Fundamentals and Challenges



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Abstract Due to its potential to revolutionize a variety of industries by providing transaction records that are decentralized and immutable, blockchain technology has received a lot of attention in recent years. However, numerous security issues that put at risk the integrity and dependability of distributed ledger systems impede the widespread use of blockchain. This review paper looks at the many different security problems that blockchain technology has, from basic flaws to new threats. Normal security chances, including 51% assaults, Sybil assaults, twofold spending, and brilliant agreement weaknesses, are examined exhaustively, alongside certifiable instances of safety breaks. In addition, the paper investigates existing mitigation and security solutions like smart contract auditing, cryptographic methods, and improvements to consensus algorithms. Also, arising patterns and future headings in blockchain security, for example, protection improving advancements, versatility arrangements, and quantum-safe cryptography, are talked about to expect and address developing dangers. Through contextual analyses and industry viewpoints, the paper gives experiences into the down-to-earth ramifications of blockchain security issues across different areas. At last, the survey closes by accentuating the significance of progressing exploration and cooperation to improve the security stance of blockchain networks and work with their broad reception in the computerized economy.

Keywords Immutable · Blockchain security · Cryptography

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1 Introduction

Blockchain innovation, which was at first considered as the establishment for Bitcoin, has quickly formed into a groundbreaking power across enterprises, promising expanded conditional straightforwardness, security, and effectiveness. Blockchain is on a very basic level a dispersed, decentralized record framework that records exchanges in a changeless, altered clear way. Applications spanning finance, medical services, store network executives, and beyond have taken note of this innovative approach to managing board information, which has garnered widespread interest and acceptance. The inborn security model of blockchain innovation, which depends on cryptographic procedures and decentralized agreement systems to ensure the uprightness and reliability of exchange records, is central to the innovation's allure. However, despite its commitment, blockchain is vulnerable to security flaws and threats. As blockchain networks expand and develop, it will become increasingly important to comprehend and address these security issues in order to realize this revolutionary technology's full potential [1, 2].

The motivation behind this survey paper is to completely research the security gives that blockchain innovation faces, including both existing weaknesses and new dangers. This paper aims to provide a nuanced understanding of the complex security scene of blockchain by examining the range of security risks, from notable attacks like 51% attacks and double spending to subtle weaknesses in smart contracts [3, 4]. This paper aims to provide insight into the reasonable ramifications of blockchain security issues across various fields by examining genuine models, contextual investigations, and existing security arrangements and alleviation methods.

2 Basics of Blockchain Security

Blockchain security is predicated on a mix of cryptographic methods, agreement components, and decentralized engineering. Decentralized Architecture.

The convergence of artificial intelligence (AI) and cybersecurity necessitates a robust infrastructure to address emerging threats effectively. Decentralized blockchain architecture, as discussed in the reviewed paper [5], emerges as a transformative solution in this domain. In summary, decentralized blockchain architecture stands at the forefront of revolutionizing AI-enabled cybersecurity, offering a robust framework to ensure the integrity, privacy, and resilience of digital ecosystems [6].

2.1 Cryptography

Blockchain employs cryptographic hash functions to secure transactions and maintain an immutable ledger, thereby fortifying the overall security posture. Through the

judicious integration of advanced cryptographic techniques, the paper endeavors to mitigate the risks associated with data breaches and upholds the confidentiality and integrity of multimedia data collected from IoT devices in today's interconnected digital landscape [7].

2.2 *Mechanisms of Consensus*

The problem of the Byzantine general serves as an illustration of how difficult it is to reach a consensus when adversarial actors are present, highlighting the need for robust consensus mechanisms to protect blockchain networks from security threats [8]. Byzantine Adaptation to non-critical failure (PBFT) offers elective ways to deal with accomplishing agreement, each with its own compromises concerning versatility, security, and decentralization [9, 10].

2.3 *Permanent Ledger*

The term “immutability” is commonly used to denote the pragmatic unfeasibility of tampering with blockchain ledger data, underscoring its crucial role in ensuring transactional integrity and upholding values of trustlessness and censorship-resistance in blockchain systems [11].

2.4 *Network Security*

To address emerging security issues and guarantee the continued trust and integrity of decentralized networks, ongoing research and innovation will be necessary as blockchain technology continues to develop [12].

3 Security Difficulties in Blockchain

Notwithstanding the commitment of blockchain innovation in giving secure and straightforward value-based systems, it faces a few security challenges. These moves present dangers to the trustworthiness, privacy, and accessibility of information put away and executed on blockchain networks.

Table 1 shows the tabulated summary highlighting the key security difficulties encountered in blockchain technology, along with associated challenges that need to be addressed for the secure and reliable operation of blockchain networks.

Table 1 Overview of security difficulties in blockchain technology

Security difficulty	Gap	Challenges
51% attacks	Occur when a single entity or group controls over 50% of a blockchain network's computing power	Challenges include preventing centralization of mining power and ensuring network security against collusion
Sybil attacks	Involve an attacker creating multiple fake identities to gain disproportionate influence	Challenges include detecting and mitigating Sybil attacks while maintaining the decentralized nature of the network
Double-spending	Refers to spending the same cryptocurrency units more than once, undermining transaction integrity	Challenges include enhancing consensus mechanisms to prevent double-spending and ensuring network trustworthiness
Smart contract vulnerabilities	Smart contracts can have coding errors or logical flaws, leading to vulnerabilities and potential exploits	Challenges include conducting thorough code audits and implementing secure coding practices to prevent exploits
Privacy concerns	While blockchain provides transparency, maintaining user privacy is challenging due to pseudonymity	Challenges include balancing transparency with privacy, especially in applications handling sensitive data
Regulatory compliance	Compliance with existing regulations such as AML/KYC poses challenges due to blockchain's decentralized nature	Challenges include navigating regulatory requirements globally while maintaining decentralization and innovation

4 Security Arrangements and Moderation Strategies

In light of the assorted exhibit of safety challenges confronting blockchain innovation, different arrangements and relief methodologies have been created to upgrade the versatility and trustworthiness of blockchain biological systems. These arrangements envelop specialized upgrades, administration measures, and local area-driven drives pointed toward shielding against expected weaknesses and assaults.

4.1 Enhance Consensus Mechanisms

Enhancements to consensus algorithms, such as hybrid models that combine PoW and PoS, aim to mitigate the weaknesses of various consensus mechanisms while maximizing their advantages [8].

4.2 Advanced Cryptographic Techniques

Blockchain systems are being researched and incorporated with post-quantum cryptography, which is designed to withstand the cryptographic threats posed by quantum computers, to safeguard against upcoming technological risks [13].

4.3 Formal Verification and Smart Contract Auditing

Smart contract auditing services evaluate and validate the code of smart contracts on their own, finding flaws, unsafe coding practices, and potential routes for attacks. Decentralized finance (DeFi) applications, in particular, benefit from third-party audits because they increase trust and transparency in smart contract deployments [14].

4.4 Network Monitoring and Intrusion Detection

Executing hearty organization checking and interruption location frameworks (IDS) empowers proactive recognition and alleviation of malignant exercises in side blockchain networks. IDS solutions use behavioral analysis, anomaly detection methods, and machine learning algorithms to spot suspicious behavior and potential security risks. Continuous observing of organization traffic, hub conduct, and agreement components works with quick reaction to security episodes and limits the effect of assaults on blockchain tasks [15, 16].

4.5 Regulatory Compliance Measures

Administrative consistence structures and industry norms assume a basic part in guaranteeing the security and authenticity of blockchain applications. Blockchain-based transactions gain trust and confidence by meeting regulatory requirements like know your customer (KYC) and anti-money laundering (AML) regulations [17]. Blockchain developers, stakeholders in the industry, and regulatory authorities' work together to create a favorable regulatory environment that strikes a balance between innovation, consumer safety, and security. By carrying out these security arrangements and moderation systems, blockchain partners can improve the versatility, honesty, and reliability of blockchain environments. However, a comprehensive approach to blockchain security must still include vigilance, collaboration, and adaptation to changing security threats [18].

Table 2 Security arrangements and moderation strategies in blockchain technology

security arrangement/strategy	Description
Consensus mechanisms	Various consensus mechanisms like Proof of Work (PoW), Proof of Stake (PoS), and Delegated Proof of Stake (DPoS) ensure agreement on the state of the blockchain
Cryptographic techniques	Implementing cryptographic techniques such as hashing, digital signatures, and encryption to secure transactions and data on the blockchain
Multi-signature (Multisig) wallets	Utilizing multisig wallets requiring multiple private keys to authorize transactions, enhancing security and reducing single points of failure
Role-Based access control (RBAC)	Implementing RBAC to manage permissions and access levels within blockchain networks, limiting the exposure of sensitive data and functions
Penetration testing	Conducting regular penetration testing to identify vulnerabilities and weaknesses in blockchain systems, enabling proactive security measures

Table 2 provides an overview of security arrangements and moderation strategies employed in blockchain technology, highlighting key measures to address security challenges and ensure the integrity and resilience of decentralized networks.

5 Contextual Investigations and Industry Perspectives

By breaking down unambiguous use cases across different businesses, we can acquire a more profound comprehension of the security gambles intrinsic in blockchain organizations and the procedures utilized to address them.

5.1 Banking and Finance

The DAO Hack, the Decentralized Independent Association (DAO) was an Ethereum-based investment store that experienced a basic security break in 2016 because of a shrewd agreement weakness. The adventure brought about the burglary of around \$50 million worth of Ether, featuring the significance of brilliant agreement evaluation and weakness remediation in decentralized finance applications [19, 20].

5.2 Production and Network Management

Walmart is able to quickly trace the source of contaminated food items by utilizing blockchain technology, reducing the impact of outbreaks of foodborne illness and improving consumer safety [21].

5.3 Healthcare

Clinical Records, the board MedRec, a blockchain-based clinical record the executives framework created by MIT specialists, expects to furnish patients with secure and interoperable admittance to their clinical records. By utilizing blockchain innovation, MedRec guarantees the honesty and classification of touchy patient information while empowering consistent information dividing between medical care suppliers [22].

5.4 Computerized Personality and Authentication

Self-Sovereign Identity, Sovrin is an open-source identity network based on blockchain that lets people securely create and manage their digital identities. Sovrin uses blockchain technology to eliminate the need for centralized identity providers, preserving user privacy and autonomy while simultaneously lowering the likelihood of data breaches and identity theft [23].

5.5 Government and Public Sector

Blockchain technology is used in a variety of industries and the security issues and solutions that come with using blockchain. A joint effort between partners, industry best practices, and ceaseless advancement are fundamental for saddling the groundbreaking capability of blockchain while guaranteeing the security and uprightness of computerized biological systems [24].

Table 3 shows the tabulated summary outlining key topics in blockchain security literature, including descriptions of each topic and associated challenges faced by researchers and practitioners in the field.

Table 3 Summary of literature survey on blockchain security

Literature	Description	Challenges
Consensus mechanisms	Examines various consensus mechanisms such as Proof of Work (PoW), Proof of Stake (PoS), and Practical Byzantine Fault Tolerance (PBFT)	Challenges include scalability, energy consumption (PoW), and centralization risks (PoS)
Cryptographic techniques	Investigates cryptographic methods used in blockchain, including hashing, digital signatures, and zero-knowledge proofs	Challenges include quantum computing threats and vulnerabilities in encryption algorithms
Smart contract security	Focuses on vulnerabilities in smart contracts, such as reentrancy, integer overflow/underflow, and lack of input validation	Challenges include formal verification complexities and the need for widespread adoption of secure coding practices
Network security	Analyzes network layer security in blockchain, including Distributed Denial of Service (DDoS) attacks, Eclipse attacks, and Sybil attacks	Challenges include mitigating network-level attacks while maintaining decentralization and peer-to-peer communication efficiency
Regulatory compliance	Explores regulatory challenges and compliance requirements for blockchain-based applications, including anti-money laundering (AML) and know your customer (KYC) regulations	Challenges include achieving regulatory clarity, navigating jurisdictional differences, and balancing privacy with transparency
Privacy and confidentiality	Addresses privacy-enhancing technologies (PETs) such as zero-knowledge proofs and ring signatures to preserve transactional privacy while maintaining auditability	Challenges include achieving a balance between privacy and transparency, scalability limitations of PETs, and regulatory concerns regarding anonymity

6 Conclusion

Blockchain innovation offers decentralized, straightforward, and secure structures however faces security challenges like 51% assaults, Sybil assaults, and savvy contract weaknesses. Arrangements incorporate upgraded agreement systems, high level cryptography, and shrewd agreement inspecting. Contextual analyses in finance, production network, medical care, and government feature viable ramifications and safety efforts. Coordinated effort and development are critical for sustaining blockchain environments. Looking forward, continuous exploration and administrative consistence will be fundamental for address arising dangers and guarantee trust in blockchain innovation. Blockchain security is fundamental to realizing the potential of decentralized digital systems, not just technical. We will be able to overcome these obstacles and build trust in the transformative power of blockchain if we embrace collaboration and innovation.

References

1. Chuannian SHEN (2024) Review on security issues of blockchains. *Comput Eng Sci* 46(01):46
2. Indrason N, Saha G (2024) Exploring blockchain-driven security in SDN-based IoT networks. *J Netw Comput Appl* 103838
3. Bal M, Chawdhry M Exploring the utility of blockchain in military operations. *Future Warfare and critical technologies: Evolving tactics and strategies* 57
4. Calik E (2024) Challenges of blockchain applications. In: *Exploring Blockchain applications*, CRC Press, pp 48–62
5. Saleh AMS (2024) Blockchain for secure and decentralized artificial intelligence in cybersecurity: A comprehensive review. *Blockchain: Res Appl* 100193
6. Mlika F, Karoui W, Romdhane LB (2024) Blockchain solutions for trustworthy decentralization in social networks. *Comput Netw* 110336
7. Dhar S, Khare A, Dwivedi AD, Singh R (2024) Securing IoT devices: a novel approach using blockchain and quantum cryptography. *Internet Things* 25:101019
8. Lashkari B, Musilek P (2021) A comprehensive review of blockchain consensus mechanisms. *IEEE Access* 9:43620–43652
9. Bach LM, Mihaljevic B, Zagar M (2018) Comparative analysis of blockchain consensus algorithms. In: *2018 41st international convention on information and communication technology, electronics and microelectronics (MIPRO)*. IEEE, pp 1545–1550
10. Ouyang Z, Shao J, Zeng Y (2021) PoW and PoS and related applications. In: *2021 international conference on electronic information engineering and computer science (EIECS)*. IEEE, pp 59–62
11. Politou E, Casino F, Alepis E, Patsakis E (2019) Blockchain mutability: Challenges and proposed solutions. *IEEE Trans Emerging Top Comput* 9(4):1972–1986
12. Manimugam S, Anitha T, Divya G, Latha CGP, Mathupriya S (2022) A survey on blockchain technology for network security applications. In: *2022 2nd international conference on computing and information technology (ICCIT)*. IEEE, pp 440–445
13. Oberoi O, Raj S (2022) Advanced cryptographic technologies in Blockchain. *Blockchain technology in corporate governance: Transforming business and industries* pp 325–351
14. Liu J, Liu Z (2019) A survey on security verification of blockchain smart contracts. *IEEE access* 7:77894–77904
15. Zhan X, Yuan H, Wang X (2019) Research on block chain network intrusion detection system. In: *2019 international conference on computer network, electronic and automation (ICCNEA)*. IEEE, pp 191–196
16. Alexopoulos N, Vasilomanolakis E, Ivánkó NR, Mühlhäuser M (2018) Towards blockchain-based collaborative intrusion detection systems. In: *Critical information infrastructures security: 12th international conference, CRITIS 2017, Lucca, Italy, October 8–13, 2017, Revised selected papers* 12, pp 107–118. Springer International Publishing
17. Charles W, Marler N, Long L, Manion S (2019) Blockchain compliance by design: Regulatory considerations for blockchain in clinical research. *Front Blockchain* 2:18
18. Garg P, Gupta B, Chauhan AK, Gupta S, Modgil S (2021) Measuring the perceived benefits of implementing blockchain technology in the banking sector. *Technol Forecast Soc Chang* 163:120407
19. Gan Q, Lau RYK, Hong J (2021) A critical review of blockchain applications to banking and finance: A qualitative thematic analysis approach. *Technol Anal Strat Manag* 1–17
20. Patel R, Migliavacca M, Oriani ME (2022) Blockchain in banking and finance: A bibliometric review. *Res Int Bus Financ* 62:101718
21. Dietrich F, Ge Y, Turgut A, Louw L, Palm D (2021) Review and analysis of blockchain projects in supply chain management. *Procedia Comput Sci* 180:724–733
22. Agbo CC, Mahmoud QH, Eklund JM (2019) Blockchain technology in healthcare: A systematic review. *In Healthc* 7(2):56

23. Hardjanto N, Supriati R, Azizah N, Santoso NPL, Maulana S (2021) Blockchain based authentication for identity management. In: 2021 9th international conference on cyber and IT service management (CITSM). IEEE, pp 1–8
24. Tan E, Mahula S, Crompvoets J (2022) Blockchain governnance in the public sector: A conceptual framework for public management. Gov Inf Q 39(1):101625

Automating Fantasy Cricket Team Formation: An Iterative Model Approach



Polinati Vinod Babu and M. V. P. Chandra Sekhara Rao

Abstract In fantasy cricket, which is based on actual cricket matches, points are awarded based on how well players perform in exact matches. This study was written to fill the literature gap by introducing an iterative methodology for automating team creation in the fantasy cricket framework. In order to create teams within predetermined parameters, the model combines a credit and point system. Our approach can efficiently generate all feasible or optimal team configurations by automating the process of team generation and allowing circumstances and user-selected criteria to be used. We put these artificial intelligence-generated teams to the test in a real-time setting against user-created ones. In a real-time setting, we tested these teams produced by the machine versus teams that were created by the user. In contrast to manually constructed teams, our results show that the teams assembled by the algorithm not only follow the given constraints but also exhibit better performance prediction accuracy.

Keywords Sports analytics · Team optimization · Automated team selection · Machine learning · Statistical modeling

1 Introduction

In interactive online games known as fantasy sports, players put together virtual teams made up of actual athletes from a particular sport in the position of team managers. These teams play each other according to the athletes' statistics results from real games. In point-based fantasy leagues, for example, players' actual performances are converted into fantasy points that may be managed and accrued by participants to improve team results.

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One of these sports which had been recently gained a lot of popularity in India is fantasy cricket. Compared to other American fantasy sports, which include a variety of sports, fantasy cricket capitalizes on the country's love of cricket in particular. The convergence of three thriving industries gaming, professional cricket, and the internet creates a profitable market for a product known as "Fantasy Cricket for Cash." To succeed in this game, players must be able to plan and accumulate points to move up the leaderboard. The game's integration into major sporting events is seen in the spikes in participation, especially during major twenty-20 games like the Indian Premier League (IPL).

There are two primary categories of fantasy cricket leagues: private and public. Private leagues are invitation-only, closed groupings where players can compete against people they know, such as friends or coworkers. Conversely, public leagues are accessible to all users and are usually organized by the platform's administrators for particular competitions. These leagues might charge an entrance fee or be free, which raises the stakes for competitors.

Creating teams within a set budget and choosing players from groups like wicket-keepers, batsmen, bowlers, and all-rounders gives the game its strategic depth. Every player choice and team composition includes a difficult decision-making process that is impacted by current and past player performances. In fantasy cricket, the ultimate goal is to score as many points as possible against rivals while following the forms of One Day International (ODI), Twenty20 (T20), Ten10 (T10), and Test cricket, each of which presents different difficulties and chances for strategic play.

This introduction lays the groundwork for investigating the creation and use of an iterative methodology intended to maximize team management and selection in the fast-paced, highly competitive world of fantasy cricket.

2 Literature Survey

The Team Formation Problem (TFP) investigates the best ways to put together a team of people to achieve optimal performance for particular activities. Operations Research (OR) and Data Mining (DM) are the two disciplines that are primarily studying this subject. The OR method concentrates on team alignment based on organizational requirements, intending to assign the most qualified applicants to specific positions or assignments within a company. On the other hand, the DM approach emphasizes the significance of social structure in team effectiveness by using social network data to identify individuals whose combined strengths and established interactions suit the expectations of a particular task.

A slightly different concept is found in Multi-Agent Systems (MAS), where team formation theories are further applied. MAS allows agents to freely choose which groups to join, in contrast to standard TFP scenarios where decisions are typically made centrally. MAS has a lot of potential, however using TFP techniques directly in these frameworks can be difficult because there isn't a set team task.

Julio Juarez et al. [1] made significant contributions to this discipline with their taxonomy of TFP, which lists the essential elements of TFP. A different noteworthy study by B. H. Boon and G. Sierksma [2] presented techniques for creating the best teams and determining the value that new team members bring. To improve teamwork effectiveness, Evimaria Terz et al. [3] suggested tactics for reducing communication costs among team members.

Abhilash Jindal et al. [4] presents optimized cricket teams by considering players' batting and bowling abilities with a novel gene representation and a multi-objective optimization technique utilizing the NSGA-II algorithm in the special context of sports, specifically cricket. This method, which reflects broader developments in sports analytics, emphasizes the expanding use of advanced data analysis tools in the building of sports teams.

Studies by Aneem-Al-Ahsan Rupai et al. [5], Tulasi B and Vudit Kanungo [7], and Nilambar Sethi et al. [8], which examine IPL teams and players' performances for predicting match results, demonstrate how research on cricket analytics extends into prediction models and performance evaluations. Furthermore, the research conducted by Awais Yasin et al. [6] and Praphula Kumar Jain, Rajendra Pathula, and Waris Quinter [9] contributes to this subject by providing fresh perspectives on the analytics of cricket matches and the use of data mining in sports.

There is still not much research on user-centric analysis and the implementation of these insights in fantasy cricket games, despite the extensive discussion of real cricket game analysis. To close this gap, Dr M V P Chandra Sekhara Rao and Vinod Babu Polinati [10] created an optimized algorithm for T10 fantasy cricket team formation that is mostly focused on players' bowling performances. This study emphasizes how combining cutting-edge analytical tools with user-driven sports platforms can improve fantasy sports decision-making and engagement.

3 Methodology

3.1 Iterative Model Overview

The iterative technique used in this study is intended to maximize the creation of fantasy cricket teams by continuously improving and modifying player selection. This algorithmic method not only increases the diversity of the team's membership but also boosts the group's output over time. Based on historical performance measures and real-time data, the model iteratively refines team configurations to guarantee that the teams adapt and adopt better player combinations and strategies.

3.2 Algorithm Outline

Step 1: Initial Team Formation.

- First, a basic team is formed by the algorithm based on predetermined characteristics. Every team needs to have:
 - 1–4 wicket-keepers
 - 3–6 batsmen
 - 1–4 all-rounders
 - 3–6 bowlers
- Each team has a maximum of 11 players, and each player's overall credit total awarded by the league commissioner based on players' prior performances cannot exceed 100.

Step 2: Variation Operation.

- The method executes a “variation operation” to each player type after building the basic team. To create new teams, this method entails switching around members in the same category to try out various combinations. Diversifying team strategies and configurations requires taking this key step.

Step 3: Rotation Operation.

- The newly created teams are then subjected to a “rotation operation” by the model. To make sure that all potential team configurations are investigated, this entails cycling players between teams on a regular basis. The goal of this stage is to maximize team performance in a variety of hypothetical match circumstances.

Example teams generated include N11, N12,..., N46, where “N” denotes a set of teams and the subsequent numbers represent specific team configurations within that set.

3.3 Problem Definition

- Restrictions encompass the uppermost wage ceiling and the constraint on player positions (such as the quantity of bowlers or batters). The model presents an obstacle to optimization as it necessitates striking a compromise between the optimal team configurations given these limitations and the inherently unpredictable player performances.
- Putting together teams that maximize points versus rivals while simultaneously following the structural regulations is the goal, which is determined by predictive analytics.

3.4 Implementation and Testing

- During Sri Lanka's 2019–20 tour to India, the suggested approach was put into practice during the second Twenty20 international match between India and Sri Lanka. The league commissioner revised player information, such as responsibilities and credits, to reflect players' anticipated contributions to the game and their recent performances.
- Teams underwent iterative construction, testing, and refinement, and the efficacy of the model was assessed by comparing performance measures against Dream Team points and manually generated team points.

3.5 Data and System Configuration

- The league commissioner supervised the collection and maintenance of player statistics and past performance data in a centralized database.
- Every participant received a distinct ID and was linked to particular performance points, which affected their choice in the model.

The adaptable nature of the iterative model and its strong testing through real-time simulations show that it can be a valuable tool for fantasy cricket players and strategists looking to improve their decision-making.

4 Experiments and Evaluations

The process for assessing the iterative model's efficacy in creating fantasy cricket teams is described in this section. During a Twenty20 international match between India and Sri Lanka, the model is applied in real-time as part of the experimental setup. Performance metrics were gathered, processed, and analyzed in order to compare manually built teams by fantasy players with teams generated by the program.

4.1 Original Scorecard and Match Data

Access to the original scorecard and comprehensive match data was possible through well-known sports websites like Sportskeeda, ESPN Cricinfo, and Cricbuzz. These sources included thorough player performance data, which was crucial for confirming the model's predictions.

The scoring categories used to assess players' contributions during the match are summarized in Tables 1 and 2.

Table 1 Detailed Fantasy Cricket Points System

Category	Action	Points
Batting	Run	0.5
	Boundary Bonus	0.5
	Six Bonus	1.0
	Half Century Bonus	4.0
	Century Bonus	8.0
	Dismissal for Duck (Other than Bowler)	- 2.0
Bowling	Wicket	10.0
	4 Wickets in an Innings	4.0
	5 Wickets in an Innings	8.0
	Maiden Over	4.0
Fielding	Catch	4.0
	Stumping/Run Out (Direct)	6.0
	Run Out (Thrower + Catcher)	6.0
Others	Captain	2.0
	Vice-Captain	1.5
	In Starting XI	2.0
Economy rate	Below 4 Runs per Over (Min 2 Overs)	3.0
	Between 4 and 4.99 Runs per Over (Min 2 Overs)	2.0
	Between 5 and 6 Runs per Over (Min 2 Overs)	1.0
	Between 9 and 10 Runs per Over (Min 2 Overs)	- 1.0
	Between 10.1 and 11 Runs per Over (Min 2 Overs)	- 2.0
	Above 11 Runs per Over (Min 2 Overs)	- 3.0
Strike rate	Between 60 and 70 Runs per 100 Balls	- 1.0
	Between 50 and 59.9 Runs per 100 Balls	- 2.0
	Below 50 Runs per 100 Balls	- 3.0

4.2 Fantasy Cricket Points System

A thorough scoring system was devised by the league commissioner to measure player performances in a number of areas, such as:

- **Batting:** Runs, boundaries, half-centuries, centuries, and penalties for getting out on a duck.
- **Bowling:** Wickets taken, bonuses for multiple wicket hauls, and maidens bowled.
- **Fielding:** Catches, stumping, and successful run-outs.
- **Additional Points:** For captains and vice-captains, initial players selected, and penalties or bonuses based on the economy and strike rates.

Fantasy cricket scorecard (Continue...).

Table 2 Fantasy cricket scorecard

CNT	CAT	POS	NAME	CRD	SELECTED BY	PTS	ANNOUNCED	RUNS	4S	6S	S/R	BALLS FACED	30/50/100	DUCK	OVERS BOWLED	WICK
IND	BW	8	STK	8.5	28.36	81	1	0	0	0	0	0	0	0	4	3
IND	BW	11	NSN	8	69.96	74	1	0	0	0	0	0	0	0	4	2
SL	BW	9	WHR	8	45	73	1	16	3	0	0	10	0	0	4	2
IND	BW	9	KYD	9	41.52	60	1	0	0	0	0	0	0	0	4	2
IND	BT	2	LRL	9.5	82.71	55	1	45	6	0	0	32	0	0	0	0
IND	BT	1	SDW	9.5	64.91	46	1	32	2	0	0	29	0	0	0	0
SL	WK	3	KPR	9	84.4	44	1	34	0	3	0	28	0	0	0	0
IND	BT	4	SIY	9	35.69	43	1	34	3	1	0	26	0	0	0	0
IND	BT	3	VKL	11.5	85.33	39	1	30	1	2	0	17	0	0	0	0
SL	BT	2	AFD	8.5	68.2	31	1	22	5	0	0	16	0	0	0	0
IND	BW	10	JBR	9.5	45	29	1	0	0	0	0	0	0	4	1	1

CNT	CAT	POS	NAME	CRD BY	SELECTED PTS	LBW/BOW BONUS	2/3/4/5 WICK BONUS	MAIDEN OVER	E/ R	CATCH	RUNOUT/ STUMPING	TOTAL
IND	BW	8	STK	8.5	28.36	81	0	3	0	2	0	81
IND	BW	11	NSN	8	69.96	74	0	2	0	4	2	74
SL	BW	9	WHR	8	45	73	0	2	0	0	0	73
IND	BW	9	KYD	9	41.52	60	0	2	0	—	1	60
IND	BT	2	LRL	9.5	82.71	55	0	0	0	0	0	55
IND	BT	1	SDW	9.5	64.91	46	0	0	0	0	1	46
SL	WK	3	KPR	9	84.4	44	0	0	0	0	0	44
IND	BT	4	SIY	9	35.69	43	0	0	0	0	0	43
IND	BT	3	VKL	11.5	85.33	39	0	0	0	0	0	39
SL	BT	2	AFD	8.5	68.2	31	0	0	0	0	0	31
IND	BW	10	JBR	9.5	45	29	0	0	0	0	0	29

The points that players received for their in-game performances are displayed in the following table, which provides a clear comparison between the iterative model's team selection process and conventional techniques.

4.3 Model Testing and Results

The model was used to analyze the chosen Twenty20 International match, and the process was followed iteratively to create the team lineups. These teams' performances were then evaluated using the predetermined scoring system and the actual match results.

4.4 Comparative Analysis

The accuracy of the iterative model in predicting top performers and ideal team compositions was evaluated using a comparative analysis. Figs. 1 and 2 show the Comparison of Dream Team Points (DTP) with Practical Team Points (PTP) showcasing the model's ability to predict player performance and displaying the accuracy percentages, comparing the number of top performers identified by the model versus actual top performers in different leagues.

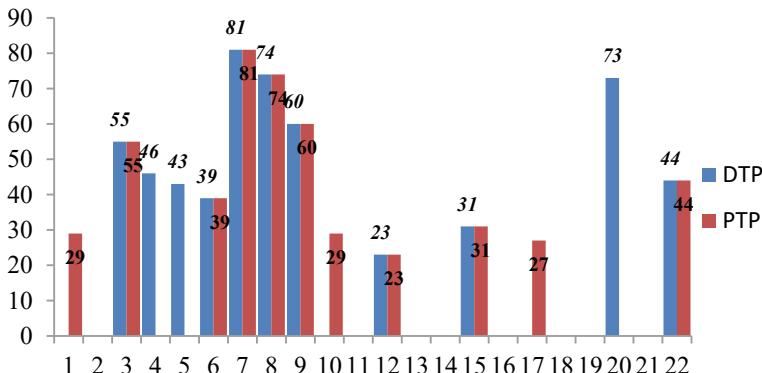


Fig. 1 Comparison of DTP (Dream Team Points of players) with PTP (Practical Team Points), which is our top-performing team from the proposed model

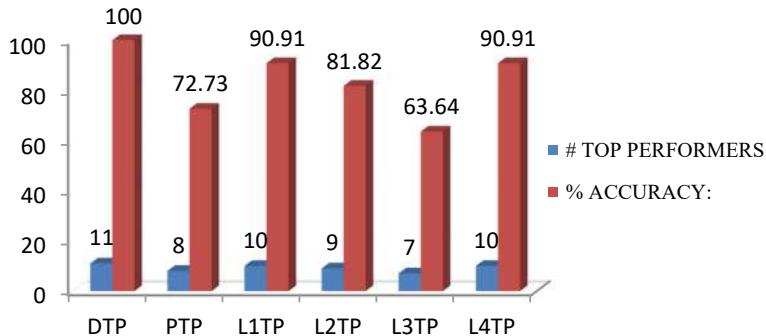


Fig. 2 Comparison of No. of top performers and their accuracy of DTP, PTP, L1TP, L2TP, L3TP, and L4TP in a match

4.5 Outcome and Model Evaluation

With an impressive accuracy of 72.73%, the iterative model outperformed numerous manually created teams in different areas, including player inclusion and point accumulation. The assessment brought to light the model's capacity to successfully optimize team configurations and anticipate player performances in an adaptable manner.

4.6 Insights and Improvements

The experiment provided important information about the model's operational effectiveness and potential improvement areas. The model's prediction powers could be further improved by introducing dynamic criteria like player form and injury status and adjusting the model's parameters, such as the weights of player credits.

5 Conclusion

The adoption of an iterative strategy to create fantasy cricket teams in a virtual environment was effectively proven by this study. The model was able to generate team configurations that either matched or exceeded the pre-defined ideal criteria by merging real-time match analytics with past performance data. This generated consistent results.

Because of the rigorous nature of our experimental methodology, we were able to evaluate these teams against user-constructed teams in a real-world setting during a live cricket match. Our model-generated teams performed much better than those created by human players, according to the comparative analysis. This demonstrates

not only how well the model performs in making decisions in real time but also how it has the potential to completely transform the formation of fantasy cricket teams by putting a greater emphasis on data-driven methods than intuition.

The study's findings support the notion that the iterative model is an effective tool for fantasy sports, providing a sophisticated way to improve the processes involved in team creation and player selection. Subsequent research endeavors may investigate additional enhancements to the model, such as adding more dynamic variables and broadening its usage to encompass different cricket formats and possibly other sports.

References

1. Juárez J, Santos C, Brizuela CA (2021) A comprehensive review and a taxonomy proposal of team formation problems. ACM Comput Surv 54(7):33. <https://doi.org/10.1145/3465399>
2. Boon BH, Sierksma G (2003) Team formation: Matching quality supply and quality demand. Eur J Oper Res 148(2):277–292.ISSN:0377-2217. [https://doi.org/10.1016/S0377-2217\(02\)00684-7](https://doi.org/10.1016/S0377-2217(02)00684-7)
3. Lappas T, Liu K, Terz E (2009) Finding a team of experts in social networks. KDD'09, 28Jun–1Jul 2009, Paris, France
4. Ahmed F, Deb K, Jindal A (2013) Multi-objective optimization and decision making approaches to cricket team selection. Appl Soft Comput 13(1):402–414.ISSN:1568–4946. <https://doi.org/10.1016/j.asoc.2012.07.031>
5. Rupai AAA, Mukta MSH, Islam AN (2020) Predicting bowling performance in cricket from publicly available data. ICCA 2020, 10–12 Jan 2020, Dhaka, Bangladesh. <https://doi.org/10.1145/3377049.3377112>, 04 Dec 2021
6. Awan MJ, Gilani SAH, Ramzan H, Nobanee H, Yasin A, Zain AM, Javed R (2021) Cricket match analytics using the big data approach. Electron 10(19):2350. <https://doi.org/10.3390/electronics10192350>
7. Tulasi B, Kanungo V (2019) Data visualization and toss related analysis of IPL teams and batsmen performances. Int J Electr Comput Eng (IJECE) 9(5):4423–4432.ISSN:2088–8708. <https://doi.org/10.11591/ijece.v9i5.pp4423-4432>
8. Sivamaraju V, Sethi N, Rajender R (2020) Heuristics for winner prediction in international cricket matches. Stat Optim Inf Comput 8:602–609. <https://doi.org/10.19139/soic-2310-5070-648>
9. Jain PK, Quamer W, Pamula R (2021) Sports result prediction using data mining techniques in comparison with base line model. Opsearch 58(1):54–70
10. Polinati VB, Chandra Sekhara Rao MVP (2021) An optimized model to create teams in fantasy cricket. Available at SSRN <https://ssrn.com/abstract=3853704>. <https://doi.org/10.2139/ssrn.3853704>

From Unified Ontology to Knowledge Base: Data Fusion for Enhanced Wildfire Management



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Abstract The increasing frequency and intensity of wildfires require an extensive plan for efficient management and response to crises. The SILVANUS project is focused on creating an integrated platform that addresses the difficulties of managing wildfires by leveraging an ontology and knowledge base (KB). The construction of the ontology and the KB's infrastructure are described in this study. They set the groundwork for a knowledge-driven strategy to handle ongoing wildfire threats. The background discusses the goals of the SILVANUS project and semantic technologies, highlighting the use of ontologies as management tools for forest fires. A thorough wildfire management ontology was created by utilizing domain-specific sources and ontologies to cover topics such as causes, climate, sensors, and tools. A methodical approach to ontology engineering was used in the technique, which included creating competency questions, gathering data, and classifying classes. The ontology evaluation met the requirements of the Ontology Summit 2013 and was thus of high quality and relevance. SILVANUS's semantic data fusion used the CASPAR framework to merge data from several sources, including social media sensing and IoT sensors. Through the use of a semantic repository, data fusion, and semantic mapping, heterogeneous data could be efficiently integrated into a Knowledge Graph (KG). By combining several data sources, the KG, which is driven by SPARQL queries, facilitates the extraction of deep insights and improves decision-making abilities. With interdisciplinary cooperation and creative technological integration, this study provides a strong ontology and knowledge base architecture that are essential for tackling the complex problems of managing wildfires.

Keywords Wildfire management · Semantic technologies · Data fusion

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1 Introduction

In an era marked by the increasing frequency and severity of wildfire events [1], addressing these challenges demands a multifaceted, interdisciplinary approach [2]. The SILVANUS project [3] offers an opportunity to tackle such challenges. The project's aim is the development of an integrated platform for effective wildfire management and emergency response.

To facilitate this approach and resolve issues related to semantic and technological interoperability, the utilization of a Knowledge Base (KB) becomes essential. This paper covers the development of both an ontology and the infrastructure of the KB. It should be noted that the creation of this ontology serves as the foundational building block for the instantiation of a KB. Such KB will be populated with real-world data and will be capable of information fusion, which will enable the continuous inference of new knowledge from existing data. This structure is instrumental for addressing the ever-evolving challenges that characterize the field of wildfire management.

In this context, the paper will include a section outlining the requirements, methodology, and ontology results. The second part of the paper will focus on the development and design of the KB.

2 Background and Related Work

2.1 Semantic Technologies

Semantic technologies imbue heterogeneous data with formal semantics, creating interconnected networks known as Knowledge Graphs (KGs). These KGs, webs of contextualized information, utilize languages that articulate relationships between data in a machine-comprehensible manner. The Semantic Web (an extension of the current World Wide Web) empowers computers with machine-interpretable metadata, enabling meaningful inferences, and transforms the Web from a collection of connected documents into a realm of linked data, facilitating the construction of a complex web of machine-processable meaning [4].

The primary distinction between semantic technology and other data technologies, such as relational databases, lies in its emphasis on the meaning of the data rather than its structure. According to the Semantic Web initiative of the World Wide Web Consortium (W3C), the objective of this technology is to establish a “universal medium for the exchange of data” by connecting the global sharing of various types of commercial, scientific, cultural, and personalized data [5].

W3C has developed a series of standards that contributed to the realization of the vision of the Semantic Web: Resource Description Framework (RDF), which provides a straightforward language for defining objects and their relations in a network [6], including OWL (Web Ontology Language) [7], SPARQL [8], and Uniform Resource Identifier (URI), for unambiguous resource identification. The

adoption of Semantic Web standards, along with any technologies that implement them, has been significantly amplified through Knowledge Graphs (KG), despite those being a relatively recent development.

KGs introduce the Semantic Web paradigm to industries by incorporating semantic metadata to enhance the efficiency of data and content management. KGs represent an advanced form of semantically referenced data. By utilizing knowledge as a context for interpretation and as a source for enrichment, they assist businesses in enhancing proprietary information. Ontologies serve as the backbone of KGs, providing a semantics-rich specification of the “schema” that KGs adhere to [9].

2.2 *SILVANUS Project*

The SILVANUS EU H2020 project focuses on advancing forest management practices with an emphasis on environmental sustainability and climate resilience. Its core objective is to develop an innovative platform to prevent and combat forest fires efficiently, utilizing state-of-the-art technologies. Central to the project are ontologies and KGs.

Ontologies provide structured frameworks for capturing knowledge in relevant fields such as forest administration, ecological processes, and resource utilization. Complementing this, KGs dynamically represent interconnected information, modeling complex relationships between the modules involved in the platform.

This facilitates a comprehensive understanding of ecological interactions, resource flows, and risk factors. SILVANUS aims to leverage KGs as a powerful analytical tool, uncovering hidden insights for data-driven decision-making in sustainable forest management. The integration of ontologies and KGs seeks to improve forest management practices, promoting resilience and environmental stewardship.

2.3 *State of the Art Ontologies*

In our pursuit of creating a robust wildfire management ontology, we decided to integrate knowledge from a variety of state-of-the-art sources. This process allowed us to construct an ontology that captures the complexity of the domain while aligning with established best practices.

One of our foundational sources was the beAWARE Ontology [10] which provided essential concepts related to crisis management and involved structures and infrastructure, while ensuring that our ontology adhered to recognized standards and practices in the field. Figure 1 illustrates the representation of an incident in this ontology.

For a comprehensive understanding of fire-related concepts, we drew upon the Bioportal Fire Ontology [11]. This resource enriched our ontology with a wide range

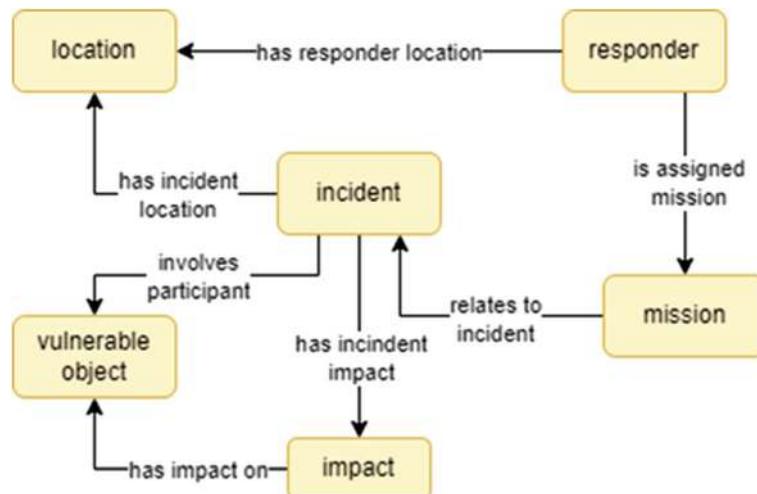


Fig. 1 beAWARE’s representation of an incident with its related classes

of information, covering different types of fires, their characteristics, and the spatio-temporal aspects of fire incidents.

To maintain relevance within the European context, we closely adhered to the European Forest Fire Information System (EFFIS) [12]. By incorporating EFFIS’s fire cause classification, our ontology was harmonized with the shared taxonomy used across European countries.

Concepts regarding fire weather calculations and assessments were added through the integration of terminology from the Canadian Fire Weather Index (FWI) System [13]. These terms, including temperature, humidity, wind speed, precipitation, and fuel moisture levels, were incorporated into our ontology.

Environmental factors also played a key role, and we leveraged the Bioportal Environment Ontology (ENVO) [14] to enrich our representation. This involved including various environmental concepts, such as different types of roads, biomes, and land usage, with their corresponding counterparts in our ontology.

To ensure standardized and interoperable representation of forestry inventory data, land use information, spatial entities, and measurements, we made use of the Cross-Forest Project Ontologies [15]. These modular ontologies contributed to the comprehensive coverage of relevant data.

Another weather-related source of terminology was the BIMERR Weather Ontology [16], part of the BIMERR project. This set of classes enhanced our ontology’s ability to represent weather phenomena relevant to wildfire management.

Finally, to improve our ontology’s representation of emergency response infrastructure, we integrated classes from the Bioportal Emergency Situation Ontology

(ESO, a resource designed to support decision-making and coordination during emergencies). This resource contributed various types of facility classes, including buildings, accommodations, communication facilities, education facilities, and medical facilities.

Our wildfire management ontology was built through the assimilation of knowledge from a diverse range of sources, using an integration approach that helped it address the domain's complexity while aligning with existing best practices and standards, enhancing its usefulness and relevance in the field.

3 Ontology Conceptualization and Engineering

This chapter delves into the conceptualization and engineering of the ontology developed as part of the SILVANUS project. This ontology serves as a fundamental building block for the instantiation of a comprehensive knowledge base in the domain of wildfire management and emergency response.

3.1 Requirements

The need for an interdisciplinary approach to effectively address the significant challenges posed by wildfires was clear from the beginning of the project. Wildfires transcend various disciplines, making it essential to design a comprehensive ontology that can capture and connect concepts from these diverse fields. However, the existing state-of-the-art lacked a dedicated ontology specifically tailored to the comprehensive 360-degree wildfire management, which the SILVANUS platform aims to address. For this reason, we identified a total of seven broad macro categories that would require addressing within our ontology: “Sensors, Tools & Resources, Biodiversity, Vulnerable objects, Climate, Causes, and Fire.” These categories encompassed a wide range of key aspects essential for comprehensive wildfire management.

In terms of the format required for sharing our ontology with the larger community, we leveraged the commonly used OWL structure. Not only does it facilitate the representation of complex knowledge but also enables knowledge inference through SPARQL queries, enhancing the ontology’s usability and adaptability for various applications.

Additionally, we ensured that our ontology adhered to the guidelines provided by the Ontology Summit 2013 Communiqué [17]. This report represents an effort in advancing the adoption of ontology evaluation practices. We incorporated ontology evaluation strategies across all phases of our ontology’s development. We conducted evaluations against the identified requirements to ensure that our ontology met the standards of quality, usability, and relevance in the domain of wildfire management.

3.2 Methodology and Ontology Development

The methodology employed in the development of the ontology was designed to ensure the ontology's robustness, relevance, and effectiveness in supporting wildfire management and emergency response. This methodology involved a series of well-defined steps, including the brainstorming of competency questions, data collection, integration of state-of-the-art knowledge, and the categorization and definition of classes and properties.

Competency Questions. To precisely define the scope of the ontology and identify relevant concepts, a set of competency questions was formulated. They served as guidelines to ensure that key aspects of fire management and emergency response were covered.

The questions spanned a wide range of topics in the wildfire management domain:

- What are the key environmental factors that contribute to wildfire ignition and spread?
- What types of resources and tools are essential for wildfire management and emergency response?
- How does a wildfire impact biodiversity and the post-fire environment?
- What climatic parameters influence the behavior of wildfires?
- What types of fires exist, and how do they differ in behavior and impact?
- What are the procedures and protocols for responding to a wildfire incident?

Data Collection and Domain Analysis. The first phase of ontology development required the gathering of a comprehensive understanding of the domain to identify the ontology's requirements and guide subsequent decisions. The following sources of knowledge were leveraged:

- Internal knowledge within the SILVANUS project served as a foundational source of insights. It included data, documentation, and expertise relevant to the project's goals and operational scenarios. This internal knowledge allowed us to identify domain-specific concepts, requirements, and challenges.
- Knowledge from Domain Experts involved in the project through interviews and workshops allowed for the collection of valuable input [18]. Their feedback and suggestions played an important role in shaping the ontology's design.
- Knowledge from Data Available to Domain Experts working on related tasks. This data encompassed diverse geographical regions, each with its unique characteristics. Information such as fire fronts, weather conditions, causes of fire incidents, vegetation conditions were extracted.

In particular, the operational scenarios yielded a condensed selection of macro-categories that serve as the primary knowledge domains to be covered within the ontology. To simplify this categorization process, each category was associated with a distinct color, facilitating the organization of all underlying concepts into their respective domains. These macro-categories include Sensors, Tools & Resources, Biodiversity, Vulnerable objects, Climate, Causes, and Fire. The following table is a

sample of the process that was repeated for all the countries hosting the operational scenarios. The legend is included on the right (Table 1).

With the help of this first categorization, we further defined these raw concepts into ontology classes. A sample of this process for macro-category Sensors is represented in Table 2.

Categorization and Definition of Classes. After this initial categorization and the further refinement of these raw concepts into ontology classes, we achieved a structured representation of the diverse aspects related to wildfire management and emergency response. Here are some sample results from this categorization process:

Sensors. Concepts related to various types of sensors and devices were grouped together, such as IoT sensors, drones, cameras, and satellites. These concepts were defined as classes such as “IoT Devices”, “UAV” (unmanned aerial vehicle), and “Camera”, providing a clear representation of the sensors and devices used for monitoring and data collection in wildfire management.

Tools & Resources. This macro-category encompassed concepts related to fire-fighting units, vehicles, heliports, evacuation measures, and more. The ontology

Table 1 Sample of categorizing knowledge from operational scenarios into the ontology main macro-categories with legend

CZECH REPUBLIC	FIRE
No precipitations	CAUSE
Fire ignition sources	BIODIVERSITY
Temperature	SENSORS
Professional and volunteer firefighting unit	TOOLS & RESOURCES
Windy conditions	VULNERABLE
Drones	OBEJCTS
UAV, UGV	CLIMATE
Positioning of deployed firefighters	

Table 2 Class definition from “Sensors” raw concepts

	Raw concepts from pilots	Derived ontology class
Sensors	UGV Robot	UGVs
	Cameras Photo data / Images related to the fire Infra-red thermal camera CCTV based smoke detection	Cameras
	Satellite Satellite multispectral image	Satellite Detection System

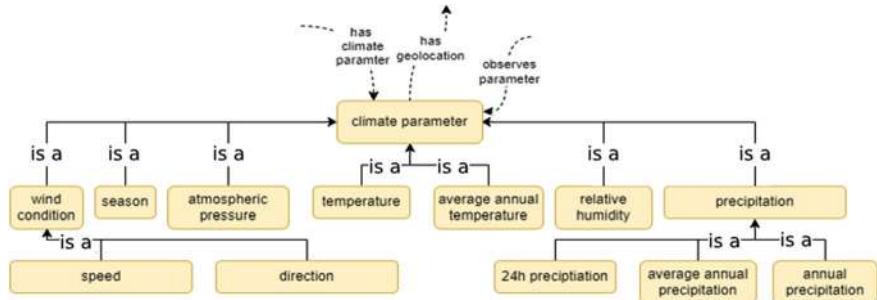


Fig. 2 Graphical view of part of the climate macro-category

defined classes such as “Responder”, “Vehicles”, “Health resources”, and “Procedures” to represent the tools, resources, and procedures used in wildfire management and emergency response scenarios.

Biodiversity. Concepts within this macro-category included vegetation types, soil properties, moisture levels, and post-fire conditions. Classes such as “Biodiversity landscape”, “Vegetation type”, “Moisture”, and “Land use” were defined to capture relevant biodiversity aspects and environmental factors associated with wildfires.

Vulnerable Objects. This macro-category covered concepts related to urbanized areas, critical infrastructure, transportation systems, and energy infrastructure. Classes such as “Urbanized areas”, “Critical infrastructure”, “Transportation”, and “Energy infrastructures” were created to represent the various objects and areas vulnerable to fire incidents.

Climate. As illustrated in Fig. 2, concepts within the climate macro-category encompassed factors like wind patterns, temperature variations, precipitation levels, and atmospheric pressure. Classes such as “Wind”, “Temperature”, “Precipitation”, and “Atmospheric pressure” were defined to capture meteorological data relevant to wildfire management and assessment.

Causes. Under the “Causes” macro-category, concepts related to the origins and triggers of wildfires were grouped together. The ontology defined classes such as “Rekindle”, “Negligence”, “Arson”, and “Natural” to represent key aspects of wildfire causes as they are identified in the EFFIS taxonomy.

Definition of properties. In this section, we introduce a subset of sample properties from the ontology designed for managing and analyzing data related to wildfire incidents. Due to space limitations, a concise overview of key object properties is provided.

hasHealthImpactMonitoringSensor. This property links a HealthImpactMonitoringSensor to a Component, indicating the association of a sensor for monitoring health impacts with a specific component, allowing the ontology to capture health data relevant to related to wildfire incidents. For instance, if there is a Component dedicated to health impact monitoring, “hasHealthImpactMonitoringSensor” would establish the link to the specific HealthImpactMonitoringSensor providing relevant health-related information.

hasAirQualityIndex. This property establishes a connection between HealthImpactMonitoring entities and AirQualityIndex indices. Applying this property indicates the specific air quality index associated with a health impact monitoring entity, offering insights into the prevailing air quality conditions. For example, an instance of HealthImpactMonitoring can be linked to the AirQualityIndex “PM2.5,” signifying the presence of fine particulate matter in the air.

hasClimateParameter. This property establishes a connection between entities like AreaBurned, Incident, and MonitoredArea to ClimateParameter components. This linkage indicates the influence of climate parameter measurements on these entities. By using this property, the ontology represents how climate parameters impact various aspects related to fighting wildfires. An illustrative example includes linking an Incident to a ClimateParameter, symbolizing the influence of climate parameters on the occurrence of the incident.

hasPost. This property establishes a link between a Post and a PostEvent to connect information related to a wildfire event. It helps organize and associate textual or multi-media content with specific wildfire events, aiding in the aggregation of relevant information. For instance, if there is a Post specifically related to a wildfire incident, the “*hasPost*” property would establish the connection to the corresponding PostEvent, ensuring proper categorization and contextualization of the information.

Integration of State-of-the-Art Ontologies. Existing, established ontologies provided a rich source of useful concepts and relationships relevant to wildfire management. To ensure coherence and interoperability, we established connections between their terminologies and ours through the RDF “*sameAs*” relation. This method enabled us to link equivalent concepts and relationships across different ontologies, facilitating the harmonization of data exchange and the process of knowledge inference across different systems and applications.

Iterative Development Process. Ontology development is an iterative process, incorporating feedback loops to align the design with project requirements, expert insights, and evolving domain knowledge. This iterative approach ensures continuous refinement, adaptation to emerging practices in wildfire management, and the integration of internal and external sources. It combines a structured approach to ontology engineering with a comprehensive exploration of domain-specific knowledge, resulting in a robust framework for managing fire-related information and interactions.

3.3 *Ontology Evaluation*

Our ontology underwent an evaluation for suitability and quality in accordance with the Ontology Summit 2013 guidelines. This process encompassed several phases:

Requirements Development Phase. Establishing the ontology’s necessity for addressing complex forest fire challenges, facilitating interdisciplinary collaboration, and promoting technological integration in fire management.

Competency Questions and Scope Definition. Defining the ontology's scope based on competency questions to ensure comprehensive coverage of wildfire management concepts.

Ontological Analysis Phase. Engaging domain experts to validate the ontology's adequacy, documentation, and clarity in capturing relevant terms and entities within the scope. A sample of the questions that guided this phase included:

- To what extent does the ontology need to accurately represent the key concepts within the domain of wildfire management?
 - The decision was to maintain a dynamic approach and remain adaptable, acknowledging the evolving nature of the project and standing ready to delve deeper into specific sections as the project unfolds. This approach ensures that the ontology remains relevant and aligns with the project's changing needs over time.
- How comprehensible is the documentation associated with the ontology? Does it facilitate a clear understanding of the ontology's structure and purpose?
 - The proactive step of documenting each class and property within the ontology ensures that the purpose of each class and property is clearly described. This documentation serves as a valuable resource, promoting a transparent understanding of the ontology's structure and objectives. Additionally, we have developed three different visualizations tailored for experts, developers, and laypersons. This diversification enables us to adapt the ontology's user experience to the specific needs of each user group, facilitating a deeper understanding and better interaction with the structure and objectives of the ontology.
- Were domain experts satisfied with the ontology's coverage of relevant terms and entities? Did it meet their expectations in capturing the intricacies of wildfire incidents?
 - Bilateral calls and questionnaires have been used for actively involving experts in shaping the ontology's content. The insights gained from these engagements ensured that the ontology effectively captured the complexity surrounding wildfire incidents, aligning with the expertise and expectations of domain specialists.

Ontology Design Phase. During the Ontology Design Phase, the choice to use Ontology Web Language (OWL) was made, because of its expressive power and compatibility with semantic web standards. Additionally, the capability of using SPARQL as the query language facilitates efficient retrieval and manipulation of data stored under the ontology schema.

System Design Phase. Examining the integration of the ontology into the system architecture, ensuring compatibility with adjacent components, and defining necessary interfaces, tools, and data sources.

Deployment Phase. Evaluating the ontology's compliance with requirements and its provision of new capabilities. No major deployment issues were identified.

This thorough evaluation process, aligning with Ontology Summit 2013 guidelines, confirmed the ontology's fitness for purpose, with an 83% compliance rate out of 53 evaluation questions, demonstrating its robustness and best practices in ontology development. Ongoing collaboration aims to refine and adapt the ontology for operational use.

3.4 Results

The outcome of our efforts in ontology conceptualization and engineering has yielded a robust knowledge framework for wildfire management and emergency response. The ontology, adhering to the standards set forth, is now available on the SILVANUS project website [19] in the OWL format, making it easily shareable with the broader community. A related paper [20] has also been published by IEEE, for those wanting to delve deeper into the topic.

Although impossible to read in detail at this scale, Fig. 3 aims to provide a glimpse over the macro-categories represented in the ontology from a bird's eye view to give an idea of its extension and modularity.

The outcome of such activity represents a step in the right direction toward addressing the multifaceted challenges of wildfires through interdisciplinary collaboration and the integration of well-established and standardized technologies. This ontology stands as a useful resource aimed at enhancing the collective understanding and response to wildfire incidents, while also serving as a model for future endeavors in complex, cross-disciplinary domains.

4 Semantic Data Fusion in SILVANUS

Semantic Data Fusion in SILVANUS involves populating a vacant semantic model with data from various sources, such as sensors and SILVANUS analysis components. This process integrates diverse components within the SILVANUS wildfire management ontology-based model, enabling a comprehensive representation of wildfire crises. At the core of this architecture is the Semantic Knowledge Base (SemKB), performing semantic fusion using outputs from different SILVANUS components.

Presently, the integrated data sources include IoT devices for fire detection, Social Media Sensing, and IoT devices for Health Monitoring. These sources continually update the SemKB with instance data, contributing to the evolving nature of the project. Subsequent sections will elaborate on the inputs that are fed into the SemKB.

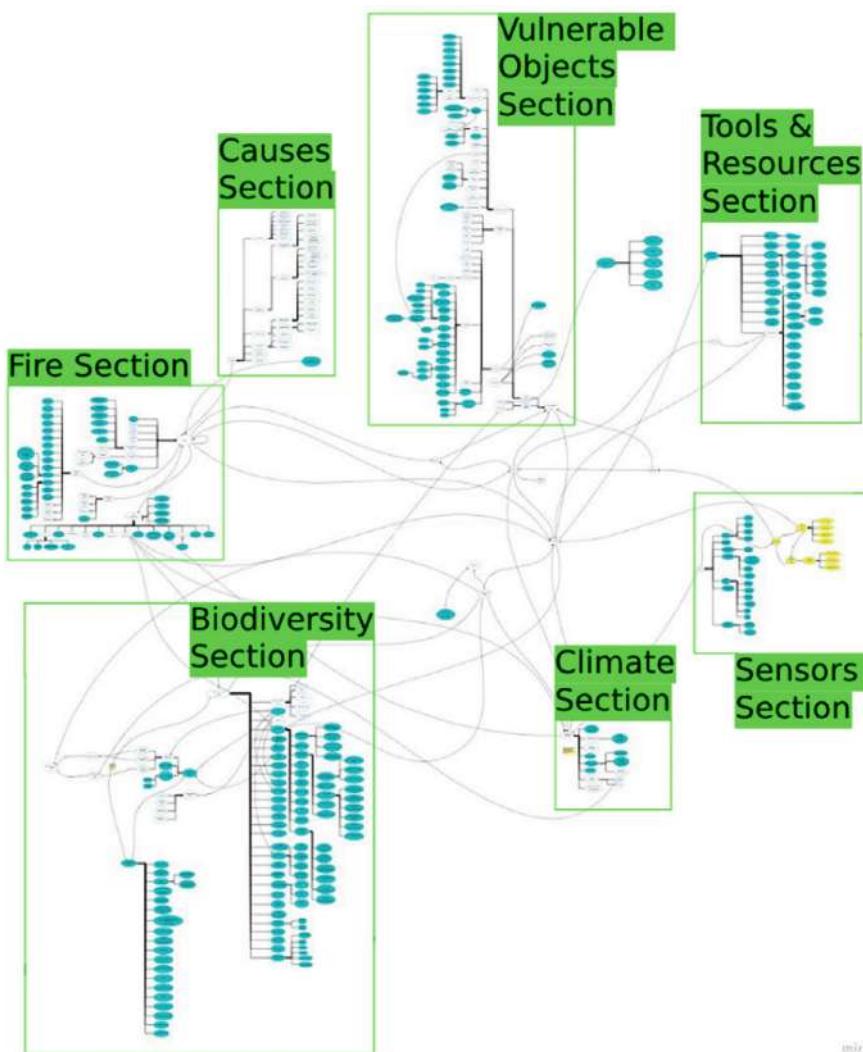


Fig. 3 Bird's eye view of the ontology

4.1 Semantic Mapping

In this section, the paper illustrates the process of mapping textual elements to semantic concepts within the SILVANUS ontology. To demonstrate the alignment between outputs, a representative example is presented, reflecting the similar process applied across various modules within the framework.

Semantic Mapping of IoT device. The IoT device gathers environmental data, utilizes machine learning algorithms at the edge to analyze it, and produces a fire/

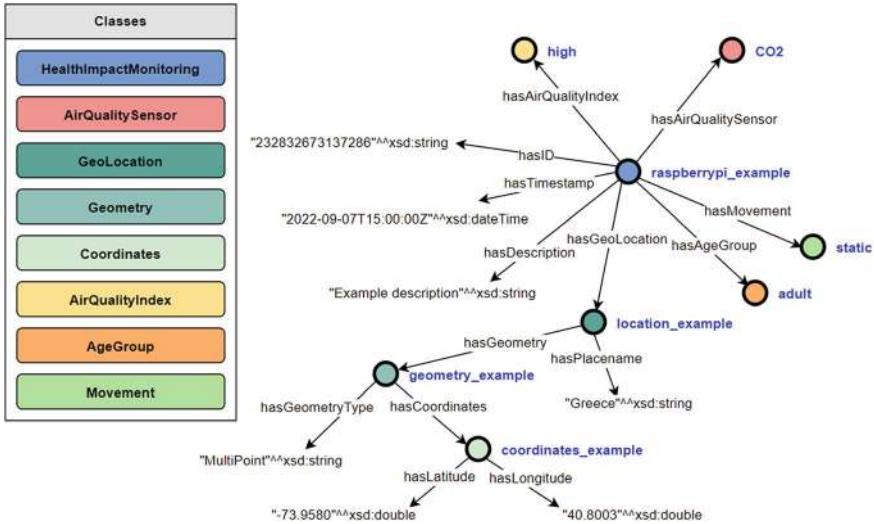


Fig. 4 Transforming IoT device output into RDF with ontological concepts

smoke event report in JSON format. This report includes the device's location, collected data, and the fire/smoke detection score (derived from machine learning). These details are fed into the SILVANUS framework and then integrated into the SemKB ontology.

In Fig. 4, a visual representation using Graffoo [21] displays the ontology's classes, instances associated with each class, as well as the object and datatype properties linked to each instance. This graphical depiction offers a sample view of the ontology's structure and its populated instances.

4.2 Semantic Data Population

The CASPAR [22] Semantic Data Fusion Framework by Catalink Ltd [23] addresses the integration of diverse semantic data within the SILVANUS project. It focuses on harmonizing heterogeneous data sources into the SILVANUS semantic model. CASPAR's design emphasizes modularity, flexibility, and scalability using microservices and message brokers. Microservices enable easier management of complex systems, fostering agility and quick implementation of improvements. These microservices, effective for large enterprise applications, pose communication challenges, resolved by messaging middleware. This middleware, with a Message Broker and message queues, establishes a scalable communication infrastructure. Message queues simplify coding, enhance performance, and enable asynchronous communication between producers and consumers. This comprehensive approach supports distributed systems while streamlining communication between components.

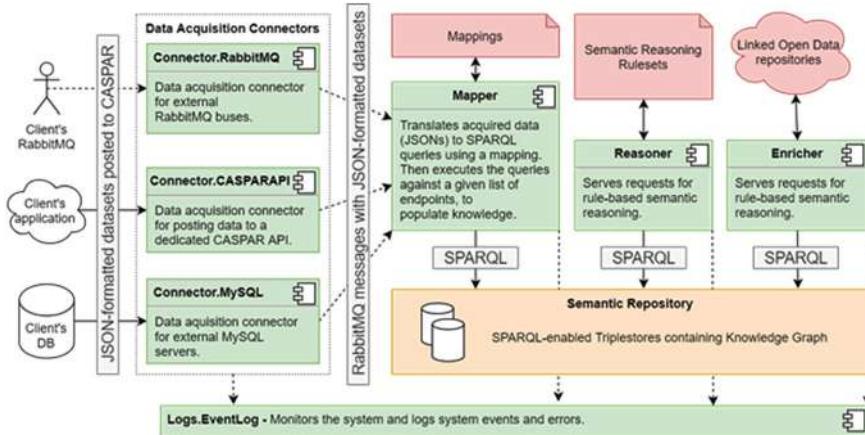


Fig. 5 Block diagram portraying the CASPAR architecture

The architecture of this system involves retrieving user data, validating and transforming it using mappings, and populating KGs in the Semantic Repository, as illustrated in Fig. 5. The KG is then enriched with external knowledge, and semantic reasoning is applied to infer new knowledge using rulesets. Event logging is also available for auditing and troubleshooting.

This architecture facilitates the integration of diverse data sources and efficient data processing/analysis using KGs and semantic reasoning.

System Implementation. CASPAR uses RabbitMQ for asynchronous intercommunication among its components. To initialize CASPAR, a RabbitMQ instance is deployed and configured, which can be accessed through its management interface. Each CASPAR component has a RabbitMQ directory in its Python code, containing a Consumer and a Producer class, along with a RabbitMQ configuration file (JSON). The configuration file for each CASPAR component allows the user to specify the settings for the RabbitMQ instance, such as the IP address and port number. This enables the component to use the selected RabbitMQ instance, for example one hosted on Digital Ocean [24].

CASPAR's modular data connections, the CASPAR API and RabbitMQ Connector, enable it to manage a wide range of structured data from multiple sources with efficiency, reflecting versatility. These connectors give clients exact control over how frequently data is posted, ensuring flexibility across a broad range of applications. Notably, by directly receiving messages from the user's RabbitMQ deployment, the RabbitMQ Connector is able to populate the KGs in real-time. The CASPAR framework then uses a Mapper module to transform external data retrieved by connectors into SPARQL queries and populate the RDF triplestore [Fig. 6].

To achieve this, the Mapper requires predefined files called Mappings, which specify how data fields associate with concepts and relationships in the KG. Each Mapping can contain one or more templates, which operate independently and

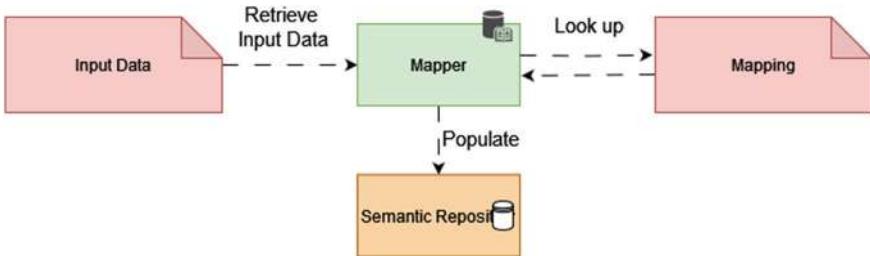


Fig. 6 Mapper functionality

contain sections for prefixes and individuals. Prefixes are structural components of SPARQL searches that define relationships in the ontology. Templates contain individuals that declare nodes to be created or updated in the KG. An individual is an instance of one or more classes in the ontology and can be defined using datatype and object properties. Datatype properties have literal values, while object properties use an attribute to link individuals. Properties in mappings are defined using predicates and objects, which indicate the relationship type and value for the property [Fig. 7].

CASPAR's Mappings also include an optional update_on field for each individual, which allows for the declaration of unique property-value pairs. This enables the framework to update existing nodes in the KG instead of generating new ones, preventing the occurrence of duplicates and enabling precise knowledge extraction. The Mapper first searches for an existing node based on the unique property-value pairs, and if found, associates the new properties with it. If no node is found, the Mapper creates a new node and populates it with the new predicate-object pairs.

```

1
`"individuals": [
  {
    "path": "raspberrypi_detections.*", For each item found in the input data in the list of field
    "namespace": "http://www.semanticweb.org/SILVANUS_onto_demo", Create an individual that starts with this namespace
    "classes": ["silvanus_demo:RaspberryPiDetection"], This individual should be of type RaspberryPiDetection
    "properties": [ This individual should have a set of properties in the Knowledge Graph
      {
        "predicates": [
          "silvanus_demo:hasID", Should have a :hasID and a :label
          "rdfs:label"
        ],
        "object": [
          "path": "raspberrypi_detections.*.id", This is the field where the value should be derived
          "datatype": "xsd:string" The value should be noted as a string
        ],
        "object": [
          "predicates": ["silvanus_demo:hasRaspberryPiSensor"], Object property that connects the 'RaspberryPiDetection'
          "object": [
            "path": "raspberrypi_detections.*.sensor_type.*" individual to the "sensor_type" individual (which is declared
          ]
        ],
      ],
    ],
  },
],
```

```

**Fig. 7** Sample of mapping individuals and properties (both object properties and datatype properties)

```

JSONParser(): 0:00:00.002007
Populator.create_triples_of_individual_populators(): 0:00:00.009942
Populator.cluster_triples_to_queries(): 0:00:00.008954
SPARQLQueryBatch(): 0:00:00.004027
Populator(): 0:00:00.026819
Total: 0:00:00.028826
Message received and validated
JSONParser(): 0:00:00.001001
Populator.create_triples_of_individual_populators(): 0:00:00.002959
Populator.cluster_triples_to_queries(): 0:00:00.001507
SPARQLQueryBatch(): 0:00:00.015375
Populator(): 0:00:00.024772
Total: 0:00:00.025773
Message received and validated
JSONParser(): 0:00:00.000484
Populator.create_triples_of_individual_populators(): 0:00:00.000526
Populator.cluster_triples_to_queries(): 0:00:00
SPARQLQueryBatch(): 0:00:00.003496
Populator(): 0:00:00.004284
Total: 0:00:00.004844

```

**Fig. 8** Sample of CASPAR populating the GraphDB

### 4.3 Semantic Repository

The Semantic Repository is a special database that stores the KGs in the form of an ontology. It uses SPARQL and HTTP requests to allow users to perform queries on the KG. The repository can be hosted on the cloud or on premise, which ensures the safety and integrity of sensitive data. The Mapper can use multiple endpoints to create multiple KGs at the same time. In this case, we used Ontotext GraphDB on a local machine. CASPAR allows users to receive, verify, and publish data with time indicators to GraphDB [Fig. 8].

As we have seen in this chapter, CASPAR plays a central role in the SILVANUS project by providing a framework for knowledge management and enabling the construction of a KG. The use of SPARQL-enabled RDF triplestore and HTTP requests enables the deployment of the triplestore on the cloud or on-premises, allowing for the preservation and consultation of KGs wherever it is required. The next subchapter will discuss the implementation of CASPAR in the SILVANUS project, examining its functionalities and how it is utilized to facilitate decision-making processes.

### 4.4 Knowledge Graph-Based Decision Support: Deeper Insights Retrieval

The creation of the SILVANUS KG has been marked by a significant focus on applying ontology engineering approaches and optimizing SPARQL usage. These

techniques have been incorporated into Ontotext's GraphDB environment, forming the core of the system's capabilities.

Figure 9 showcases a sample SPARQL query, highlighting its role in retrieving more profound insights.

By integrating this data, the SPARQL query demonstrates the potential for synergy. It adeptly amalgamates insights from two IoT devices, with a particular focus on fire detection and air quality. The ultimate outcome, highlighted by the alignment of SPARQL queries that integrate both data sources, presents a view that amplifies decision-making capabilities (see Fig. 10). For instance, one can notice a significant decline in air quality to a 'very poor' state mere hours after the detection of a fire incident in the same area. This integration of information provides a more nuanced understanding, which is invaluable for informed decision-making.

```
PREFIX : <https://silvanus-project.eu/wp-content/uploads/2022/09/SILVANS-Ontology.zip#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

SELECT ?HealthMonitoringDateTime ?AirQuality ?IoTDateTime ?FireProbability ?FireDetection
?Placename
WHERE {
 ?health rdf:type :HealthImpactMonitoring;
 :hasGeolocation ?geolocation1;
 :hasTimestamp ?HealthMonitoringDateTime;
 :hasAirQualityIndex/rdfs:label ?AirQuality.
 ?geoLocation1 :hasPlacename ?Placename.
 ?rasp rdf:type :RaspberryPiDetection;
 :hasGeolocation ?geoLocation2;
 :hasTimestamp ?IoTDateTime;
 :hasSensoryData ?sensoryData.
 ?geoLocation2 :hasPlacename ?placename2.
 ?sensoryData :hasFireDetection ?FireDetection;
 :hasFireProbabilityIndex/rdfs:label ?FireProbability.
 FILTER (CONTAINS(UCASE(STR(?Placename)), "CROATIA"))
 FILTER (CONTAINS(UCASE(STR(?placename2)), "CROATIA"))
 FILTER (?HealthMonitoringDateTime > "2022-01-01T00:00:00Z"^^xsd:dateTime &&
?HealthMonitoringDateTime < "2024-01-01T00:00:00Z"^^xsd:dateTime)
 FILTER (?IoTDateTime > "2022-01-01T00:00:00Z"^^xsd:dateTime && ?IoTDateTime <
"2024-01-01T00:00:00Z"^^xsd:dateTime)
 FILTER (?AirQuality = "very poor")
 FILTER (?FireDetection = true)}}

```

**Fig. 9** Retrieval of fire incidents and the corresponding health monitoring

| HealthMonitoringDateTime | AirQuality | IoTDateTime           | FireDetection | Placename |
|--------------------------|------------|-----------------------|---------------|-----------|
| Apr 6, 2020, 4:02 PM     | very poor  | Apr 6, 2020, 11:52 AM | true          | Croatia   |

**Fig. 10** Fire incident and the corresponding health monitoring

## 5 Conclusions

This paper explores the use of semantic technologies in the SILVANUS Project, an EU H2020 initiative dedicated to advancing forest management practices with a focus on sustainability and resilience. The paper emphasizes the importance of ontologies and KGs, which serve as key components in the project's pursuit of interdisciplinary solutions. It also highlights the integration of knowledge from diverse sources to construct a comprehensive wildfire management ontology.

The ontology conceptualization and engineering process is discussed, demonstrating a structured approach to developing a knowledge framework. The evaluation process and adherence to best practices underline the ontology's value as a resource for interdisciplinary problem-solving.

Furthermore, the paper showcases the implementation of semantic data fusion within SILVANUS, utilizing the CASPAR framework to integrate data from diverse sources. The incorporation of semantic mapping and the utilization of KGs are key elements to enhancing decision support for wildfire management.

Future directions for the SILVANUS Project involve a multimodal strategy to improve wildfire management via semantic technology.

The first feature pertains to expanding the current Semantic Knowledge Base's reach through the integration of various data sources, including social media feeds, meteorological forecasts, historical wildfire records, and remote sensing data. By creating a dynamic library, this thorough integration aims to improve decision-making processes by providing a comprehensive understanding of wildfire episodes.

Moreover, the SILVANUS ontology needs to be expanded and improved upon continuously. The integration of more detailed information on various aspects of managing wildfires, such as the complexities of fire behavior, ecological effects, and community resilience, will be made possible through cooperative efforts with subject matter experts. The ontology's completeness and relevance are ensured by this iterative procedure.

In parallel, the project intends to enhance the Semantic Knowledge Base's decision-making support by leveraging useful SPARQL rules. Deeper and more complex querying capabilities will be made possible by these rules, giving stakeholders detailed information about wildfire trends, risk evaluations, and the best ways to allocate resources. Integration of the Knowledge Base with an easy-to-use interface is the focus of efforts to improve accessibility and usability. By utilizing dashboards, infographics, and user-friendly tools to aid in understanding and application of the semantic data, this interface will enable efficient interaction for forest managers, emergency responders, and policymakers.

Finally, the exploration of machine learning and AI techniques within the semantic framework has the potential to revolutionize wildfire management. By leveraging these advanced technologies, the project aims to enable predictive analytics, anomaly detection, and pattern recognition, further augmenting the decision-making process.

The convergence of these efforts marks a commitment to advancing wildfire management practices, leveraging semantic technologies within the SILVANUS Project.

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## References

1. National Academies of Sciences, Engineering, and Medicine (2017) A century of wildland fire research. In: Long-term approaches for wildland fire management. Washington, DC
2. Omitola T, Wills G (2019) Emergency response ontology informatics: Using ontologies to improve. *Int J Intell Comput Res (IJICR)* 10(3):1022–1032
3. SILVANUS Consortium, SILVANUS (2023) Integrated technological and information platform for wildfire management, SILVANUS Consortium, <https://silvanus-project.eu/>. Accessed 12 Jul 2023
4. Berners-Lee T, Hendler J, Lassila O (2001) The semantic web. *Sci Am* 284(5):34–43
5. W3C (2023) <https://www.w3.org/>. Accessed 31 Oct 2023
6. RDF (2023) Semantic web standards W3C, <https://www.w3.org/RDF/>. Accessed 31 Oct 2023
7. OWL (2023) Semantic web standards, <https://www.w3.org/OWL/>. Accessed 31 Oct 2023
8. SPARQL (2023) Query language for RDF, <https://www.w3.org/TR/rdf-sparql-query/>. Accessed 31 Oct 2023
9. Gutierrez C, Sequeda JF (2021) Knowledge Graphs. *Commun ACM* 64(3):96–104
10. Kontopoulos E, Mitzias P, Moßgraber J, Hertweck P (2018) Ontologybased representation of crisis management procedures for climate events. In: 15th international conference on information systems for crisis response and management (ISCRAM 2018) (ICMT 2018), Rochester NY, USA
11. Souza A (2023) Fire Ontology—Summary | NCBO BioPortal, 24 Feb 2014, <https://bioportal.bioontology.org/ontologies/FIRE?p=summary>. Accessed 12 Jul 2023
12. Camia A, Durrant Houston T, San-Miguel-Ayanz J (2013) Harmonized classification scheme of fire causes in the EU adopted for the European Fire Database of EFFIS, Publications Office of the European Union, Luxembourg
13. Government of Canada (2023) Canadian wildland fire information system | Canadian Forest Fire Weather Index (FWI) System, Government of Canada, [https://cwfis.cfs.nrcan.gc.ca/bac\\_kground/summary/fwsi](https://cwfis.cfs.nrcan.gc.ca/bac_kground/summary/fwsi). Accessed 12 Jul 2023
14. Buttigieg P, Pafilis E, Lewis SE, Schildhauer MP, Walls RL, Mungall CJ (2016) The environment ontology. *J Biomed Semantics* 7
15. Cross-Forest Consortium, Ontologies —Cross Forest, Cross-Forest Consortium, 2020. <https://crossforest.eu/results/ontologies/>. Accessed 12 Jul 2023
16. González-Gerpe S (2023) BIMERR Weather Ontology, Universidad Politécnica de Madrid, 2021. <https://bimerr.iot.linkeddata.es/def/weather/>. Accessed 12 Jul 2023
17. Neuhaus F, Vizedom A, Baclawski K, Bennett M, Dean M, Denny M, Gruninger M, Hashemi A, Longstreth T, Obrst L, Ray S, Sriram R, Schneider T, Vegetti M, West M, Yim P (2013) Ontology Summit 2013 Communiqué, National Institute of Standards (NIST), Gaithersburg
18. SILVANUS Consortium, D3.1- First report on the formal specification of sustainable and resilient forest management knowledge model, 30 September 2022. <https://silvanus-project.eu/wp-content/uploads/2022/10/D3.1.pdf>. Accessed 31 Jul 2023

19. SILVANUS Consortium, Ontology | SILVANUS, SILVANUS Consortium, 30 Sept 2022. <https://silvanus-project.eu/results/resources/ontology/>. Accessed 12 Jul 2023
20. Marotta SM, Masucci V, Caterino C, Cafarelli MS (2023) From diverse sources to a unified framework: Constructing an operational ontology for fire management. In: 2023 6th international conference on information and communications technology (ICOIACT), Yogyakarta, Indonesia
21. Peroni S (2023) Graffoo graphical framework for OWL Ontologies, <https://essepuntato.it/graffoo/>. Accessed 27 Nov 2023
22. C. LTD, CASPAR, <https://caspar.catalink.eu/>. Accessed 27 Nov 2023
23. C. LTD, Catalink—The catalyst for innovation, Catalink LTD, <https://catalink.eu/>. Accessed 27 Nov 2023
24. DigitalOcean, DigitalOcean | Cloud Hosting for Builders, DigitalOcean, <https://www.digitalocean.com/>. Accessed 27 Nov 2023

# The Problem of Coreference in NLP



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and Hamroqulova Marjona

**Abstract** Artificial intelligence methods for performing a query in search engines require effective solution of the task of automatic processing of texts in the database. One of the important tasks of implementing machine learning is the development of a rule system. This article discusses the problem of coreference calculated from preliminary studies aimed at automatic determination of meaningful distances expressed in Uzbek language texts. Basic rules and stages of solving the coreference problem are also analyzed. Explanations of a number of terms such as anaphoric relations and their main types, the main used anaphora, antecedent, cataphora, clustering, singleton, etc., which create the coreference problem, are given.

**Keywords** NLP · Coreference resolution · Mention detection · NER · Pipeline conveyor · Tokenization · Coreference · Proper nouns · Pronoun recognition

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## 1 Introduction

In this article, we will consider the issue of coreference in Uzbek language texts. It is one of the tasks belonging to the speech analysis part of NLP, and the sentences in the text form a single research object. Solving the issue of coreference in the text is a clustering task of NLP, which serves to determine the content distance between all names referring to one object/event in a sentence/document/corpus (all units naming one referent) [1, 2].

As an example, language units that represent an organization, person, place, object name can be given. Many natural language applications such as question-answer systems in NLP, automatic summarization of documents or machine translation need to identify references to objects in the text at the initial step [3–5]. To understand the coreference issue, let's consider the following example:

*Nilufarning aytishicha, Azimjon juda iltifotli yigit, chunki u har doim Azizani ishga o'ziolib keladi, mashinaning eshigini ham o'zi ochib, ayolini ishxonasiga kuzatib qo'yadi. (According to Nilufar, Azimjon, is a very kind man, because he always brings Aziza to work, opens the door of the car himself and escorts her to his office.)*

We highlight all notes in this sample that can name a subject with a single referent in a different color. These are:

*Azimjon, U, O'zi, Aziza, Ayol*

Therefore, the automatic determination of exactly which of these indicated notes have the same referent represents the essence of solving the coreference problem.

The task of automatic detection of coreference problems in the text can be carried out in the following two steps:

1. Identify object reference names; (object-reminiscent names-note)
2. Clustering.

### 1. Determining Names (Notes) in Relation to the Object

The main goal of this step is to identify all the candidates that can refer to the objects. For example, the following example highlights candidate applications:

*Nilufarning Aytishicha, Azimjon Juda Iltifotli Yigit, Chunki U Har Doim Azizani Ishga O'ziolib Keladi, Mashinaning Eshigini Ham O'ziochib, Ayolini Ishxonasiga Kuzatib Qo'yadi.*

At this stage, three different links are identified [6–8]:

- pronouns are defined;
- nouns (NER) are defined;
- noun phrases (NPs) are defined.

## 1.1 Identifying Pronouns

Pronouns are words with an independent meaning—nouns, adjectives, numbers, adverbs, etc., which do not indicate a person, object, character or quantity, but are used instead of words, phrases and sentences, and refer to them. Since pronouns have a vague and general meaning, their main meaning and which word group they are used for is determined according to the text content. This semantic feature of pronouns can be seen in the following text:

*Zamira bugun uyda. U hovli-joylarni supurib, kir yuvishga tutindi. Guldor kiyimlarni alohida ajratdi, chunki bunday kiyimlarni boshqalariga aralashtirib bo ‘lmaydi. Bitta sovunni maydalab kir mashinasiga solar ekan, “Oyim ham shuncha sovun ishlatarmidilar”,—deb o‘yladi. (Zamira is at home today. She swept the yards and did the laundry. The florist separated the clothes separately, because such clothes cannot be mixed with others. As he crushed one bar of soap and put it in the washing machine, he thought, “My mother would use so much soap.”).*

In this text, pronouns *u*, *bunday*, *shuncha* are used instead of Zamira (noun), guldor (adjective), bitta (number), and they perform the same function as they did in the sentence. However, if these sentences are separated from the text, their meaning becomes abstract. Pronouns are divided into 7 different types according to their relative meanings and grammatical signs [9]:

1. *Personal pronouns* are used instead of personal nouns and refer to them.
2. *Demonstrative pronouns*—Person, object, sign, action expressed through independent words.
3. *Interrogative pronouns*—pronouns used to ask about a person, thing, sign-property, action-state.
4. *Disjunctive pronouns* are pronouns that take the place of independent words and summarize their meaning.
5. *Infinitive pronoun*—come in the place of independent words denoting person-thing, sign-property, and indicate its negation.
6. *Reflexive pronouns*—is used instead of personal pronouns in all three persons and emphasizes its meaning.
7. *Indefinite pronoun*—pronouns that take the place of independent words denoting a person-thing, sign-property, guess its meaning and suspect it.

Types of pronouns are listed in Table 1.

A pronoun is a word that replaces nouns and noun compounds and usually includes anaphora, in which the meaning of the pronoun depends on the preceding sentence (antecedent). But not all types of pronouns mentioned above form anaphoric relations. Some pronouns (3rd person personal pronouns, demonstrative pronouns, reflexive pronouns) represent anaphora in linguistics and depend on an antecedent. For example:

*A ‘zam bilan Toshkentda ko‘rishgan edim, bu xabarni o ‘sha aytib berdi.*

(I Met Azam in Tashkent, He Told Me This News.)

In this sentence, the personal pronoun “u” and the word “A ‘zam” have one referent, and the pronoun refers to the noun in the previous part of the sentence.

**Table 1** Uzbek pronouns

| Personal pronoun | Demons-trative pronouns | Interro-gative pronouns | Disjunc-tive pronouns | Infinitive pronoun | Reflexive pronouns | Indefinite pronoun |
|------------------|-------------------------|-------------------------|-----------------------|--------------------|--------------------|--------------------|
| Men              | U                       | kim?                    | hamma                 | hech kim           | o 'z               | Kimdir             |
| Sen              | Bu                      | nima?                   | barcha                | hech nima          |                    | Nimadir            |
| U                | Shu                     | qaysi?                  | bari                  | hech qancha        |                    | Qaysidir           |
| Biz              | o 'sha                  | qancha?                 | har kim               | har qanday         |                    | Allakim            |
| Siz              | mana bu<br>(manavi)     | necha?                  | har nima              | har qaysi          |                    | Allanarsa          |
| Ular             | mana shu                | nimaga?                 | Har qancha            | hech bir           |                    | Allaqanday         |
|                  | Ushbu                   | qani?                   | har bir               |                    |                    |                    |

**Table 2** Pronouns representing anaphora in the Uzbek language

| Personal pronouns | Demonstrative pronouns | Possesive pronouns |
|-------------------|------------------------|--------------------|
|                   | <i>U</i>               | <i>o 'z</i>        |
|                   | <i>o 'sha</i>          |                    |
| <i>u, ular</i>    | <i>bu, ushbu</i>       |                    |
|                   | <i>Shu</i>             |                    |

Pronouns representing anaphora in the Uzbek language are listed in the following Table 2:

## 1.2 Identification of Proper Nouns (NER)

Names given to certain persons or things are called proper nouns and are written with capital letters. They include:

- Names and nicknames of people: Dilmurod, Ravshan Mahmudov, Zarifa Hakimjon qizi, Cho 'Ipon, Julqunboy, etc.
- Names given to pets: Olapar, To 'rtko 'z, Mosh, Boychibor, Yo 'lbars, etc.
- Geographical and astronomical names: O 'sh, Chirchiq, Oqtosh, Kavkaz, Dnepr, Mars, Oy, Quyosh, etc.
- Names of republics and higher organizations: *O 'zbekiston Respublikasi, Vazirlar Mahkamasi, Yevropa Taraqqiyot va Tiklanish Banki, Oliy Kengash*, etc.
- The first part of the name of scientific institutions, higher educational institutions, ministries and enterprises: *Til va adabiyot instituti, Moliya vazirligi, Bank-moliya akademiyasi*, etc.

- Names of high positions, high honorary titles: *O ‘zbekiston Prezidenti, Bosh Vazir, O ‘zbekiston Qahramon;*
- Names of factories, various organizations, collective farms, cinema, theater, books, newspapers, magazines are written with capital letters in quotation marks: *Qizil tong” fabrikasi, “Sharqyulduzi” jurnali, “Umid” jamg ‘armasi, “Muqimiy” teatri.*
- The first part of the names of historical events, dates, scientific conferences, documents: *Mustaqillik kuni, Toshkent deklaratsiyasi, Qurbon hayiti kabi.*
- The first letters of abbreviated initials: *JIDU Jahon iqtisodi va diplomatiya universiteti, BMA Bank-moliya akademiyasi*, etc.

Using the NER model, nouns are identified and categorized from unstructured text [10]. For example, personal names, organization names, place names, product names. The process of identifying NER objects is carried out in the following stages:

1. Extract information—the first step in determining NER is to extract the objects indicated in the sentence, paragraph, text. At this stage, the whole text is marked and the text border is defined. Here, the text is divided into sentences according to the capital letter system.
2. Tokenization process—chunked sentences are now tokenized within themselves.
3. Determining the limit of tokens according to the “IOB” or “BILUO” scheme and “collecting” them again—in this case, the tokens of several NERs are “united” based on the model.
4. Object search—the next process in NER is searching for NER objects in tokens.
5. Assign the correct category to identified NER objects.

Explaining the above process differently, the identified nouns are analyzed not only morphologically, but also semantically. The nouns separated from the text are defined according to their “proper noun” characteristics. Prominent nouns are analyzed according to “NER features” (occurrence in the text in capital letters, non-dictionary lexicon, addition of suffixes, object renaming, etc.). The dictionary also serves as a tool for identifying NER objects. But this base cannot be a perfectly effective solution.

NER is an NLP method that can extract the main objects in the text and divide them into predefined categories [11]. The process of identifying named objects from the text that do not exist in the dictionary, such as personal names, location names, company names, etc., is an important step in solving many NLP tasks. Named object recognition in NLP is also commonly referred to as object identification, object extraction, or object segmentation. NER object detection algorithms are the following models [12] (Fig. 1).

- analysis based on rules;
- dictionary search;
- POS tagging (morphological tagging);
- Parsing (syntactic tagging).

Toshkent LOC – O'zbekistonning LOC poytaxti va eng yirik shahri, aholisi bo'yicha Markaziy Osiyoragi LOC eng katta shahar.

**Fig. 1** Identification of NER objects

To understand the process of identifying NER objects from text content, consider the following sentence:

The blue ones here are nouns. Some of these nouns represent real objects that exist in the world. For example, from the above, the following nouns represent existing locations on the map: “*Toshkent*”; “*O'zbekistonning*”; “*Markaziy Osiyoragi*”.

If we can find nouns in a text, specifically named nouns, with this kind of accuracy, we can use this information to identify a list of named objects automatically in the text in NLP. The goal of NER is to identify and label these nouns with relevant real-world concepts. (For example: Unicef is an organization (ORG); Alisher is a person's name (PER)).

NER systems do more than just look up a simple dictionary. Perhaps they use a statistical model to determine how a word appears in a sentence in the text and what type of noun that word represents [12]. The problem of identifying NER objects in the Uzbek language was analyzed by Elov and Samatboyeva [10].

### 1.3 Identification of Noun Phrases

In the Uzbek language, the word combinations that are freely connected in the subordinate-dominant relationship, and the main word is represented by a noun, are noun combinations. For example: *shamoldan tez, qiziqarli kitob, aqliy bilish, tezkor xotira*. It can be seen that in Uzbek, noun compounds can be expressed by words such as adjectives, numbers, adverbs, gerund or infinitive. Since solving the coreference problem is focused on specific nouns, we will focus only on compound nouns that express the modification signs of these nouns. That is, we determine the attributive relational combinations expressed by the name and the words used to describe it.

For example: *yosh, iste 'dodli, mas 'uliyatli xodim.*

### 1.4 Clustering

After performing the tasks in the first stage, we try to identify candidates/notes that refer to an object. We perform the process of clustering the referent candidates/notes expressed in the content into clusters corresponding to the objects indicated in the text.

For example: *Nilufarning aytishicha, Azimjonjuda iltifotli yigit, chunki u har doim Azizani ishga o 'ziolib keladi, mashinaning eshigini ham o 'zi ochib, ayolini*

*ishxonasiga kuzatib qo ‘yadi. (Nilufar says that Azimjon is a very kind guy, because he always brings Aziza to work, opens the door of the car himself and escorts her to the office).*

In this example, we have marked the candidate/note group that caused the coreference in separate colors. In this sentence, *Azimjon* and *u, o’zi*; *Aziza* and *ayol* belong to the same object, and represent a cluster (group) among the candidates/notes representing each object. Names of nouns or objects that do not have a reference in the content are called singletons (a cluster containing only one unit).

### 1.4.1 Basic Terms

We will explain the terms used in the corpus in solving the issue of coreference in the example of the following sentences:

*Qizaloq bog ‘dan chiqishni istamadi, chunki u arg ‘imchoqlarning barchasida uchmoqchi edi. (The girl did not want to leave the park, because she wanted to swing on all flip flops).*

- **Antecedent**—the object that participated in the front part of the sentence/text/content—the unit that determines the meaning of the next pronoun in the text. For example, in the example above, the meaning of the pronoun [u] is determined by [qizaloq]. Therefore, [qizaloq] is the antecedent of [u].
- **Anaphora** is a unit that refers to a person or thing (object) in the context, to what was said before (the expressed object). For example.

*Tort yesang, muzlatkishga bir bo ‘lak bor. (If you eat a cake, there is a piece in the freezer).* The word [*bir bo ‘lak*] in the second part of the sentence is an anaphoric unit referring to the word [*tort*].

- **Cataphora** is a form of anaphora, which differs in that the pronoun is expressed before the noun it refers to [13]. For example,

*Negadir u musobaqada kutilgan natijani ko ‘rsata olmadi, Anvar odatda bunday tadbirlarga puxta tayyorlanar edi. (For some reason, he could not show the expected result in the competition, Anvar usually prepared carefully for such events).*

In this sentence, the demonstrative pronoun [u] precedes the word (object) it refers to [Anvar].

For another example, *Jasmin ingliz tili kurslariga qatnaydi, endi Malika ham unga qo ‘shildi, chunki u ham ingliz tilini o ‘rganmoqchi* (*Jasmin attends English classes, and now Malika has joined her, because she also wants to learn English*).

In this sentence, [u] refers to [Malika] because this word is closer to [Jasmin] in the sentence.

In a sentence, the subject position is referred to more often than the object position. For example, *Jasmin ingliz tili kurslariga qatnaydi, endi Malika ham unga qo ‘shildi, chunki u ham ingliz tilini o ‘rganmoqchi*.

In this case, [her] reference refers to [Jasmine] because [Malika] is in object position and [Jasmine] is subject position.

**Professor navbatdag'i ma'ruzani o`qigach, talabalarga uning mavzulari yakunlanganini, mashg'ulotlar nihoyalaganini, endi ular imtihonga puxta tayyorgarlik ko'rishlari kerak ekanligini e'lon qildi.**

**Fig. 2** The semantic connection of the words in the sentence

### 1.4.2 Parallelism

*Nazokat Feruza Bilan Kinoga Bordi, Aziza Esa U Bilan Savdo Markaziga Bordi* (*Nazokat Went to the Cinema with Feruza, and Aziza Went to the Mall with Her*).

In this sentence, since the word *with* creates a parallel structure, it refers to **Nazokat**.

It should be noted that in the following sentence, the word “**his**” refers to the word “**professor**” and not to the word “**students**” (Fig. 2).

### 1.4.3 Verb Semantics

Compare the following two sentences:

– *Qizim qunt bilan tort pishirdi va endi u san 'at darajasiga yetdi.*

(*My daughter baked a cake diligently, and now it has reached the level of art*).

*Qizim Qunt Bilan Tort Pishirdi, Endi U Juda Charchadi.*

(*My Daughter Baked a Cake Diligently, Now She is Very Tired*).

According to the structure, the above sentences have the same construction. But in each of these sentences, it is necessary to correctly determine what (which object) the pronoun “*u*” means.

Semantics can also tell us about the connections between the notes in a sentence.

The animal didn't cross the street because it was too tired.

The animal didn't cross the street because it was too wide.

In the first sentence, we know that the word **it** refers to an animal, and in the second sentence, it refers to the street through the words **tired** and **wide**.

### 1.4.4 Additional Features

There are a few more features (PNG constraints) that help create manageable classifiers:

- person (1st person, 2nd person, 3rd person);
- number (one or more);
- gender (male or female).

### 1.4.5 Co-reference in Uzbek Language Texts

In the traditional method, we first need to identify all the pronouns through the pipeline process. For this purpose, it is necessary to implement the process of POS tagging in the text using the Uzbek language morphoanalyzer developed by Elov, Alayev and Hamroyeva. In the second step, using the NER object detection system developed by B. Elov and M. Samatboyeva, the list of necessary NERs in the text is determined. In the next step, a syntactic analyzer and systems for identifying references to nouns and clustering coreferences are used. As a result, a set of words and phrases related to coreference in Uzbek textbooks is determined through a sequence of 5 steps.

## 2 Conclusion

This article describes the main conditions and stages of solving the coreference problem in Uzbek language texts. Products such as electronic libraries and language corpora that reflect the national language, display it electronically, and store it in digital format are necessary tools of today's globalization era. Processing natural language, bringing it to the level of machine language, significantly increases the viability and status of the language. In order to do this, it is necessary to develop NLP applications such as semantic analyzers, question–answer systems, and machine translation that automatically analyze Uzbek language texts. We have focused on the automatic solution of the coreference problem, which is one of the urgent issues that will be necessary in the implementation of such tasks. In our further studies, we will discuss detailed information about algorithms and models of automatic solution of this problem.

## References

1. McShane M, Nirenburg S (2021) Basic coreference resolution. In: Linguistics for the age of AI. <https://doi.org/10.7551/mitpress/13618.003.0007>
2. Toshniwal S, Xia P, Wiseman S, Livescu K, Gimpel K (2021) On generalization in coreference resolution. In: 4th workshop on computational models of reference, Anaphora and Coreference, CRAC 2021—Proceedings of the workshop. <https://doi.org/10.18653/v1/2021.crac-1.12>
3. Urbizu G, Soraluze A, Arregi O (2020) Sequence to sequence coreference resolution. In: Proceedings of the third workshop on computational models of reference, Anaphora and coreference
4. Sukthanker R, Poria S, Cambria E, Thirunavukarasu R (2020) Anaphora and coreference resolution: a review. Inf Fusion 59:139–162. <https://doi.org/10.1016/j.inffus.2020.01.010>
5. Stylianou N, Vlahavas I (2021) A neural entity coreference resolution review. In Expert Syst Appl 168. <https://doi.org/10.1016/j.eswa.2020.114466>
6. Lata K, Singh P, Dutta K (2022) Mention detection in coreference resolution: survey. Appl Intell 52(9). <https://doi.org/10.1007/s10489-021-02878-2>

7. Cruz AF, Rocha G, Cardoso HL (2020) Coreference resolution: toward end-to-end and cross-lingual systems. *Information* (Switzerland) 11(2). <https://doi.org/10.3390/info11020074>
8. Ji D, Gao J, Fei H, Teng C, Ren Y (2020) A deep neural network model for speakers coreference resolution in legal texts. *Inf Process Manag* 57(6). <https://doi.org/10.1016/j.ipm.2020.102365>
9. Сайфуллаева Р., Менглиев Б., Курбонова М., Бокиева Г., Юнусова З., Абузалова М. Хозирги ўзбек адабий тили. Ўқув кўлланмаси. Тошкент, 2005. 388 б.
10. Elov B, Samatboyeva M (2023) Identifying NER (Named Entity Recognition) objects in Uzbek language texts. *Sci Innov Int Sci J* 2(4)UIF-2022:8.2 | ISSN:2181–3337
11. Dobrovolskii V (2021) Word-Level coreference resolution. EMNLP 2021—2021 conference on empirical methods in natural language processing, Proceedings. <https://doi.org/10.18653/v1/2021.emnlp-main.605>
12. <https://www.analyticsvidhya.com/blog/2021/06/part-1-step-by-step-guide-to-master-natural-language-processing-nlp-in-python/> (2021)
13. Kantor B, Globerson A (2019) Coreference resolution with entity equalization. In: ACL 2019—57th Annual meeting of the association for computational linguistics, Proceedings of the conference. <https://doi.org/10.18653/v1/p19-1066>

# Development of Management Artifacts for the Front End of Innovation Using Design Science Research: A Literature Review



Romullo Girardi and Paulo César Pellanda

**Abstract** Innovation management, particularly at the Front End of Innovation (FEI), presents significant challenges for organizations, necessitating structured procedures to mitigate failures. This article provides a systematic literature review on the application of Design Science Research (DSR) in developing FEI management artifacts. The methodology included conducting searches in the Web of Science and Scopus databases, which led to the selection of 11 documents. These documents were categorized based on the type of DSR artifact developed (constructs, model, method, and instantiation) and their alignment with FEI activities (opportunity identification and analysis; idea generation, enrichment, and screening; and product concept definition). The results revealed a predominance of ontological approaches and highlighted the need for rigorous theoretical and robust practical models to enhance FEI management. This review contributes to the literature by providing the first systematic macro-analysis on this topic and offers valuable insights for future initiatives in developing FEI management artifacts.

**Keywords** Design science research · Innovation · Front end of innovation · Literature review

## 1 Introduction

The process of innovation management encompasses a wide range of organizational activities, from identifying new opportunities and ideas to their actual implementation. Consequently, managers at all levels face challenges in managing innovation effectively within their organizations [1].

Failures in innovation are rarely attributed to a lack of creativity; rather, it is often the absence of discipline that plays a critical role [2]. Boeddrich [3] asserts that structured procedures are crucial in the early stage of the innovation process,

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termed the Front End of Innovation (FEI), to mitigate negative impacts throughout the innovation management continuum.

The FEI is critical as it drives favorable results for new products and overall business success [4]. Markham [5] highlights that the success of activities in the initial phase is the most significant independent predictor of new product performance among all analyzed variables.

However, for an FEI model to be successfully adopted, it is essential to take into account factors such as the organization's size, culture, and decision-making style [6]. Various studies have sought to develop approaches for structuring the initial phase of the innovation process in specific contexts [7], including the iterative design science paradigm [8].

Design science aims to create outputs that serve specific human purposes, focusing on producing artifacts that are rigorously designed and evaluated [9–11]. This approach involves creating artifacts to improve current practices and existing research knowledge [12]. Design science has emerged as a rapidly developing field, with Design Science Research (DSR) being the term most commonly associated with this area in the last decade [13]. The integration of DSR and FEI aligns with the experimental and iterative nature of both approaches, ensuring that artifacts developed for FEI are both theoretically grounded and practically relevant.

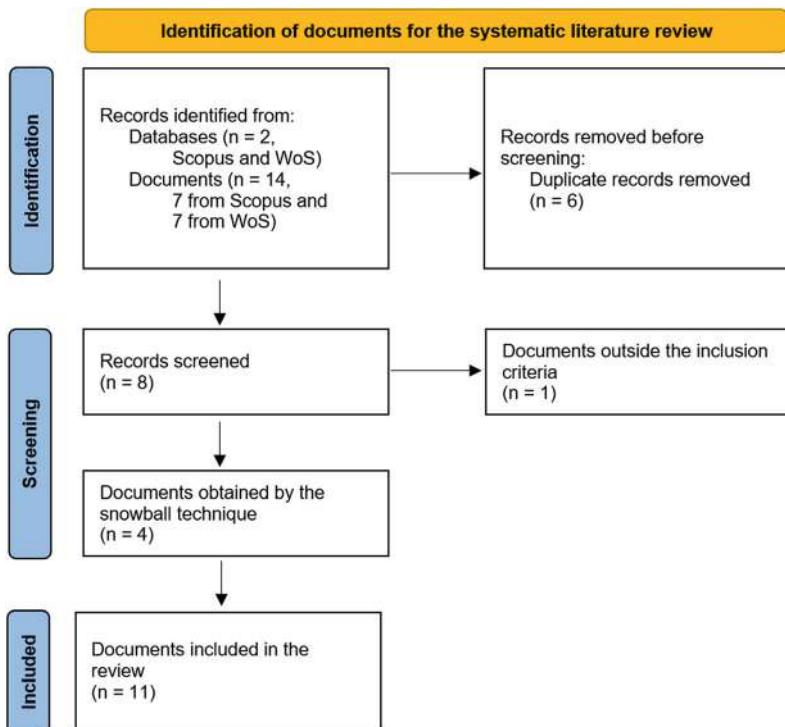
Despite the availability of various DSR applications for developing FEI management tools in scientific databases, no studies have conducted a macro-analysis of these applications. This article aims to fill this gap by presenting a systematic literature review on the development of FEI management artifacts using DSR. The research seeks to answer the following question: How can DSR be employed in developing FEI management artifacts?

Guided by the research question, the article follows this organization. Section 2 covers the methodological aspects of the research. Section 3 outlines the results of the review. Section 4 addresses and discusses relevant findings of the study. Lastly, Sect. 5 presents the conclusions.

## 2 Methodology

The initial strategies for searching the academic literature [14] included the following:

- **Databases:** Web of Science (WoS) and Scopus [15].
- **Search string:** The search string combined terms related to the front end of innovation and the design science approach: ((“front end of innovation” OR “front-end of innovation” OR “front end innovation” OR “front-end innovation” OR “fuzzy front end” OR “fuzzy front-end”) AND (“design science”)). The search was conducted on November 9, 2023, targeting terms in the title, abstract, and keywords.
- **Inclusion criteria:** Documents had to be written in Portuguese, English, or Spanish and be fully available. Additionally, publications needed to explicitly address the use of DSR in developing FEI management artifacts.



**Fig. 1** Stages of the review process (adapted from [16])

The search in academic literature returned seven documents from both the WoS and Scopus databases. Upon further analysis, six duplicates were identified, resulting in eight unique documents. Subsequently, one article did not meet the inclusion criteria, narrowing the review to seven documents.

After the initial search, the snowball method was used to find other relevant documents that either cite or are cited by the selected publications. Additional documents written by the authors of the selected publications were also reviewed, yielding four more documents.

In total, 11 documents were selected for review. Notably, no similar review works were found during the search. Figure 1 provides a summary of the stages of the systematic literature review using the diagram PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses), which illustrates the flow of information through the various phases of the review process [16].

The documents selected for review were classified according to the type of DSR artifact developed and their framework in FEI activities. The classification of DSR artifact types was based on [13, 17], as shown in Table 1. The categorization regarding FEI activities used the review in [18] based on the seminal works identified in [7, 8], as presented in Table 2.

### 3 Results

This section provides an overview of the 11 selected documents, followed by their classification based on the type of DSR artifact developed (see Table 1) and their framework in FEI activities (see Table 2). The documents are presented in chronological order of publication.

Bullinger [22] discusses the development of the OntoGate ontology, designed for idea evaluation during the early stage of the innovation process. This ontology, based on the On-To-Knowledge methodology, involved creating specific taxonomies to represent the idea evaluation and selection processes within companies, ultimately leading to a generic taxonomy. The author emphasizes the use of all four artifact types proposed by March and Smith [17]: constructs, model, method, and instantiation. The artifact encompasses the activities of opportunity identification and analysis, as well as idea generation, enrichment, and screening.

**Table 1** Types of DSR artifacts (adapted from [13, 17])

| Type          | Definition                                                                                      |
|---------------|-------------------------------------------------------------------------------------------------|
| Constructs    | Conceptual vocabulary of a domain                                                               |
| Model         | Set of propositions that express relationships between constructs                               |
| Method        | Set of steps to perform a task, manipulating constructs so that the model leads to a solution   |
| Instantiation | Application of an artifact in its environment, operationalizing constructs, models, and methods |

**Table 2** FEI activities and their relation to FEI seminal models (adapted from [18] based on the seminal works identified in [7, 8])

| Activities                                     | FEI seminal models structure                                                                                                                                                                                          |
|------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Identification and analysis of opportunities   | <ul style="list-style-type: none"> <li>– Discovery [19]</li> <li>– Pre-phase zero [6]</li> <li>– Identification and analysis of opportunities [20]</li> <li>– Boundary interface [21]</li> </ul>                      |
| Generation, enrichment, and screening of ideas | <ul style="list-style-type: none"> <li>– Discovery and idea screen [19]</li> <li>– Pre-phase zero [6]</li> <li>– Generation, enrichment, and selection of ideas [20]</li> <li>– Gatekeeping interface [21]</li> </ul> |
| Product concept definition                     | <ul style="list-style-type: none"> <li>– Scoping and build business case [19]</li> <li>– Phase zero and phase one [6]</li> <li>– Concept definition [20]</li> <li>– Project interface [21]</li> </ul>                 |

Brandtner et al. [9] present a multicriteria selection procedure for DSR projects, specifically to choose appropriate prospecting methods for the innovation process. The procedure integrates theoretical and practical perspectives and is tested through the InnoStrategy 2.0 research project. It emphasizes selecting methods that address both innovative and strategic aspects of FEI, and its relevance and rigor are ensured through focus groups and literature review. The artifacts developed include a method and an instantiation (InnoStrategy 2.0), focusing on opportunity identification and analysis.

Barradas [23] presents the development and evaluation of an ontological framework and a software tool for collaborative knowledge creation in the FEI. The research emphasizes integrating external and internal knowledge, supported by Web 2.0 mashups, to enhance collective intelligence and learning in the innovation process. The ontology serves as a high-level formal specification for managing activities and resources within Collaborative Innovation Networks (COINs), facilitating the co-creation of new concepts. The developed artifacts include constructs, models, methods, and instantiations (two business case studies), integrating these into the FEI holistically.

Gregor and Hevner [24] propose the KIM-FEI (Knowledge Innovation Matrix-Front End of Innovation), a theoretical model for FEI. This model differentiates four categories of innovation: invention, exaptation, advancement, and exploitation, using a theoretical basis from innovation, creativity, knowledge, and DSR. The model's evaluation is theoretical, with a call for further research to expand innovation theories and applications in FEI management. The artifact is classified as a model, relating types of innovation with the FEI structure and covering opportunity identification and analysis, as well as idea generation, enrichment, and screening.

Groher et al. [25] present a method to support companies in the early stage of the innovation process, particularly in analyzing Innovation Search Fields (ISF) based on market, technology, and company criteria. The method uses AI, specifically natural language processing and information retrieval, to replace intuitive decision-making with fact-based considerations, thus improving decision-making quality and speed. Initial tests demonstrated the method's effectiveness, with further tests needed to enhance AI functionality. The artifact developed is a method for evaluating innovation search fields, focusing on opportunity identification and analysis.

John et al. [26] describe the development of the Project Client Map (PCM), a visual tool designed to help students solve real-world problems in class projects in partnership with industry. PCM aims to enhance the educational process by providing a methodology for understanding and formulating FEI problems. Preliminary evaluation in a case study with students showed promising results. Future steps include applying PCM in more case studies and adapting it for non-academic environments, such as startups. The artifact developed is a model addressing how constructs (organizational, environmental, and human elements) interrelate in problem identification, focusing on opportunity identification and analysis.

Pereira et al. [8] present the development of the FEI2O (Front End of Innovation Integrative Ontology), a comprehensive knowledge representation of the initial phase

of the innovation process. This ontology serves as a formal reference model, providing a common vocabulary to facilitate understanding and communication among those involved in FEI. The FEI2O was evaluated using qualitative and quantitative methodologies, including interviews, focus group discussions, and attribute agreement analysis, validating its utility and effectiveness. The artifact includes a vocabulary with 98 concepts (constructs), an ontology (model), a method (sub-ontologies organized according to key FEI concepts), and an instantiation (application in two case studies), covering the FEI holistically.

Ebel et al. [27] describe the Pattern-Based Smart Service Innovation (PBSSI) method for smart service innovation in manufacturing. This method guides companies in creating intelligent product and service systems and data-driven service offerings, focusing systematically on the customer. Developed using the DSR approach, PBSSI integrates value proposition patterns based on empirical data with existing techniques. The artifact was evaluated through Delphi method rounds and case studies. The developed artifacts include a method and instantiations (case studies), addressing opportunity identification and analysis, as well as idea generation, enrichment, and screening.

Castro and Ferreira [28, 29] developed an ontology based on the FEI2O ontology by Pereira et al. [8] to support Project Portfolio Management (PPM) in FEI within non-profit research centers. An integrative literature review analyzed 170 published articles to understand how PPM is applied in FEI activities and identify gaps in current knowledge, presenting a first draft of the ontology [28]. In [29], the development of the artifact (Front-End of R&D) is detailed, and its evaluation involves analyzing its societal impact, including technology transfer, intellectual property generation, startup creation, and knowledge dissemination. The artifact includes a vocabulary (constructs), an ontology (model), and a method (sub-ontologies organized according to key FEI concepts), covering the front end of innovation holistically.

Parolin et al. [30] present a technological evaluation model that incorporates sustainability into new product development in manufacturing companies. A systematic literature review identified 170 technological evaluation approaches, which were analyzed, filtered, and integrated into sustainability evaluation in the early stage of the innovation process. Using a design science approach, the artifact's evaluation is theoretical, highlighting the need for further research to refine sustainability evaluation tools. The artifact is classified as a model, offering propositions that express relationships between technological evaluation approaches and sustainability concepts, integrating these into the front end of innovation holistically.

## 4 Discussion

Following the presentation of the review results, it is essential to discuss several key points identified during the study.

#### ***4.1 Summary of the Results***

Table 3 provides a summary of the results obtained from the review. It synthesizes the studied artifacts, the classification according to the type of artifact developed, and their alignment with FEI activities.

#### ***4.2 Highlight on Ontological Development***

The review identified ontological development as a prominent approach in DSR applied to FEI, being employed in 5 out of the 11 studies analyzed (approximately 45%).

An ontology is a formal description of concepts in a domain, defining a common vocabulary for information sharing [31]. Unlike purely conceptual models, an ontology provides a formal knowledge model by exploring structured relationships between concepts. This enables the creation of a model useful for both human interpretation and computational implementation, thereby improving the effectiveness of knowledge representation [32]. Feilmayr and Wöß [33] outline the main benefits of using ontologies:

- **Communication:** An ontology facilitates standardized communication (uniform language) between humans, between computational systems, and between humans and computational systems, thereby enhancing knowledge transfer.
- **Knowledge Organization:** Domain analysis is necessary to make explicit the assumptions of the domain and share an understanding of the information structure and knowledge organization.
- **Reuse:** Ontologies enable the reuse of domain knowledge and the integration of new knowledge built upon existing knowledge, facilitating the constant evolution of the ontology.

#### ***4.3 Contributions***

In terms of literature, this review is the first to systematically analyze the development of FEI management artifacts using DSR based on WoS and Scopus databases. Practically, this review offers valuable insights for new research initiatives aiming to employ DSR in this process.

**Table 3** Summary of documents, artifacts developed, and their classification

| Document                     | Artifact developed                                                                              | Type of DSR artifact                                                                                                                      | FEI activities                                                                                                                                             |
|------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bullinger [22]               | OntoGate ontology                                                                               | <ul style="list-style-type: none"> <li>– Constructs</li> <li>– Model</li> <li>– Method</li> <li>– Instantiation</li> </ul>                | <ul style="list-style-type: none"> <li>– Identification and analysis of opportunities</li> <li>– Generation, enrichment, and screening of ideas</li> </ul> |
| Brandtner et al. [9]         | Multicriteria selection procedure for choosing prospective approaches for FEI                   | <ul style="list-style-type: none"> <li>– Method</li> <li>– Instantiation (InnoStrategy 2.0)</li> </ul>                                    | Identification and analysis of opportunities                                                                                                               |
| Barradas [23]                | Ontological framework and software tool for FEI collaborative knowledge creation                | <ul style="list-style-type: none"> <li>– Constructs</li> <li>– Model</li> <li>– Method</li> <li>– Instantiation (case studies)</li> </ul> | Holistic approach                                                                                                                                          |
| Gregor and Hevner [24]       | KIM-FEI (Knowledge Innovation Matrix-Front End of Innovation)                                   | <ul style="list-style-type: none"> <li>– Constructs</li> <li>– Model</li> </ul>                                                           | <ul style="list-style-type: none"> <li>– Identification and analysis of opportunities</li> <li>– Generation, enrichment, and screening of ideas</li> </ul> |
| Groher et al. [25]           | Method for analyzing Innovation Search Fields (ISF)                                             | Method                                                                                                                                    | Identification and analysis of opportunities                                                                                                               |
| John et al. [26]             | Project Client Map (PCM)                                                                        | <ul style="list-style-type: none"> <li>– Constructs</li> <li>– Model</li> <li>– Instantiation (case studies)</li> </ul>                   | Identification and analysis of opportunities                                                                                                               |
| Pereira et al. [8]           | FEI2O (Front End of Innovation Integrative Ontology)                                            | <ul style="list-style-type: none"> <li>– Constructs</li> <li>– Model</li> <li>– Method</li> <li>– Instantiation (case studies)</li> </ul> | Holistic approach                                                                                                                                          |
| Ebel et al. [27]             | Pattern-Based Smart Service Innovation (PBSSI)                                                  | <ul style="list-style-type: none"> <li>– Method</li> <li>– Instantiations (case studies)</li> </ul>                                       | <ul style="list-style-type: none"> <li>– Identification and analysis of opportunities</li> <li>– Generation, enrichment, and screening of ideas</li> </ul> |
| Castro and Ferreira [28, 29] | Front-end of R&D                                                                                | <ul style="list-style-type: none"> <li>– Constructs</li> <li>– Model</li> <li>– Method</li> </ul>                                         | Holistic approach                                                                                                                                          |
| Parolin et al. [30]          | Technological evaluation model seeking to incorporate sustainability in new product development | <ul style="list-style-type: none"> <li>– Constructs</li> <li>– Model</li> </ul>                                                           | Holistic approach                                                                                                                                          |

#### 4.4 Limitations

The research has two main limitations:

- The categorization of DSR artifact types was based solely on the frameworks provided in [13, 17].
- The identification of FEI activities relied exclusively on the review in [18], which was based on seminal works identified in [7, 8].

### 5 Conclusion

This study conducted a systematic literature review on the application of DSR in developing artifacts for FEI management. The review revealed a predominance of ontological approaches and underscored the importance of well-structured artifacts for the effectiveness of FEI. Despite some limitations, such as reliance on specific categorizations and the limited scope of the databases, the study offers significant contributions to academia and practice. For academia, it provides an unprecedented and comprehensive analysis of the use of DSR in developing FEI artifacts. For practice, it suggests pathways for practically applying the research results. Future research should focus on the empirical validation of the identified artifacts and the exploration of new approaches for FEI management.

### References

1. Tidd J, Bessant J (2020) Managing innovation: integrating technological, market and organizational change. Wiley
2. Keeley L, Walters H, Pikkil R, Quinn B (2013) Ten types of innovation: the discipline of building breakthroughs. Wiley
3. Boeddrich H-J (2004) Ideas in the workplace: a new approach towards organizing the fuzzy front end of the innovation process. *Creat Innov Manag* 13:274–285. <https://doi.org/10.1111/j.0963-1690.2004.00316.x>
4. Kock A, Heising W, Gemünden HG (2015) How ideation portfolio management influences front-end success. *J Prod Innov Manag* 32:539–555. <https://doi.org/10.1111/jpim.12217>
5. Markham SK (2013) The impact of front-end innovation activities on product performance. *J Prod Innov Manag* 30:77–92. <https://doi.org/10.1111/jpim.12065>
6. Khurana A, Rosenthal SR (1998) Towards holistic “front ends” in new product development. *J Prod Innov Manag* 15:57–74. [https://doi.org/10.1016/S0737-6782\(97\)00066-0](https://doi.org/10.1016/S0737-6782(97)00066-0)
7. Pereira AR, Ferreira JJP, Lopes A (2017) Front end of innovation: an integrative literature review. *J Innov Manag* 5:22–39. [https://doi.org/10.24840/2183-0606\\_005.001\\_0004](https://doi.org/10.24840/2183-0606_005.001_0004)
8. Pereira AR, Ferreira JJP, Lopes A (2020) A knowledge representation of the beginning of the innovation process: the Front End of Innovation Integrative Ontology (FEI2O). *Data Knowl Eng* 125:1–20. <https://doi.org/10.1016/j.datapk.2019.101760>
9. Brandtner P, Helfert M, Auinger A, Gaubinger K (2015) Multi-criteria selection in design science projects—a procedure for selecting foresight methods at the front end of innovation.

- In: Donnellan B, Helfert M, Kenneally J, VanderMeer D, Rothenberger M, Winter R (eds) *New horizons in design science: broadening the research agenda*. Springer International Publishing, Cham, pp 295–310
- 10. Hevner AR, March ST, Park J, Ram S (2004) Design science in information systems research. *MIS Q Manag Inf Syst* 28:75–105. <https://doi.org/10.2307/25148625>
  - 11. Gregor S, Hevner AR (2013) Positioning and presenting design science research for maximum impact. *MIS Q* 37:337–355. <https://doi.org/10.25300/MISQ/2013/37.2.01>
  - 12. Baskerville R, Baiyere A, Gregor S, Hevner A, Rossi M (2018) Design science research contributions: finding a balance between artifact and theory. *J Assoc Inf Syst* 19:358–376. <https://doi.org/10.17705/1jais.00495>
  - 13. Vaishnavi V, Kuechler B, Stacey P Design science research in information systems. <http://www.desrist.org/design-research-in-information-systems>
  - 14. Thomé AMT, Scavarda LF, Scavarda AJ (2016) Conducting systematic literature review in operations management. *Prod Plan Control* 27:408–420. <https://doi.org/10.1080/09537287.2015.1129464>
  - 15. Ferreira JJP, Mention AL, Torkkeli M (2020) Phrasing the giant: on the importance of rigour in literature search process. *J Innov Manag* 8:1–10. [https://doi.org/10.24840/2183-0606\\_008.002\\_0001](https://doi.org/10.24840/2183-0606_008.002_0001)
  - 16. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE, Chou R, Glanville J, Grimshaw JM, Hróbjartsson A, Lalu MM, Li T, Loder EW, Mayo-Wilson E, McDonald S, McGuinness LA, Stewart LA, Thomas J, Tricco AC, Welch VA, Whiting P, Moher D (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews
  - 17. March ST, Smith GF (1995) Design and natural science research on information technology. *Decis Support Syst* 15:251–266. [https://doi.org/10.1016/0167-9236\(94\)00041-2](https://doi.org/10.1016/0167-9236(94)00041-2)
  - 18. Girardi R, Galdino JF, Pellanda PC (2024) The front end of innovation in defense: a comprehensive literature review. In: Burt S (ed) *National security in the digital and information age*. IntechOpen. <https://doi.org/10.5772/intechopen.1005191>
  - 19. Cooper RG (2008) Perspective: the stage-gates idea-to-launch process—update, what's new, and NexGen systems. *J Prod Innov Manag* 25:213–232. <https://doi.org/10.1111/j.1540-5885.2008.00296.x>
  - 20. Koen P, Ajamian G, Boyce S, Clamen A, Fisher E, Fountoulakis S, Johnson A, Puri P, Seibert R (2002) *Fuzzy front end: effective methods, tools, and techniques*. In: *The PDMA toolkit for new product development*. Wiley
  - 21. Reid SE, De Brentani U (2004) The fuzzy front end of new product development for discontinuous innovations: a theoretical model. *J Prod Innov Manag* 21:170–184. <https://doi.org/10.1111/j.0737-6782.2004.00068.x>
  - 22. Bullinger AC (2008) Innovation and ontologies: structuring the early stages of innovation management
  - 23. Barradas LCS (2015) Information technology and enterprise integration for the fuzzy front end of innovation
  - 24. Gregor S, Hevner AR (2015) The front end of innovation: perspectives on creativity, knowledge and design. In: Donnellan B, Helfert M, Kenneally J, VanderMeer D, Rothenberger M, Winter R (eds) *New horizons in design science: broadening the research agenda*. Springer International Publishing, Cham, pp 249–263
  - 25. Groher W, Rademacher F, Csillaghy A (2019) Leveraging AI-based decision support for opportunity analysis. *Technol Innov Manag Rev* 9:29–35. <https://doi.org/10.22215/timreview/1289>
  - 26. John PK, Lear E, Decosta PLE, Dann S, Sun R (2020) Designing a visual tool for teaching and learning front-end innovation. *Technol Innov Manag Rev* 10:16–26. <https://doi.org/10.22215/timreview/1386>
  - 27. Ebel M, Jaspert D, Poeppelbuss J (2022) Smart already at design time—pattern-based smart service innovation in manufacturing. *Comput Ind* 138:103625. <https://doi.org/10.1016/j.compind.2022.103625>

28. Castro RN, Ferreira JJP (2020) Project portfolio management in the front-end of innovation of research centers: a literature review. *Technol Innov Rev* 10:46–59. <https://doi.org/10.22215/timreview/1409>
29. Castro RN, Ferreira JJEP (2023) The front-end of R&D at non-profit research centers: how does research produce impact? *Int J Innov Technol Manag* 20:1–22. <https://doi.org/10.1142/S0219877023500141>
30. Parolin G, Mcaloone TC, Pigosso DCA (2024) How can technology assessment tools support sustainable innovation? A systematic literature review and synthesis. *Technovation* 129. <https://doi.org/10.1016/j.technovation.2023.102881>
31. Noy NF, McGuinness DL (2001) Ontology development 101: a guide to creating your first ontology. *Stanford Knowl Syst Lab* 25. <https://doi.org/10.1016/j.artmed.2004.01.014>
32. Suárez-Figueroa MC, García-Castro R, Terrazas BV, Gómez-Pérez A (2011) Essentials In ontology engineering: methodologies, Languages, And Tools
33. Feilmayr C, Wöß W (2016) An analysis of ontologies and their success factors for application to business. *Data Knowl Eng* 101:1–23. <https://doi.org/10.1016/j.datak.2015.11.003>

# Leveraging Eduinformatics to Foster Network-Type Thinking in Early Childhood Education Through Picture Books



Hibiki Ito , Kenya Bannaka, Ryosuke Kozaki , Katsuhiko Murakami , Koichi Akashi , Sayaka Matsumoto , and Kunihiko Takamatsu

**Abstract** Our contemporary society is in a complex transition toward sustainability, driven by the rapid advancement of information technologies. This societal transformation necessitates reconsideration of the current education systems. Network-type thinking is a significant competence emphasized in this context of global educational trend. This paper explores the role of early childhood education in fostering network-type thinking through the use of picture books. Specifically, it is possible to enhance young children's network-type thinking by developing their ability to identify connections among the contents of picture books. Hence, by applying eduinformatics as our approach, we investigate how picture books can be mapped and connected within a semantic space. Utilizing natural language processing techniques, including bag-of-words, TF-IDF, and doc2vec, we analyzed 302 Japanese picture books to examine their distribution and clustering. Our findings suggest that picture books are almost uniformly distributed in the semantic space, with doc2vec proving most effective in identifying similarities. A close reading of similar books revealed thematic connections that could be used to cultivate network-type thinking. Overall, this study underscores the potential of picture books in early childhood education to develop network-type thinking, an essential cognitive skill aligning with global educational trends.

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**Keywords** Early childhood education · Eduinformatics · Network-type thinking · Picture books

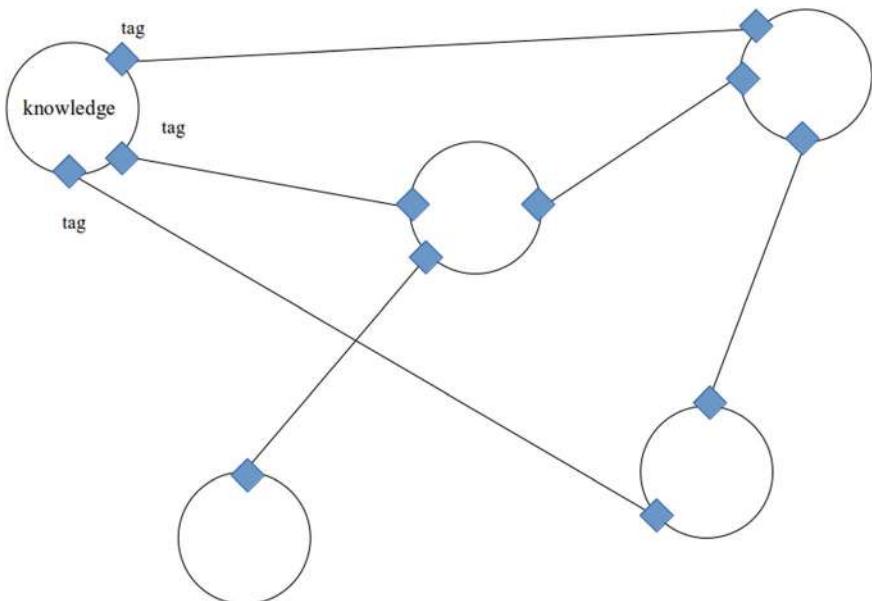
## 1 Introduction

The rapid development of information technologies has introduced various socio-technical challenges toward sustainability, including the reconstruction of education systems. The Organization for Economic Co-operation and Development (OECD) has launched the Future Education and Skills 2030 project to foster extensive discussions of learning and teaching in the twenty-first century [1]. This project highlights several crucial skills, with systemic thinking being one of the key competencies [1]. In alignment with this global educational trend, we have conceptualized the process of knowledge creation as the dynamics of a network model (see Fig. 1) [2]. In this model, acquired pieces of information—constituting knowledge—are distributed within a learner's knowledge space. A knowledge network is then developed by interweaving these various pieces of information. To facilitate the formation of a cohesive and interconnected knowledge network, “tags” are assigned to individual pieces of knowledge, aiding in the establishment of meaningful connections [2, 3]. This approach not only mirrors the interconnected nature of modern information landscapes but also enhances the learner's ability to synthesize and apply knowledge effectively.

Early childhood education is a crucial and impactful arena for developing values and behaviors, especially as society navigates the complex transition toward sustainability [4]. Within this context, this study explores the significant potential of picture books in early childhood education. As mentioned above, enhancing systemic or network-type thinking involves encouraging learners to observe relationships between pieces of information. By fostering young children's ability to identify connections among the contents of picture books, it is possible to cultivate network-type thinking skills. This early development can better prepare children for formal education, where they will engage in similar cognitive activities, thereby laying a strong foundation for their future learning experiences.

However, establishing connections among picture books is not straightforward. A previous study explored these relationships by utilizing topic modeling, resulting in the identification of multiple categories based on broad topics [5]. To effectively use picture books for enhancing network-type thinking in early childhood education, our objective is to validate the concept of a picture book network. Specifically, our research questions are formulated as follows:

- RQ1: How can picture books be mapped to a semantic space? Are there any clusters or are they uniformly distributed?
- RQ2: How can picture books be connected in the semantic space? What tags could be used to create an edge between nodes (books)?



**Fig. 1** The concept of knowledge network model

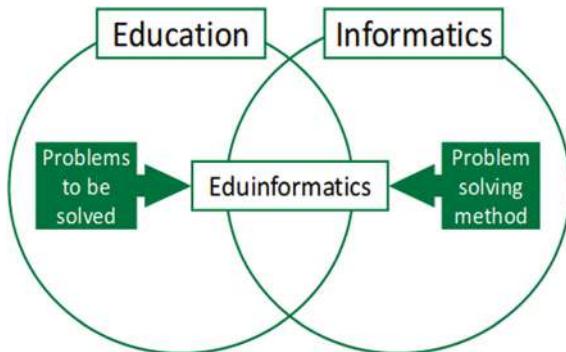
## 2 Approach

### 2.1 Eduinformatics

Nowadays, the increasing data availability in education has created a vast demand for advanced computational techniques to derive useful insights for educational practice. As a specialized domain within education research, *eduinformatics* was conceptualized to draw more attention to the development of informatics theory and methodology aimed at educational challenges (see Fig. 2) [6]. In the contemporary scientific landscape, educational data mining (EDM) and learning analytics (LA) are established fields that also employ computational methods within the educational realm [7]. Despite their many overlapping aspects, they are considered distinct fields [7, 8]. Specifically, while EDM focuses on understanding educational settings, LA aims not only to understand learners and learning environments but also to optimize them, incorporating elements of design science [7–9].

A key difference between eduinformatics and EDM/LA is that eduinformatics is problem-oriented [6, 10]. Eduinformatics research endeavors to identify issues collaboratively with educationists and pragmatically develop computational methods to address these challenges. This study adopts the eduinformatics approach to tackle our research questions. The following subsection delineates the materials and methods used in our approach.

**Fig. 2** The concept of euinformatics from [6]



## 2.2 Materials and Methods

Text data from 302 Japanese picture books were prepared as the materials for this study. Here picture books refer to books that contain visuals and texts, aimed at young children, but not necessarily for educational purpose. To investigate the research questions, we employed three different distributed representations in natural language processing (NLP) to elucidate the semantic relationships between the books.

The bag-of-words method induces a vector representation for each document in a set of multiple documents by simply counting the frequencies of words that appear in the whole dataset [11]. As there were 9931 distinct words (excluding stop-words) in the dataset of 302 picture books, each book was encoded into a vector of 9931 dimensions by the bag-of-words method.

Next, the Term Frequency-Inverse Document Frequency (TF-IDF) technique was used. While the bag-of-words method treats all vocabularies equally, TF-IDF weights vocabularies to give more importance to words that are unique to certain documents and compared to common words [12].

Finally, a doc2vec model trained using Japanese Wikipedia entries was applied. Unlike the previous two methods, a doc2vec model captures the order of words and the structure of documents [13].

Having encoded the books by those methods, the distribution and potential clusters were investigated (RQ1). In addition, the most similar pairs of picture books were identified for close reading to reveal the relationships and potential features that connect them (RQ2).

### 3 Results

#### 3.1 Distribution of Vector Representations (RQ1)

To explore the distribution of document embeddings of the picture books, pairwise cosine similarities were calculated. If  $v_1$  and  $v_2$  are vectors representing some books, then the cosine similarity between these two books is defined as follows:

$$\text{similarity} = \frac{v_1 \cdot v_2}{|v_1||v_2|} \quad (1)$$

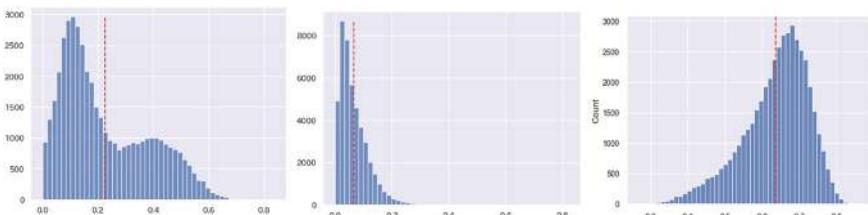
Therefore, the value falls between 0 and 1, and a larger value close to 1 indicates that the books are similar, and vice versa.

Figure 3 shows the histograms of pairwise cosine similarities for each encoding method. The three encoding methods produced different distributions of similarities between the picture books. For the bag-of-words method, there are two local peaks around 0.1 and 0.4. This possibly implies that there are two big clusters within the semantic space. However, the similarities of books within a cluster are not high (mostly less than 0.7), indicating that the clusters might not clearly tell distinct features of the books. The TF-IDF encoding led to lower similarities among the picture books. Many pairs of picture books have cosine similarity close to zero. However, the smooth tail of the similarity distribution possibly shows that the books are mostly uniformly distributed in the semantic space. The doc2vec representation shows this trend more clearly with a relatively symmetric bell-shaped curve. Nonetheless, it should be noted that this does not necessarily imply a uniform distribution of picture book embeddings.

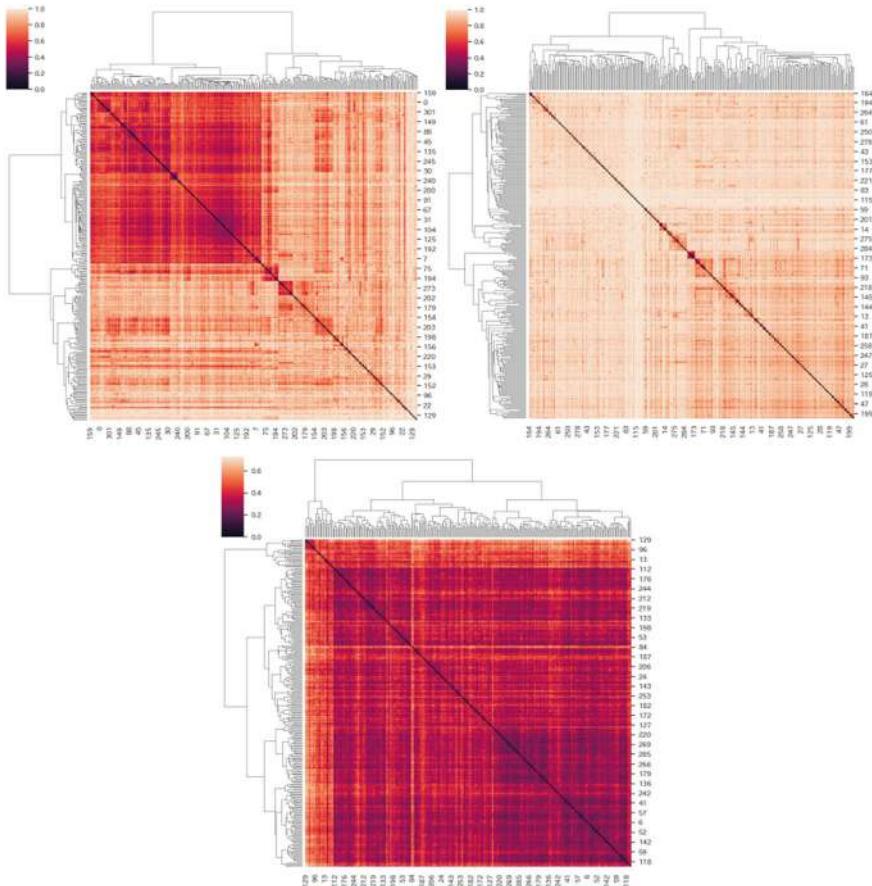
Therefore, we next applied hierarchical clustering. For this task cosine similarity values are converted into distances:

$$\text{distance} = 1 - \frac{v_1 \cdot v_2}{|v_1||v_2|} \quad (2)$$

Ward's minimum variance method was used for clustering [14]. Figure 4 shows the results with heat maps and dendograms. As mentioned previously, there appear to



**Fig. 3** The histograms of pairwise cosine similarities between vector representations of picture books. The vectors are obtained by bag-of-words (Left), TF-IDF (Center), and doc2vec (Right)



**Fig. 4** The heat maps of cosine distances of vector representations and the dendograms obtained by hierarchical clustering. The picture books are encoded into vectors by bag-of-words (Top left), TF-IDF (Top right), and doc2vec (Bottom)

be two large clusters when the embeddings are obtained by the bag-or-words method. Otherwise, it can be observed that the picture books are uniformly distributed in the semantic space, validated by TF-IDF and doc2vec representations.

To find out features of the two potential clusters, the most frequent words that are unique to each cluster were extracted (see Table 1). It is not clear how to characterize those clusters based on those feature words. However, the frequencies in Table 1 combined with the distribution in Fig. 1 suggest that picture books within Cluster 1 are relatively connected to each other and the other books belonging to Cluster 2 are distributed almost uniformly around Cluster 1.

Overall, these results support the claim that the picture books analyzed in this study are almost uniformly distributed in a semantic space. In practice, doc2vec

**Table 1** The five most frequent words unique to each cluster

|   | Cluster 1   | Frequency | Cluster 2         | Frequency |
|---|-------------|-----------|-------------------|-----------|
| 1 | Guri (name) | 130       | Dwarf             | 33        |
| 2 | Johnny      | 116       | Meow (cat crying) | 31        |
| 3 | Piglet      | 84        | Babar             | 31        |
| 4 | Harry       | 75        | Small (name)      | 30        |
| 5 | Tommy       | 72        | (older) sister    | 30        |

encoding is the most effective representation to establish a picture books network and to discover similar books within the network.

### 3.2 Relationship Between Similar Books (*RQ2*)

Based on the previous results, the two most similar books are identified for close reading in terms of the cosine similarity of doc2vec encoding: Two Little Bears [15] and Town Musicians of Bremen [16]. The summaries of the picture books are given in Table 2. There are several aspects that can be pointed out as common features or “tags” that connect those books:

1. Both stories feature animals as characters. In Two Little Bears the protagonists are bear cubs, while in Town Musicians of Bremen, the protagonists are a donkey, a dog, a cat, and a rooster.

**Table 2** Summaries of Two Little Bears and Town Musicians of Bremen

| Two Little Bears                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Town Musicians of Bremen                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| During a cold winter, two little bears, one male and one female, are born in a warm underground. As spring arrives, they eagerly venture outside to experience the sun and nature. Their mother warns them not to wander far as she goes to gather honey. However, the little bears forget her warning and explore far from home. They play and discover various things but eventually realize they are lost and miss their mother. Despite obstacles, they continue searching and encounter various animals, none of whom have seen their mother. Exhausted and disheartened, they fall asleep. Meanwhile, their worried mother returns and, with the help of a crow, finds them. The little bears joyfully reunite with their mother and promise never to wander off again | An old donkey, no longer able to work, leaves his home and heads to Bremen to become a town musician. Along the way, he meets a dog, a cat, and a rooster, all of whom have been abandoned by their owners due to old age and join him on his journey. As night falls, they find a house occupied by robbers. They decide to scare the robbers away by making loud noises together, which works, and the robbers flee. The animals enjoy the food left behind and settle in for the night. When one robber returns to investigate, he is frightened away by the animals once more. The robbers never return, and the four animals live happily in the house, abandoning their journey to Bremen |

2. The animals embark on a journey. The little bears explore their surroundings and get lost, while the Bremen musicians travel to the town of Bremen with the intention of becoming musicians.
3. Both stories depict the animals acting independently from their usual caretakers. The little bears venture away from their mother, and the animals in the Bremen story leave their owners due to old age and neglect.
4. The main characters meet other animals along the way. The bears encounter various forest animals, and the Bremen musicians meet each other and later face robbers.
5. Each story concludes with a positive resolution. The bear cubs are reunited with their mother, and the Bremen musicians find a new home where they can live together happily.

The list above is not exhaustive at all, and one could think of other tags that potentially relate the stories with each other. Nevertheless, there are many connections that can be established between those two books. From this example pair of similar picture books, it can be stated that the doc2vec encoding captures the relationships of picture books well enough for a reader to find many common attributes of similar books. That is, dev2vec provides an effective method to map picture books into a semantic space, allowing young learners or educational practitioners to find similar books.

### 3.3 *Limitations*

There are several limitations of this study to be recognized. First, the number of picture books analyzed in this study is limited and the books are only in Japanese. The results could change if more books and various languages are incorporated. Second, the doc2vec model was trained using Japanese Wikipedia entries, possibly not reflecting language generally used in picture books, as those books are aimed at young children. A direction of future research would be considering writing styles and vocabularies unique to picture books. Third, our dataset does not contain visual information. As picture books involve many images and they might influence children's cognitive processes while reading, future research should also integrate this aspect.

## 4 Discussion and Conclusion

This study has provided valuable insights into the significant potential of picture books in early childhood education, particularly in nurturing network-type thinking essential for navigating the complexities of the modern information age. By applying eduinformatics approach, we explored the distribution of picture books within a

semantic space, revealing a pattern of largely uniform distribution. This observation suggests that picture books offer a rich tapestry of potential connections, presenting educators with abundant opportunities to scaffold children's cognitive development through the exploration and synthesis of diverse narratives.

Furthermore, our analysis using doc2vec encoding highlighted the efficacy of computational methods in capturing the latent relationships between stories. By identifying common features or "tags" among pairs of similar books, we gained valuable insights into the underlying thematic threads that weave through children's literature. This also offers practical implications for designing curriculum and instructional strategies that leverage these inherent connections to promote deeper engagement and comprehension.

Beyond the realm of early childhood education, the implications of our findings resonate with broader discussions surrounding educational reform and the cultivation of 21st-century skills. By recognizing and leveraging the network structure of knowledge embedded within picture books or literature in general, educators across all levels can foster this network-type thinking among their students. This underscores the transformative potential of integrating literature into curricular frameworks as a means of not only fostering literacy but also nurturing the cognitive competencies necessary for success in an increasingly interconnected and dynamic information society.

However, it is essential to acknowledge the limitations inherent in this study. The relatively small sample size of picture books, along with the focus on Japanese language texts, warrants caution in generalizing the findings to broader contexts. Future research endeavors could address these limitations by expanding the dataset to include a more diverse range of picture books from different cultural and linguistic backgrounds. Additionally, integrating visual elements from picture books into computational analyses could offer a more comprehensive understanding of how text and imagery synergistically contribute to children's cognitive processes during reading and comprehension.

In summary, this study illustrates the transformative potential of picture books as catalysts for developing network-type thinking in early childhood education. By embracing interdisciplinary approaches and leveraging computational methodologies, educators can harness the rich tapestry of narratives within picture books to cultivate critical thinking, creativity, and a deeper appreciation for the interconnectedness of knowledge among young learners. This not only prepares them for success in formal educational settings but also equips them with the tools necessary to thrive in an increasingly complex and interconnected information society, fostering a generation of lifelong learners poised to navigate the challenges of the future with confidence and competence.

## References

1. OECD Future of Education and Skills 2030—Organisation for Economic Co-operation and Development. <https://www.oecd.org/education/2030-project/>. Accessed 19 May 2024
2. Kirimura T, Takamatsu K, Bannaka K, Noda I, Omori M, Adachi R, Mitsunari K, Nakata Y (2017) Three-step knowledge network model. Bulletin of Kobe Tokiwa University 51–60
3. Takamatsu K, Bannaka K, Kirimura T, Noda I, Murakami K, Mitsunari K, Nakata Y (2017) Tag-based knowledge network models. Bull Kobe Tokiwa Univ 51–60. <https://doi.org/10.20608/00000391>
4. Engdahl I, Furu A-C (2022) Early childhood education: a vibrant arena in the complex transformation of society towards sustainability. IJEC 54:1–12. <https://doi.org/10.1007/s13158-022-00323-0>
5. Bannaka K, Kozaki R, Murakami K, Ito H, Akashi K, Matsumoto S, Takamatsu K (2024) Enhancing network-type thinking in early childhood: a topic model approach to picture book analysis based on eduinformatics. In: Proceedings of 9th international congress on information and communication technology ICICT 2024, London (in press)
6. Takamatsu K, Murakami K, Kirimura T, Bannaka K, Noda I, Raphael-Joel WL, Mitsunari K, Seki M, Matsumoto E, Bohgaki M, Imanishi A, Omori M, Adachi R, Yamazaki M, Sakamoto H, Takao K, Asahi J, Nakamura T, Nakata Y (2018) Eduinformatics: a new education field promotion. Bull Kobe Tokiwa Univss 27–44. <https://doi.org/10.20608/00000958>
7. Baker R, Siemens G (2014) Educational data mining and learning analytics. In: Sawyer RK (ed) The Cambridge Handbook of the Learning Sciences, 2nd edn. Cambridge University Press, pp 253–272
8. Siemens G (10/2013) Learning analytics: the emergence of a discipline. Am Behav Sci 57:1380–1400. <https://doi.org/10.1177/0002764213498851>
9. Hevner AR (2007) A three cycle view of design science research. Scand J Inf Syst 19:87–92
10. Takamatsu K, Kozaki Y, Murakami K, Sugiura A, Bannaka K, Mitsunari K, Omori M, Nakata Y (2019) Review of recent eduinformatics research. In: 2019 International congress on applied information technology (AIT), pp 1–6. <https://doi.org/10.1109/AIT49014.2019.9144820>
11. Qader WA, Ameen MM, Ahmed BI (2019) An overview of bag of words;importance, implementation, applications, and challenges. In: 2019 international engineering conference (IEC), pp 200–204. <https://doi.org/10.1109/IEC47844.2019.8950616>
12. Sammut C, Webb GI (2010) TF-IDF. Encyclopedia of machine learning. Springer US, Boston, MA, pp 986–987. [https://doi.org/10.1007/978-0-387-30164-8\\_832](https://doi.org/10.1007/978-0-387-30164-8_832)
13. Le Q, Mikolov T (2014) Distributed representations of sentences and documents. Int Conf Mach Learn 1188–1196
14. Murtagh F, Legendre P (2014) Ward’s hierarchical agglomerative clustering method: which algorithms implement Ward’s criterion? J Classification 31:274–295. <https://doi.org/10.1007/s00357-014-9161-z>
15. Ylla (1990) Two little bears (in Japanese). Koguma Publishing
16. Grimm (1964) Town mucisians of Bremen (in Japanese). Fukuinkan Shoten Publishers

# Evaluating the ResNet and DenseNet Models for Birdcall Audio Classification



Rohit Gunti and Abebe Rorissa

**Abstract** We present findings from a study evaluating audio classification in a Kaggle Multiclass competition. Although the open-source Baseline model was a crucial step, it initially performed poorly with an accuracy of 0.02 public score. The Kaggle platform played a vital role in training and evaluating models to address the complexities of improving a poorly performing model. Rigorous experimentation with ResNet models (18, 34, 50, 101, 152) and the DenseNet models (121, 161, 169, 201) were performed with under-sampling and oversampling to measure the accuracy of a birdcall. The methodology involved identifying peaks, creating audio metadata for training data, training it, and measuring accuracy on the Kaggle platform. The model was tested using a manually collected dataset and cross-validated using the truth table from the Birdwatch website to enhance flexibility. Our approach resulted in competitive results against Google inference, confirming the prevailing literature that downsampling a dataset would lead to the development of adaptability and accuracy across competition datasets.

**Keywords** Birdcall identifier · Audio classification · Resnet · Densenet

## 1 Introduction

In machine learning, the effectiveness of evaluating a classification model is tied to the quality and characteristics of the training data [1]. This is a crucial consideration across various domains, from simulated scenarios to real-world applications. The study uses the same evaluation and inspired by key insights from the relevant literature [2–5], the authors explore an approach that underscores the influence of sampling techniques on audio data, including low sampling rates, on the training of audio classification models. The study's approach of transforming raw audio data into image data, such as spectrograms, can be advantageous for several reasons. Firstly, these transformations provide a visual representation of the audio signal,

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capturing time–frequency information that highlights important patterns and features like peaks and pitches, which are crucial for tasks such as bird call identification for bird monitoring, voice recognition for interactive robots, and so forth. Convolutional Neural Networks (CNNs), which are highly effective in image processing, can leverage these visual patterns to extract relevant features, potentially leading to better performance compared to using raw audio data. Additionally, these image representations can enhance the interpretability of the data, making it easier to visualize and understand the underlying structures in the audio signal. While features could be extracted directly from raw audio, the visual representations often encapsulate complex relationships in a more accessible form for models designed to handle images, thereby simplifying the feature extraction process and potentially improving accuracy and efficiency in various audio processing tasks. Drawing upon the observations from studies covering supervised classification problems with misclassified training data [2], event-based visual classification with spatial and temporal down-sampling [3], cropland mapping [4], and crop classification [5] from remote sensing data, the authors retrieve valuable perspectives on the interplay between data characteristics and model performance. The exploration aligns with the utilization of renowned models, specifically ResNet (Residual Networks) and DenseNet (Densely Connected Convolutional Networks), known for their effectiveness in image classification tasks [6]. Therefore, the reliability of the image data preprocessing on different classification types is still ongoing.

- (RQ1) How does image data preprocessing affect the accuracy and reliability of machine learning models for different audio or text classification tasks?
- (RQ2) How flexible is the developed baseline model trained using spectrogram data in detecting birdcalls?

## 1.1 *Methodology*

Kaggle Training Dataset: The training dataset (Holger, 2023), hereafter represented as train dataset, is composed of over sixteen thousand short recordings of 264 individual bird labels sourced from xenocanto, a website dedicated to sharing wildlife sounds from all over the world. Additionally, the train dataset incorporates 10-min soundscape recordings from two locations similar to the test set. Additionally, the Kaggle testing dataset (Holger, 2023) is designed to evaluate the model’s performance in classifying bird species within 5-s segments of 10-min soundscape recordings.

Custom Testing Dataset: In addition to the train dataset, a custom test set 2 is recorded to test the model’s flexibility, using TASCAM DR-100, consisting of eight audio files, consisting of known bird species from Ireland website in OGG format. These files are characterized by varying lengths, with most containing at least one 15-min recording and multiple 10-min recordings from two distinct locations in Ireland—Bohernabreena Reservoir and Saint Catherine’s Park, Lucan, Dublin. Including longer recordings in the custom test set allows for assessing the model’s performance on more extended audio sequences. While not directly comparable in

structure to the train dataset, this custom test set offers an opportunity to evaluate the model's robustness across different recording lengths and locations, providing valuable insights into its generalization capabilities.

The methods employed in this image-processed audio classification are computational, involving mel spectrograms as a representation of sound to train a baseline model [7] for the task. Rather than directly using raw audio data, the approach of transforming audio into mel spectrograms is chosen for its commonality and effectiveness. The data preparation involves setting up data loaders to read specified audio clips and convert them into mel spectrograms. The below straightforward approach was implemented.

1. Data Preprocessing: The Data Preprocessing begins by loading audio files from the train audio directory using the librosa python library. The Chunk to Spec function was defined to convert audio chunks into mel spectrograms, which represent the audio signal in the frequency domain.
2. Exploratory Data Analysis (EDA): The code includes functions to visualize mel spectrograms and peak-related information. Peaks in the spectrogram are detected using the Per-channel energy normalization (PCEN-SNR) based signal-to-noise ratio approach. PCEN-SNR is a technique commonly used in audio processing tasks such as speech and music recognition. PCEN normalizes the energy of a signal across frequency channels, helping mitigate the effects of background noise and improving the signal-to-noise ratio [8].
3. Feature Extraction: The feature extraction involves the peaks [7] from the audio signal using the PCEN-based SNR approach. It is designed to be applied to an entire audio recording. Information such as filename, audio length, label, and peak locations are extracted for each audio file in the train audio directory.
4. Model Training: A neural network model was trained for audio classification using the fastai library. A separate Class named Clip Transform is defined for data transformation. Data loaders are created, dividing the dataset into training (80%) and validation (20%) subsets. The model architecture is based on ResNet101, and the training process incorporates transfer learning. Following training, the model is saved. Notably, the training is conducted on Kaggle, employing a low sample rate (250) to enhance accuracy and accommodate computational constraints.
5. Submission on Kaggle: The exported model, previously trained on the Kaggle 2023 train dataset, is loaded for inference. The code systematically processes the test audio files, extracting relevant features, and subsequently generates predictions for the presence of bird species. Most of the final predictions are formatted into a structured Data Frame to facilitate submission after the competition deadline and saved as a CSV file. The peak detection technique in this study adopts a unique approach by utilizing PCEN-based signal-to-noise ratio (SNR) for identifying peaks. This involves calculating SNR from the PCEN spectrogram and subsequent processing to pinpoint peaks. Mel spectrograms were employed as a standard preprocessing step for converting audio chunks into a concise representation of frequency content in audio signals. Transfer learning is incorporated

- through pre-trained ResNet and DenseNet models, enabling the utilization of knowledge acquired from a model trained on a large dataset.
6. Cross-validating on the Birdwatch Website: Validation is meticulously conducted by cross-referencing the computationally detected birds with manual checks on the Birdwatch Ireland website. This meticulous approach involves manually verifying the identified birds against credible online sources, ensuring the accuracy and reliability of the classification results, as shown in Fig. 2.

## 2 Results

The study's results encompass a comprehensive evaluation of the experimentation. After thorough experimentation, the statistical significance of the ResNet and DenseNet model scores have been observed when the train dataset is tuned with a downsampling parameter. This statistical significance is further explained in the literature [2–5]. The model's initial poor performance is due to ResNet-18's relatively small and simple model, the approach to data preprocessing and handling was basic and served primarily to establish a starting point. This included simple spectrogram transformations and using off-the-shelf signal-to-noise ratio methods to detect bird calls. To optimize the ResNet and DenseNet model's performance, the experimentation began with data preprocessing and augmentation, such as normalization and balancing the dataset. The model architectures are adjusted by modifying the depth, width, and specific layers, and using pre-trained models for fine-tuning. Hyperparameter tuning involved experimenting with learning rates, batch sizes, and regularization techniques like dropout and batch normalization. Training techniques included early stopping and checkpointing. Additionally, explored audio-specific augmentations, adjusted the start time and duration of audio loading, and tried different loss functions and optimization strategies. Finally, employed ensemble methods to combine predictions from multiple models and used transfer learning followed by fine-tuning to enhance performance. A notable difference in score is observed when the model is trained with a low sample rate of 250, a decision that could stem from computational constraints or specific dataset characteristics, adding an interesting dimension to the methodology. This comprehensive approach led to significant improvements in model accuracy and robustness. According to the Kaggle scores, macro average precision score for the number of correctly classified birdcalls, the resultant approach proved to be a competitive model, as shown in Table 1. Notably, the scores are also nearly equal and markedly higher than the initial competition submission score of 0.012, demonstrating the effectiveness of the developed audio classification system. The comparison results of ResNet and DenseNet models, illustrated in Fig. 1, offer valuable insights and implications for both the current research and potential future studies in the field of audio classification. To augment the study's robustness, an additional set of results is presented in Fig. 1, detailing the birds detected during the classification of the custom dataset. This dataset likely represents a unique context, including the fact that specific bird classifications add depth to the evaluation.

Moreover, it's crucial to highlight the classification of the custom dataset validation employed in the study. Additionally, the study underscores the importance of validating against the locations where data were originally collected. This multi-layered validation strategy adds credibility to the findings and reinforces the robustness of the developed audio classification system. Finally, the findings from Table 1 address RQ1 that image data preprocessing leads to more accurate and reliable machine learning models for audio classification. In Fig. 1, species observed at the two locations were sourced from the Ireland website for validation purposes. The truth table juxtaposes the spotted bird codes from the Ireland website with the detected bird codes obtained through the classification of eight 10-min-long test clips using the ResNet 101 model addressing RQ2. The low recall, 0.1, observed in the results can be attributed to inadequate labeling during the data collection process, particularly in the sampling conducted at two locations. Thus, the developed open-source trained model using the image data preprocessing and spectrograms underscore the flexibility to detect birdcalls that are tested from different geographical locations rather than training and testing from the same locations. However, limitations arose from the inability of the audio device to effectively track down bird visuals, resulting in only two true positive bird call detections out of 19 predictions.

The evaluation metric (1) for the above Kaggle submission is padded cmAP of the macro-averaged precision score represented as AP.

$$AP = \sum_n (R_n - R_{n-1})P_n \quad (1)$$

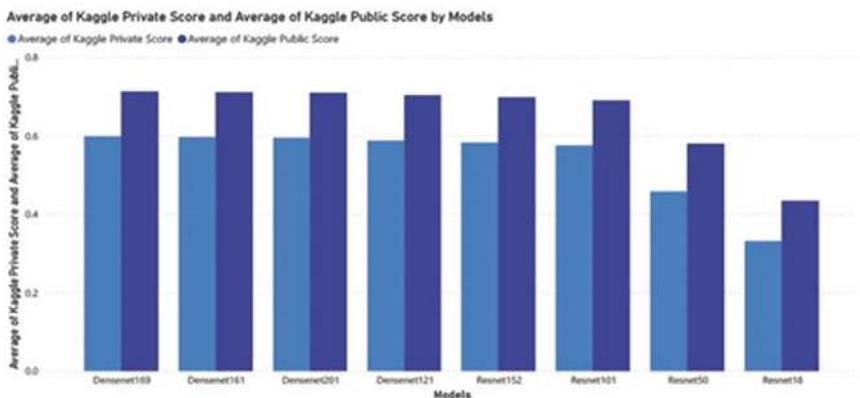
where  $P_n$  and  $R_n$  are the precision and recall at the nth threshold. This implementation is not interpolated and is different from computing the area under the precision-recall curve with the trapezoidal rule, which uses linear interpolation and can be too optimistic.

In addition to the comparison of Kaggle scores in Table 1, detailed training metrics for the most successful ResNet 101 model are meticulously outlined in Table 2. This includes accuracy, loss, and other pertinent metrics, providing a granular understanding of the models' performance characteristics. To augment the Table 1 scores, an additional set of results is introduced in Table 2, detailing the training metrics during the classification of the train dataset. Finally, the comparison results and Table 2 metrics of ResNet and DenseNet models in the study offer valuable insights and implications for both the current research and potential future studies in the field of audio classification.

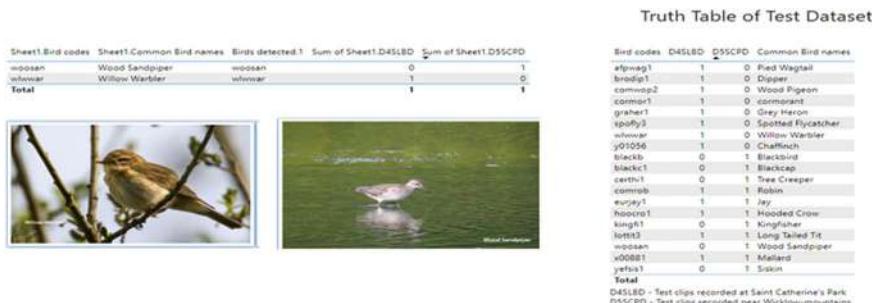
**Table 1** Table captions should be placed above the tables

| Models                                       | Private score | Public score |
|----------------------------------------------|---------------|--------------|
| Inferring birds with Kaggle models–version 2 | 0.60218       | 0.71704      |
| Developed baseline model–version 21          | 0.60213       | 0.71696      |

## Assessing the performance of ResNet and DenseNet models through Public and Private Accuracy Metrics on the Kaggle platform.



**Fig. 1** The collective average scores across all the Resnet and Densenet models exhibited significant consistency, registering at 0.71 for the public score, on the Kaggle leaderboard score, and 0.6 for the private score, hidden for individual only, as shown in Table 1



**Fig. 2** A comprehensive overview of the truth table analysis conducted on 10-min test audio clips recorded at two distinct locations in Ireland

Figure 2 presents a comprehensive overview of the truth table analysis conducted on 10-min test audio clips recorded at two distinct locations in Ireland—Saint Catherine’s Park (D5SCPD) and Bohernabreena Reservoir near the Wicklow Mountains (D4SLBD). Based on the prevailing literature, the study’s assumption focuses that downsampling a dataset would lead to better adaptability and accuracy across competition datasets (Holger, 2023). Indeed, this approach resulted in competitive results against Google inference. Surprisingly, when tested on reliability outliers (custom dataset) that had not been part of the training process, the analysis successfully detected two instances, which were later validated through cross-validation with data obtained from the Birdwatch website. This study results leads to hypothesis that

**Table 2** Below are the training metrics of the ResNet101 model, which achieved the highest Kaggle results when trained on a dataset comprising 80% training and 20% validation data. The attained training accuracy closely approximates the actual accuracy, showcasing the efficacy of the model's training process

| Epochs | Train loss | Valid loss | Accuracy |
|--------|------------|------------|----------|
| 0      | 4.482451   | 3.699099   | 0.301653 |
| 1      | 3.367077   | 2.809159   | 0.427096 |
| 2      | 2.607291   | 2.225477   | 0.526860 |
| 3      | 2.088249   | 1.806042   | 0.619540 |
| 4      | 1.710518   | 1.621060   | 0.659681 |
| 5      | 1.479637   | 1.585469   | 0.666175 |

lower sampling rates can significantly impact a model's performance and efficiency by reducing high-frequency information, which might degrade accuracy due to the loss of critical features, while also simplifying the data, potentially leading to underfitting. However, the reduction in data volume enhances computational efficiency, resulting in faster processing times and lower memory usage, making the model more feasible for deployment on resource-constrained devices. This creates a trade-off between accuracy and efficiency: lower sampling rates might decrease accuracy if high-frequency details are important, but the gains in efficiency can be substantial. For datasets where high-frequency details are less critical, the impact on accuracy may be minimal, but tasks requiring such details could see more pronounced accuracy declines. Finding the optimal balance involves empirical testing to align the sampling rate with the specific dataset characteristics and application requirements, ensuring an appropriate trade-off between computational constraints and model performance. Thus, all the assumptions made in this study were substantiated providing decent outcomes. Therefore, to study sampling rate of the training process and evaluate its impact on classification performance, more experiments can be added for future. For instance, comparing models used identical features, and so on, but may vary in their sampling strategies. Although the proposed models achieved overall good performance, the paper could benefit from a more detailed experimentation on the limitations and challenges faced during the study. The optimization process was challenging, particularly when trying to increase the accuracy above 0.6 on different processes. Additionally, the Kaggle test set provided only one 10-min recording, which may not be representative when tested on larger datasets. During hyperparameter tuning, decreasing the sampling rate was found to be the most effective, while increasing the learning rate resulted in moderate improvements. Although the batch size did not explicitly change the accuracy, it impacted the submission run on Kaggle notebook. Computational constraints influenced the choice of low sampling rates; previous work showed that tuning the train dataset with downsampling parameters significantly affected the performance of ResNet and DenseNet models, as supported by the literature. In addition, a follow up study can be focused on determining the optimal sample rate for training this type of model. For example, evaluate how low

a sample rate can be effective, or suggest a specific range of sample rates for the training process. According to Abelson [9], it's evident that ensuring the validity of data collection methods is paramount. It's crucial to acknowledge that with more comprehensive and accurate sampling techniques, the developed model's performance could be significantly improved [9]. Hence, for future work, validity across various forms of data and datasets ensures that the measurements accurately reflect the underlying constructs that authors seek to understand.

## References

1. Abu-Mostafa Y S, Magdon-Ismail M, Lin HT (2012) Learning from data: a short course. AMLbook.com
2. Bolin J, Finch W (2014) Supervised classification in the presence of misclassified training data: a Monte Carlo simulation study in the three group case. *Front Psychol* 5. <https://doi.org/10.3389/fpsyg.2014.00118>
3. Cohen G, Afshar S, Orchard G, Tapson J, Benosman R, Schaike A (2018) Spatial and temporal downsampling in event-based visual classification. *IEEE Trans Neural Netw Learn Syst* 29:5030–5044. <https://doi.org/10.1109/TNNLS.2017.2785272>
4. Waldner F, Jacques D, Löw F (2017) The impact of training class proportions on binary crop-land classification. *Remote Sens Lett* 8:1122–1131. <https://doi.org/10.1080/2150704X.2017.1362124>
5. Tatsumi K, Yamashiki Y, Torres M, Taipe C (2015) Crop classification of up-land fields using random forest of time-series Landsat 7 ETM+ data. *Comput Electron Agric* 115:171–179. <https://doi.org/10.1016/j.compag.2015.05.001>
6. Zhang C, Benz P, Argaw DM, Lee S, Kim J, Rameau F, Bazin JC, Kweon IS (2020) ResNet or DenseNet? Introducing dense shortcuts to ResNet. <https://doi.org/10.48550/arXiv.2010.12496>
7. Whitaker J (2021) Baseline Model. Kaggle. Accessed 4 Oct 2023. <https://kaggle.com/code/johnnowhitaker/baseline-model>
8. Lostanlen V, Palmer K, Knight E, Clark C, Klinck H, Farnsworth A, Wong T, Cramer J, Bello J (2019) Long-distance detection of bioacoustic events with per-channel energy normalization1. In: Proceedings of the detection and classification of acoustic scenes and events 2019. New York, NY, USA, pp 1–8
9. Abelson RP (1995) Statistics as principled argument. Lawrence Erlbaum Associates, Hillsdale, NJ
10. Klinck H, Dane S, Kahl S, Denton T (2023) BirdCLEF 2023. Kaggle. <https://kaggle.com/competitions/birdclef-2023>

# The Role of Traditional Leaders in Implementing Sustainable Smart Cities in Rural Municipalities



Nkhangweni Lawrence Mashau and Jan Hendrik Kroeze

**Abstract** As the implementation of smart cities continues to gain traction globally, the debate in the literature still focuses mostly on urban municipalities, ignoring rural municipalities. However, rural municipalities have unique challenges compared to urban municipalities. The implementation of sustainable smart cities in rural-based municipalities requires focused approaches to assess rural municipalities' resources and institutions. Moreover, in rural municipalities resources and institutions are controlled and managed by traditional leaders. There is a lot of literature that examines the development and implementation of smart cities. However, there is limited literature that explores the role of traditional leaders in the development of sustainable smart cities in rural municipalities. This study investigates the role of traditional leaders in the development of sustainable smart cities in rural municipalities. The study is carried out using a qualitative approach using interviews as the data collection instrument to explore the value that traditional leaders have in smart city initiatives in rural municipalities. Through this investigation, the study finds that traditional leaders must be involved from the beginning of smart city initiatives in order to resolve issues such as land rights and demarcation. Lastly, the findings of this study may provide valuable insights for policymakers, town and regional planners, and community stakeholders seeking to develop strategies to implement sustainable smart cities in rural municipalities.

**Keywords** Smart city · Traditional leaders · Sustainable city · Implementation · Rural municipality · Land rights · Strategic planning · Governance structures

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## 1 Introduction

Globally, most countries are engaging in smart city initiatives to address their economic and service delivery challenges posed by high population rates [1, 2]. In 2010, around 50% of the global population was residing in urban areas [2]. This number is expected to rise to 70% in the year 2025 [3]. The rise of the population presents more challenges, “such as providing housing, health, education, welfare, security as well as transport for its citizens” [4, 5]. These challenges will, furthermore, affect the economy and service delivery negatively [5, 6].

Therefore, there is a need for a solution that will transform rural municipalities and minimise the movement of people from rural areas to urban areas to seek greener pastures [5, 7]. Some scholars postulate that rural municipalities can be transformed through the implementation of smart cities [8, 9]. The term *smart city* is not novel globally and in the academic sphere since it has been around for more than three decades. It was invented in 1991 [10].

Rural municipalities can implement the smart city concept successfully if they ensure that the main components that are critical for smart city implementation are realised [11]. Furthermore, they have to engage key stakeholders from the inception of smart city initiatives to avoid any hiccups during the implementation phase [7, 11, 12]. Such setbacks may result in smart city project failure which will lead to economic and service delivery issues exacerbating [11].

In rural municipalities, traditional leaders are important stakeholders because they are usually respected and influential figures in the communities [13, 14]. Also known as chiefs, headmen or community heads, they play a significant role in rural governance. These leaders have indispensable knowledge of local customs, needs, land demarcation and governance structures [14].

The literature shows that traditional leaders can play a vital role in smart city implementation [15, 16]. The lack of traditional leaders' involvement from the onset may cause delays in smart city projects [15]. Although there is a need for smart leaders to implement a sustainable smart city [17], there is a lack of studies that explore the role of traditional leaders in the realisation of sustainable smart cities. Therefore, this study seeks to investigate the role of traditional leaders in implementing sustainable smart cities in rural municipalities.

## 2 Literature Review

### 2.1 Smart City Definition

In the academic domain, the smart city concept is not new; it is defined as an inventive approach that transforms a city to manage its infrastructure effectively [18]. Alternatively, the smart city concept is described as a city that uses advanced technologies

to allocate its resources [19, 20], or as the use of digital infrastructure to enhance service delivery in the city [6, 8].

The divergent definitions indicate a lack of consensus in the literature on the definition of a smart city concept. Guo et al. [21] indicate that there is a need for a clear definition that will make it easier for practitioners to understand this concept. In this study, the smart city concept is defined as a “digital integration of information systems components to collect digital data and analyse it in real-time in order to monitor and manage the city infrastructure and to allocate resources effectively, thereby improving service delivery and the quality of life of the citizens” [7].

## ***2.2 Sustainable Development of Rural Municipalities***

In rural municipalities, sustainable development encompasses the incorporation of economic, technological, environmental and social aspects to improve the lives of the citizens [11, 17]. The literature on rural sustainability underlines the significance of involving the community, managing local resources and having strategies that are focused specifically on rural municipalities [22, 23].

Furthermore, rural municipalities may transform their municipalities by implementing smart city technologies. This may assist in addressing issues of limited infrastructure, access to services and providing economic opportunities [24]. These technologies will assist municipalities in managing their limited infrastructure and allocating their resources effectively [3].

## ***2.3 Role of Leaders in Community Development***

Historically, traditional leaders play a crucial role in community development and governance in various spheres [11]. The literature points out the effect of traditional leaders as a mediator between local communities and formal state structures to promote social cohesion and ensure the buy-in of citizens on any smart city development initiatives [10, 25]. Their understanding of local dynamics, priorities, laws and needs makes them key stakeholders for any project in rural areas [26]. Their involvement is particularly crucial in rural areas where they often hold more influence than formal government representatives [11]. The literature further shows that traditional leaders in African countries can lead the initiative on technology adoption by mobilising community support [10, 25].

## 2.4 Smart City Initiatives

Examining previous smart city initiatives is significant because they can assist cities in avoiding the same mistakes made by other cities when engaging in smart city projects. A smart city initiative is when a municipality or city engages in a project to transform its city from a traditional city into a smart city [27]. Smart city initiatives are also called smart city projects and are often funded and supported by city municipalities [28]. Recently, most cities worldwide have engaged in smart city projects [24].

Smart cities are considered a global phenomenon since they have expanded throughout the world and produced similar interdependencies and features on a global level [29]. The present study views smart cities as a local phenomenon because each city is distinct and has different features, challenges, resources, policies and problems, requiring specific solutions for addressing them [30].

Cities are mostly engaged in smart city initiatives to address sustainability issues and to improve the quality of the lives of the city's inhabitants as well as the effectiveness of its services [6]. Thus far, most studies on smart city initiatives mainly focused on congested areas like big cities while excluding small suburbs, towns and rural areas [31].

In the past, most smart city initiatives focused on social elements and sustainability while paying less attention to information technology hardware and data [29]. Additionally, those initiatives followed top-down approaches to diffuse technology [17]. A city needs strong leaders like mayors with the vision and will to advocate for smart city strategies towards executing a smart city project [17, 26]. Most of such initiatives have also involved citizens because they are regarded as valuable and, therefore, must be able to access the improved services and systems [26]. Thus, to develop a competitive city, municipalities and public sector institutions are required to introduce a new way of management and the utilisation of innovations [32].

Moreover, a smart city initiative can be used as a mechanism with which to deal with cities' challenges (economic restructuring and energy shortages) posed by the increased population in cities [11]. These initiatives seem to differ around the world since modern cities have complicated ecosystems with different management of discrete economic, environmental and social issues [33, 34]. Most studies on smart city initiatives suggest that when addressing the challenges faced by municipalities, an ecosystem must be created, and public sector information must be reused to achieve smart city goals [3]. Furthermore, municipalities or cities aiming to ensure social and environmental sustainability should prioritise the innovation of ecosystems from traditional urban characteristics to modern urban characteristics in their smart city projects [35].

### **3 Research Methodology**

#### ***3.1 Research Design***

A research methodology is a plan that uses a specific procedure to accomplish and attain the desired results [36, 37]. According to Borgstede and Scholz [38], qualitative and quantitative approaches are key when investigating a problem. This study employed a qualitative research approach because of its suitability to understand complex problems.

#### ***3.2 Population and Sampling Technique***

The population for this study comprised participants from rural municipalities that belonged to two provinces in South Africa. These provinces were chosen because they had enough representation of rural municipalities [39]. To select municipalities, purposive sampling was used. To select the initial interviewees, purposive sampling was used. In addition, to identify more interviewees, snowball sampling was used in order to avoid being biased.

The literature is not conclusive in terms of sample size when employing an interview data collection instrument. Saunders [40] and Marshall et al. [41], postulate that a sample size between 5 and 25 is sufficient for a qualitative study. However, other studies indicate that when using interviews, the researcher is likely to reach saturation at participant number 12 [42]. In this study, the saturation point was reached at participant number 14. Therefore, in total, 14 participants were interviewed from rural municipalities.

#### ***3.3 Data Collection***

Data was gathered from March to September 2022 by means of semi-structured interviews. Each session took around 30 to 45 min. Before each interview session, permission to record was sought. All the participants agreed to be recorded and a digital recorder was used to record the interviews. Later on, all the audio recordings were transcribed using Microsoft Word.

### 3.4 Ethical Consideration

Ethical clearance was sought and approved by the University of South Africa, College of Science, Engineering and Technology's ethics review committee. The reference for ethical clearance is 2022/CSET/SOC/001.

## 4 Results and Discussion

In this study, five rural municipalities participated to provide their insight into the role of traditional leaders in the implementation of smart cities. In these municipalities, 14 participants were interviewed in order to solicit their experience regarding the role of traditional leaders or headmen in the implementation of smart cities in rural municipalities. In this section, P followed by a number refers to a specific participant.

One of the questions that were posed to participants was to identify key stakeholders in the implementation of smart cities. Therefore, interviewee respondents show that traditional leaders are one of the stakeholders or assessment measures in smart city development. Involving the traditional leaders may assist in alleviating resistance to change by the community because they will see that the projects are not aimed at the advantage of external institutions but are locally endorsed and beneficial. P3 said: "*Traditional leaders have to be used as one of the assessment criteria.*" P4 confirmed this sentiment: "*In my view, as a municipality, we need applications, digital infrastructure, sensors, citizens and not forgetting traditional leaders and data.*"

The research asked why traditional leaders are regarded as one of the main stakeholders. The interviewees highlighted that traditional leaders are regarded as the main stakeholders because they are the ones who own and manage the land in rural municipalities. Due to the ownership of land, interviewees saw it fit that they must be involved during the development of smart cities in these municipalities. P1 stated: "*As a municipality, we are very small and we are situated in the 'homelands' and we don't have that capacity.*" P4 amended this opinion: "*In small and rural municipalities, traditional leaders can bridge the gap between municipality authorities and local citizens to ensure that citizens know about smart city projects; they are also involved and supportive of smart city projects.*" P9 agreed: "*Traditional leaders can help to explain the benefits of a smart city and a long-term vision to the community and how the community will benefit from these initiatives.*"

The participants were probed to highlight the role that traditional leaders play in the implementation of rural municipalities. The interview data shows that traditional leaders can play a significant role in implementing smart city projects successfully in rural municipalities by acting as a link between municipal authorities and the citizens. P4 highlighted the fact that traditional leaders ensure that citizens are informed about and involved in these projects, fostering community support. P9 added that these

leaders can explain the value that the citizens will get after the implementation of a smart city.

Gurick and Felger [43] postulate that the authorities and community leaders encounter various challenges, such as budget and service levels, just to name a few, to resolve land claims. P13 mentioned an important issue in rural municipalities, which is land rights. The interviewee indicated that the involvement of traditional leaders from the start in a smart city project will resolve land disputes timely to avoid delays [15]. The interviewee also provided a practical example of a smart city project that has stopped due to land claims. P4 said: "*Traditional leaders are some of the stakeholders. For example, in our municipality, most of the land belongs to the traditional leaders. So, in everything we want to do, we have to engage them.*" P12 supported this notion: "*In our municipality, most of the land is owned by traditional leaders, yes I would say traditional leaders are critical.*" P13 also affirmed the phenomenon: "*Traditional leaders or headmen are crucial in smart development because they can assist in resolving land issues when necessary. For instance, a smart city project in this area was halted due to land claim disputes. If you examine the situation, it becomes clear that these leaders were not involved from the start of the project.*"

## 5 Conclusion

The aim of this study was to explore the role of traditional leaders in the implementation of a smart city in rural municipalities. This was achieved by collecting and analysing data from rural municipalities. This study found that traditional leaders must be involved in a smart city project from the onset because traditional leaders serve as a link between the citizens and the municipalities. Traditional leadership is key in getting citizens' buy-in in a smart city project. Traditional leaders are also crucial in resolving land claims between the municipalities and citizens. These findings will influence government officials and decision-makers to develop policies that ensure respect for traditional leaders and their regulating bodies, as well as collaboration with them. Involving these leaders should foster community engagement and resolve conflicts that may affect the success of smart city initiatives. Specific challenges traditional leaders might face in integrating smart city technologies into rural communities may be internal issues (e.g., resistance to change, cost implications and insufficient infrastructure) or external issues (e.g., legislation, administration and security barriers) [44].

A few limitations are acknowledged. The study employed a qualitative approach. In follow-up work, a quantitative approach could be used to confirm and support the results. Traditional leaders' awareness of the smart city concept can be investigated to equip them with the necessary knowledge to share with their citizens. Furthermore, researchers may conduct comparative analyses with case studies from other regions or countries to enrich the findings of this study [45, 46].

## References

1. Praharaj S, Han H (2019) Building a typology of the 100 smart cities in India. *Smart Sustain Built Environ* 8:400–414. <https://doi.org/10.1108/SASBE-04-2019-0056>
2. Dewi MAA, Hidayanto AN, Purwandari B, Kosandi M, Budi NFA (2018) Smart city readiness model using technology-organization-environment (TOE) framework and its effect on adoption decision. In: Proceedings of PACIS 2018. [https://www.semanticscholar.org/paper/Smart-City-Readiness-Model-Using-\(TOE\)-Framework-on-Dewi-Hidayanto/4d87cef9dc08c642b83b6d3383328b82a17748ad](https://www.semanticscholar.org/paper/Smart-City-Readiness-Model-Using-(TOE)-Framework-on-Dewi-Hidayanto/4d87cef9dc08c642b83b6d3383328b82a17748ad), [https://www.researchgate.net/publication/325527825\\_Smart\\_City\\_Readiness\\_Model\\_based\\_on\\_Technology-Organization-Environment\\_TOE\\_Framework\\_and\\_Its\\_Effect\\_on\\_Adoption\\_Decision\\_Completed\\_Research\\_Paper](https://www.researchgate.net/publication/325527825_Smart_City_Readiness_Model_based_on_Technology-Organization-Environment_TOE_Framework_and_Its_Effect_on_Adoption_Decision_Completed_Research_Paper)
3. Ibrahim M, El-Zaart A, Adams C (2018) Smart sustainable cities roadmap: readiness for transformation towards urban sustainability. *Sustain Cities Soc* 60:530–540. <https://doi.org/10.1016/j.scs.2017.10.008>
4. Eremia M, Toma L, Sanduleac M (2017) The smart city concept in the 21st century. In: 10th international conference interdisciplinarity in engineering, INTER-ENG 2016. Procedia Eng 12–19. <https://doi.org/10.1016/j.proeng.2017.02.357>.
5. Desdemouster J, Crutzen N, Cools M, Teller J (2019) Smart city appropriation by local actors: an instrument in the making. *Cities* 92:175–186. <https://doi.org/10.1016/J.CITIES.2019.03.021>
6. Desdemouster J, Crutzen N, Giffinger R (2019) Municipalities' understanding of the smart city concept: an exploratory analysis in Belgium. *Technol Forecast Soc Change* 142:129–141. <https://doi.org/10.1016/j.techfore.2018.10.029>
7. Mashau NL, Kroese JH, Howard GR (2021) An integrated conceptual framework to assess small and rural municipalities' readiness for smart city implementation: a systematic literature review. In: Lecture Notes in Computer Science, vol 13117. Springer Science and Business Media Deutschland GmbH, pp 262–273. [https://doi.org/10.1007/978-3-030-91540-7\\_28](https://doi.org/10.1007/978-3-030-91540-7_28)
8. Arief A, Abbas MY, Wahab IHA, Latif LA, Abdullah SD, Sensuse DI (2019) The smart islands vision: towards smart city readiness in local government of Archipelagos. *J Phys Conf Ser* 1569:42006. <https://doi.org/10.1088/1742-6596/1569/4/042006>
9. Bustos RR, Sánchez-Ortiz V (2018) Assessment of e-government services offered by local governments in Chile. *RELCASI* 10(5). <https://doi.org/10.17705/1relc.00055>
10. Dameri RP (2013) Searching for smart city definition: a comprehensive proposal. *Int J Comput Technol* 11:2544–2551. <https://doi.org/10.24297/ijct.v11i5.1142>
11. Mashau NL, Kroese JH, Howard GR (2022) Key factors for assessing small and rural municipalities' readiness for smart city implementation. *Smart Cities* 5:1742–1751. <https://doi.org/10.3390/smartcities5040087>
12. Berst J, Enbysk L, Caine C, Williams C, Davis T (2014) Smart cities readiness guide: the planning manual for building tomorrow's cities today. Smart Cities Council, Seattle. <https://www.rinnovabiliti.it/wp-content/uploads/2013/12/SmartCitiesCouncil-ReadinessGuide.pdf>
13. Adams P, Malephane L (2020) Citizens endorse traditional leaders, see greater role in contemporary Lesotho. Afrobarom Dispatch 1–8. [https://www.afrobarometer.org/wp-content/uploads/2022/02/ad413-basotho\\_endorse\\_greater\\_role\\_for\\_traditional\\_leaders-afrobarometer\\_dispatch-19dec20.pdf](https://www.afrobarometer.org/wp-content/uploads/2022/02/ad413-basotho_endorse_greater_role_for_traditional_leaders-afrobarometer_dispatch-19dec20.pdf)
14. Ramolobe KS (2023) The dynamics of traditional leaders' relationship with municipal councillors and service delivery. *J Local Gov Res Innov* 4:1–7. <https://doi.org/10.4102/jolgr.v4i0.95>
15. Žofčinová V, Čajková A, Král R (2022) Local leader and the labour law position in the context of the smart city concept through the optics of the EU. *TalTech J Eur Stud* 12:3–26. <https://doi.org/10.2478/BJES-2022-0001>
16. Schiavo FT, de Magalhães CF (2022) Smart sustainable cities: the essentials for managers' and leaders' initiatives within the complex context of differing definitions and assessments. *Smart Cities* 5:994–1024. <https://doi.org/10.3390/smartcities5030050>

17. Enwereji PC, Uwizeyimana D (2022) Smart city readiness in South African municipalities: a qualitative study. *HOLISTICA J Bus Public Adm* 13:93–109. <https://doi.org/10.2478/HJBPA-2022-0006>
18. Cilliers L, Flowerday S, McLean S (2016) A crowdsourcing, smart city model for a developing country. In: International conference on information resources management (CONF-IRM), pp 74–87. <https://aisel.aisnet.org/confirm2016/74>
19. Mahesa R, Yudoko G, Anggoro Y (2019) Dataset on the sustainable smart city development in Indonesia. *Data Br* 25:1–6. <https://doi.org/10.1016/j.dib.2019.104098>
20. Przybilowicz E, Cunha MA, Macaya JFM, de Albuquerque JP (2018) A tale of two “smart cities”: investigating the echoes of new public management and governance discourses in smart city projects in Brazil. In: Proceedings of the 51st Hawaii international conference on system sciences, pp 2486–2495. [https://www.researchgate.net/publication/322337516\\_A\\_Tale\\_of\\_two\\_Smart\\_Cities\\_Investigating\\_the\\_Echoes\\_of\\_New\\_Public\\_Management\\_and\\_Governance\\_Discourses\\_in\\_Smart\\_City\\_Projects\\_in\\_Brazil](https://www.researchgate.net/publication/322337516_A_Tale_of_two_Smart_Cities_Investigating_the_Echoes_of_New_Public_Management_and_Governance_Discourses_in_Smart_City_Projects_in_Brazil)
21. Guo K, Lu Y, Gao H, Cao R (2018) Artificial intelligence-based semantic internet of things in a user-centric smart city. *Sensors* 18:1341. <https://doi.org/10.3390/s18051341>
22. Ranchod R (2020) The data-technology nexus in South African secondary cities: the challenges to smart governance. 57:3281–3298. <https://doi.org/10.1177/0042098019896974>
23. Mashau NL, Kroeze JH (2023) Challenges that affect smart city implementation in small and rural municipalities. *SA J Inf Manag* 25:1–6. <https://doi.org/10.4102/SAJIM.V25I1.1703>
24. Das DK (2020) Perspectives of smart cities in South Africa through applied systems analysis approach: a case of Bloemfontein. *Constr Econ Build* 20:65–88. <https://doi.org/10.5130/AJCEB.v20i2.6657>
25. Musakwa W, Mokoena BT (2018) Smart cities in South Africa! A case of misplaced priorities? *Comput Urban Plan Urban Manag* 1–16. [https://www.researchgate.net/publication/326711215\\_Smart\\_cities\\_in\\_South\\_Africa\\_A\\_case\\_of\\_misplaced\\_priorities](https://www.researchgate.net/publication/326711215_Smart_cities_in_South_Africa_A_case_of_misplaced_priorities)
26. Scholtz B, Van Der Hoogen A (2022) Access to technology and data in smart cities for South African digital citizens. In: The 8th African conference on information systems and technology proceedings, pp 1–17. <https://digitalcommons.kennesaw.edu/acist/2022/presentations/3>
27. Zhang F, Lee VE, Jin R, Garg S, Choo K-KR, Maasberg M, Dong L, Cheng C (2019) Privacy-aware smart city: a case study in collaborative filtering recommender systems. *J Parallel Distrib Comput* 127:145–159. <https://doi.org/10.1016/j.jpdc.2017.12.015>
28. Hyllová L, Slach O (2018) The smart city is landing! On the geography of policy mobility. *GeoScape* 12:124–133. <https://doi.org/10.2478/geosc-2018-0013>
29. Dameri RP, Ricciardi F (2015) Smart city intellectual capital: an emerging view of territorial systems innovation management. *J Intellect Cap* 16:860–887. <https://doi.org/10.1108/JIC-02-2015-0018>
30. Supangkat SH, Arman AA, Nugraha RA, Fatimah YA (2018) The implementation of Garuda smart city framework for smart city readiness mapping in Indonesia. *J Asia Pacific Stud* 32:169–176. <https://core.ac.uk/download/pdf/286959071.pdf>
31. Hosseini S, Frank L, Fridgen G, Heger S (2018) Do not forget about smart towns: how to bring customized digital innovation to rural areas. *Bus Inf Syst Eng* 60:243–257. <https://doi.org/10.1007/s12599-018-0536-2>
32. Mazurek C, Stroinski M (2019) Common data and technological partnership—the foundation for the development of smart cities—Poznań case study. In: Proceedings of the 52nd Hawaii international conference on system sciences, pp 7390–7398. [https://www.researchgate.net/publication/332088408\\_Common\\_Data\\_and\\_Technological\\_Partnership\\_-\\_The\\_Foundation\\_for\\_the\\_Development\\_of\\_Smart\\_Cities\\_-\\_Poznan\\_Case\\_Stud](https://www.researchgate.net/publication/332088408_Common_Data_and_Technological_Partnership_-_The_Foundation_for_the_Development_of_Smart_Cities_-_Poznan_Case_Stud)
33. Adapa S (2018) Indian smart cities and cleaner production initiatives—integrated framework and recommendations. *J Clean Prod* 172:3351–3366. <https://doi.org/10.1016/J.JCLEPRO.2017.11.250>
34. Bibri SE (2021) Data-driven smart eco-cities and sustainable integrated districts: a best-evidence synthesis approach to an extensive literature review. *Eur J Futur Res* 9. <https://doi.org/10.1186/S40309-021-00181-4>

35. Maye D (2019) ‘Smart food city’: Conceptual relations between smart city planning, urban food systems and innovation theory. *City Cult Soc* 16:18–24. <https://doi.org/10.1016/j.ccs.2017.12.001>
36. Saunders M, Lewis P, Thornhill A (2019) Research methods for business students. Pearson Education Limited, New York
37. Crotty MJ (1998) The foundation of social research. Sage Publications, London, New Delhi
38. Borgstede M, Scholz M (2021) Quantitative and qualitative approaches to generalization and replication—a representationalist view. *Front Psychol* 12:1–9. <https://doi.org/10.3389/FPSYG.2021.605191/BIBTEX>
39. Municipal Demarcation Board. (2018). Municipal Powers and Functions Capacity Assessment 2018: National Report, p 189. <https://www.demarcation.org.za/wp-content/uploads/2021/07/National-draft-FINAL-FINAL-1.pdf>
40. Saunders MNK, Tosey P (2012) The layers of research design. *Rapp Mag NLP Prof* 14:58–59. [https://www.academia.edu/4107831/The\\_Layers\\_of\\_Research\\_Design](https://www.academia.edu/4107831/The_Layers_of_Research_Design)
41. Marshall B, Cardon P, Poddar A, Fontenot R (2013) Does sample size matter in qualitative research?: a review of qualitative interviews in is research. *J Comput Inf Syst* 54:11–22. <https://doi.org/10.1080/08874417.2013.11645667>
42. Constantinou CS, Georgiou M, Perdikogianni M (2017) A comparative method for themes saturation (CoMeTS) in qualitative interviews. *Qual Res* 17:571–588. <https://doi.org/10.1177/1468794116686650>
43. Gurick M, Felger S (2022) Organisation and community intelligence in smart city leadership and beyond. *IET Smart Cities* 4:47–55. <https://doi.org/10.1049/smcc2.12022>
44. Ševčík M, Chaloupková M, Zourková I, Janošková L (2022) Barriers to the implementation of smart projects in rural areas, small towns, and the city in Brno metropolitan area. *Eur Countrys* 14:675–695. <https://doi.org/10.2478/EUCO-2022-0034>
45. Schwarz-Herion O (2019) The role of smart cities for the realization of the sustainable development goals. In: Omran A, Schwarz-Herion O (eds) *Sustaining our environment for better future: challenges and opportunities*. Springer, Singapore, pp 209–257. [https://doi.org/10.1007/978-981-13-7158-5\\_13](https://doi.org/10.1007/978-981-13-7158-5_13)
46. Zavratnik V, Podjed D, Trilar J, Hlebec N, Kos A, Duh ES (2020) Sustainable and community-centred development of smart cities and villages. *Sustainability* 12:1–17. <https://doi.org/10.3390/SU12103961>

# Enhancing University Sustainability Through Eduinformatics: A Collaborative Approach to Resolving Common Management Issues from a Macro Perspective



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**Abstract** The sustainability of universities has become a pressing concern worldwide, particularly in Japan, where the declining 18-year-old population has led to a significant decrease in university applicants. This paper argues that to enhance the sustainability of universities, it is essential to incorporate a “realistic perspective” of “advanced management” alongside the pursuit of educational ideals. Drawing on the principles of Eduinformatics and the UNESCO learning analytics framework, we propose a collaborative approach that leverages the expertise of external partners, such as education companies, to support the resolution of common management issues faced by multiple universities from a macro perspective. By fostering collaboration between faculty and staff, optimizing workflows, and engaging in strategic decision-making, universities can navigate the complexities of the modern educational landscape and develop innovative solutions to sustainability challenges. Our

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findings underscore the importance of embracing a multi-level perspective that integrates the micro, meso, and macro levels of learning analytics, with a particular emphasis on the macro level. We argue that by partnering with education companies, universities can benefit from their management expertise and gain valuable insights into emerging trends and best practices, ultimately contributing to the long-term sustainability of higher education institutions in the face of unprecedented challenges.

**Keywords** Eduinformatics · Sustainability · University management · Learning analytics · Collaboration

## 1 Introduction

### 1.1 *Transition Motive for Universities*

In Japan, the 18-year-old population has been rapidly declining. This is not only a problem in Japan but also in countries such as Hong Kong, Germany, South Korea, and Portugal, making it a global issue [1]. In Japan, the 18-year-old population began to decrease after peaking at 2.49 million in 1966, and although it temporarily recovered, the decline resumed in 1993 [1]. According to the latest data for the 2023 academic year, at the time this paper is being penned, the 18-year-old population has reduced to 1.1 million, 44% of its peak population [1]. As a result, in recent years, the number of university enrollees and the university's enrollment capacity have become almost equal, and prospective university students can now definitely enroll in a university if they do not choose a specific one. From the perspective of universities, many institutions are facing a situation where the number of applicants has significantly shrunk, and they can no longer select the candidates. The universities have necessitated the transition to a more sustainable model.

The concept of sustainability has become a crucial keyword in recent years. In fact, sustainability is one of the main themes of this international conference, the World Conference on Smart Trends in Systems, Security, and Sustainability. Undoubtedly, this is the foundational notion that the higher education institutes today ought to embrace in such a predicament of contemporary Japan, where universities face a highly difficult challenge in terms of managing their institutions in a sustainable manner. In other words, the pressing issue in Japanese higher education is the sustainability of universities.

## 1.2 *Eduinformatics*

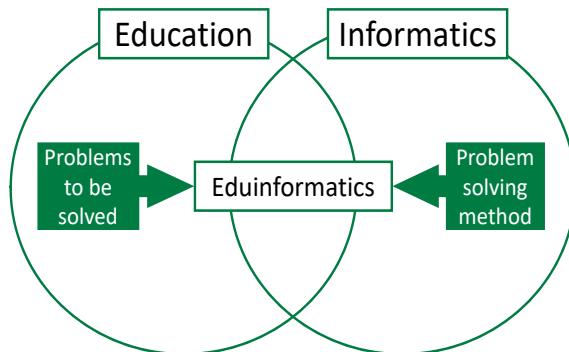
In 2018, our research team introduced a pioneering interdisciplinary field called *Eduinformatics*, as reported in [2]. This innovative domain emerges at the intersection of informatics and education, aiming to tackle the growing challenges in educational sectors by harnessing the advanced methodological approaches that stem from informatics, which significantly enhance problem-solving capabilities [3] (see Fig. 1).

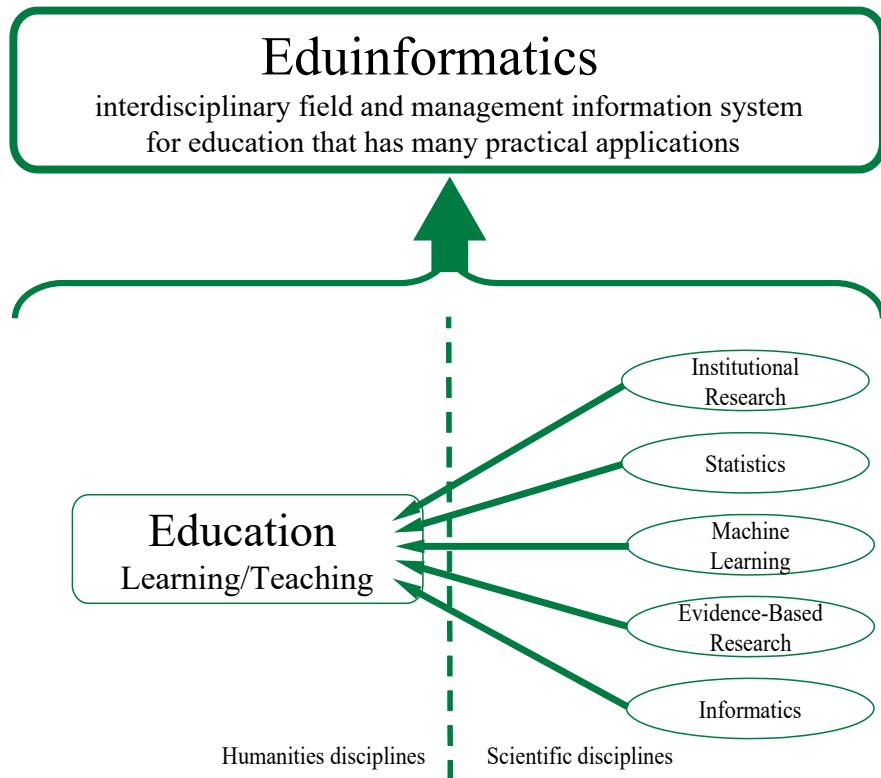
The foundational concept of Eduinformatics bridges the gap between Humanities and Sciences (Fig. 2). Research suggests that the application of Eduinformatics in higher education can lead to elevated educational quality for students, as evidenced by previously published studies [3–6].

Specifically, we introduce a novel framework that integrates digital transformation, institutional research, and information and communication technology, grounded in the principles of Eduinformatics—a nascent interdisciplinary realm that combines informatics and education [7]. By analyzing student data assisted by developing innovative analytical methods, Eduinformatics aims to redefine higher education through the convergence of digital transformation and educational practices. Employing an example of a Japanese university as a case study, we illustrate how Eduinformatics serves as the crucial link connecting digital transformation, information, and communication technology, and institutional research within the higher education landscape, ultimately leading to the refinement and advancement of educational practices and outcomes.

We have presented our research findings at the ICICT conferences from 2021 to 2024 [8–11], and at the WS4 conferences from 2021 to 2023, all of which were based on the principles of Eduinformatics [4, 5, 12].

**Fig. 1** The concept of eduinformatics from Takamatsu [2]





**Fig. 2** Concept of eduinformatics: eduinformatics combines humanities and scientific discipline (from Takamatsu [2])

### 1.3 Research Question

From the perspective of university management, the era where students spontaneously gathered if the university provided high-quality and meaningful “ideal” education has come to an end. Universities must now incorporate a more “advanced management” approach with a “realistic perspective” to attract students, or they will no longer be able to sustain themselves as educational institutions.

This paper discusses methods for Japanese universities, which are currently facing such a challenging circumstance, to achieve growth as more sustainable institutions by incorporating a “realistic perspective” rather than simply discussing ideals.

Based on this, we set our Research Question as follows:

How can we enhance the sustainability of universities?

## 2 Referring to Environmental Issues and Discussing the Sustainability of the University

### 2.1 Example of Environmental Issues

The concept of sustainability appears in various fields. One example that immediately comes to mind is environmental issues. There are global efforts to protect the Earth's environment in a sustainable fashion, such as countermeasures against global warming. These endeavors are represented by the "Conference of the Parties to the United Nations Framework Convention on Climate Change," including the Kyoto Protocol and the Paris Agreement.

The Kyoto Protocol was an agreement reached at COP3 held in Kyoto in December 1997, where 161 participating countries agreed to work toward reducing greenhouse gases during the period from 2008 to 2012 [13].

Originally, the "United Nations Framework Convention on Climate Change" was created at the "Earth Summit" (officially known as the United Nations Conference on Environment and Development) held in Rio de Janeiro, Brazil, in 1992. It was decided that specific measures to combat global warming would be determined at the annual "Conference of the Parties to the United Nations Framework Convention on Climate Change" (hereinafter referred to as COP) starting from 1995. The Kyoto Protocol was actually created at the third COP (1997).

The Kyoto Protocol set a target for developed countries as a whole to reduce each greenhouse gas by at least 5% from the base year (either 1990 or 1995, depending on the type of gas) during the period from 2008 to 2012. Adherence to this target was mandatory, and penalties were imposed on developed countries that failed to meet the criteria. However, measures to achieve the target were also introduced, known as the "Kyoto Mechanisms."

The "Kyoto Mechanisms" allowed countries to trade the amount of greenhouse gas reductions achieved in other countries and convert them into their own emission reduction targets. The purpose was to make it more feasible for countries to achieve their goals when domestic measures alone were insufficient. This incorporated a "realistic perspective" toward achieving the "ideal" of greenhouse gas reduction targets. As a result, during the first commitment period from 2008 to 2012, 11 out of the 23 developed countries that were parties to the protocol achieved their targets. When the Kyoto Mechanisms and absorption by forest management were taken into account, all participating countries achieved their targets.

The Kyoto Protocol was later transformed into the Paris Agreement at COP21 held in Paris in 2015 [14]. While the Kyoto Protocol set global warming countermeasure targets until 2020, the Paris Agreement outlined the framework for the post-2020 period, succeeding the Kyoto Protocol. The Paris Agreement also introduced the use of market mechanisms, utilizing a bilateral credit system.

The above example demonstrates that sustainability in environmental issues incorporates not only ideals but also economic perspectives.

Could the same situation apply to higher education? In the “Grand Design for Higher Education toward 2040” report released by the Central Council for Education in November 2018, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) [15] called for governance reforms in school management with an unprecedented tone, stating that “in the future, stronger guidance will be provided to school corporations to improve management, and guidance will be given to encourage early and appropriate management decisions, including withdrawal, in cases of management difficulties.”

The percentage of private universities unable to meet their enrollment capacity has exceeded 50% for the first time in the academic year 2023/24, as they struggle to attract applicants by merely promoting “ideal” education. This situation highlights the need to incorporate a “realistic perspective” of “advanced management” rather than solely pursuing “ideals”.

In the same report [15], the Central Council for Education argues that “it is necessary to strengthen the management functions and business capabilities of each university through the analysis of educational, research, and financial information.” This emphasizes the necessity of promoting university institutional research (IR).

One of the keys to answering the Research Question is likely the concept of Eduinformatics, introduced in the background section.

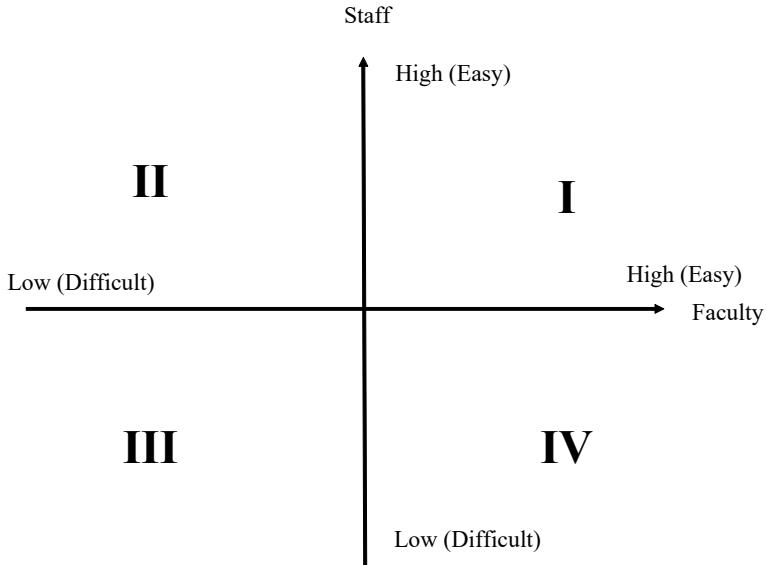
## 2.2 *Eduinformatics and UNESCO’s Learning Analytics Framework*

According to our co-author, a specialist in Eduinformatics, analyzing the first, second, and fourth quadrants of the following UNESCO’s learning analytics framework at the macro, meso, and micro levels concludes that close collaboration between university faculty and staff is essential for analyzing and utilizing data to improve university management and education at the meso level [16].

In 2012, the United Nations Educational, Scientific and Cultural Organization (UNESCO) put forward a three-tier model for learning analytics [17] (Fig. 3). The tiers are characterized as follows:

Macro-level analytics facilitate cross-institutional examinations via surveys of existing practices [18] or improved access to standardized evaluation data spanning students’ academic trajectories. These analytics progressively assimilate real-time data from the meso and micro tiers and could gain from benchmarking and data integration strategies developed in sectors outside education. Nevertheless, apprehensions emerge concerning the perils of decontextualized data and the educational paradigms they may perpetuate.

Meso-level analytics operate at the organizational echelon, positioning educational institutions as a novel Business Intelligence (BI) market segment. They harness BI tools to amalgamate data silos, rationalize workflows, generate dashboards, excavate unstructured data, and anticipate customer attrition and future markets. The BI



**Fig. 3** The separation of data access between faculty and staff: challenges in utilizing information in universities from the perspective of UNESCO’s three-tier learning analytics hierarchy from Takamatsu [16]

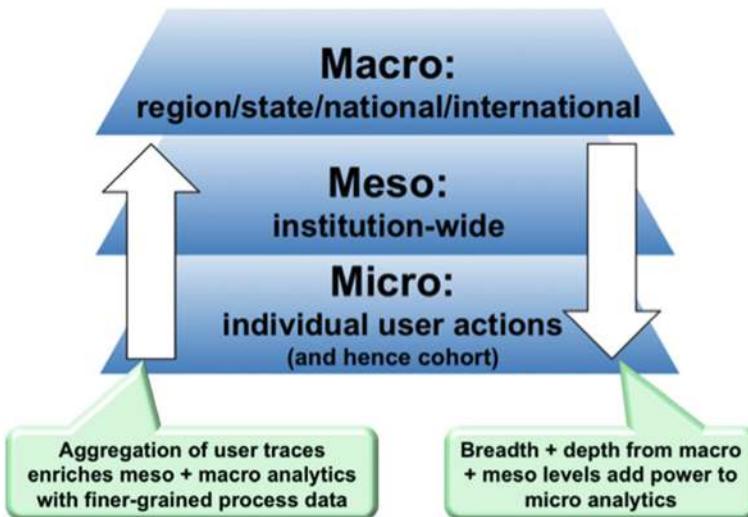
imperative to streamline business processes partially propels endeavors to construct institution-level “academic analytics” [19], with communities of practice materializing explicitly for BI within educational entities, each possessing their distinct cultures and legacy technologies (Fig. 4).

Micro-level analytics empower the monitoring and interpretation of process-level data for individual learners and cohorts. This data holds paramount significance for learners and those accountable for their success, as it delivers the most granular insights, ideally in real-time. However, this data is also the most confidential, potentially divulging online activity, physical activity, library loans, purchases, and interpersonal data such as social networks.

To manipulate these data, researchers adapt techniques from sundry disciplines: serious gaming, automated marking, educational data mining, computer-supported collaborative learning, recommender systems, intelligent tutoring systems/adaptive hypermedia, information visualization, computational linguistics, argumentation, and social network analysis.

It is crucial to bring together the perspectives of both university faculty at the micro level, who engage in “ideal” educational practices using data, and university staff at the meso level, who analyze data. Moreover, it is important to incorporate a “realistic perspective” of “advanced management” and collaborate with each other.

Furthermore, the First Author is not an internal member of a university but rather an individual from a company involved in the education industry, capable of viewing



**Fig. 4** Layers of learning analytics by UNESCO IITE from UNESCO [17]

universities from an external perspective. This position allows them to possess a macro perspective within UNESCO's learning analytics framework.

By collaborating with multiple universities, sharing micro- and meso-level data, and analyzing them, there may be ways to support the resolution of common management issues faced by many universities from a macro perspective. From the point of view of a personnel from an external company, it can be advocated that they might be able to incorporate a "realistic perspective" of "advanced management."

Universities could also have the option of incorporating the perspectives of such external collaborators to make strategic decisions.

### 3 Conclusion

At this point, we restate our Research Question here:

How can we enhance the sustainability of universities?

In conclusion, by collaborating with multiple universities and applying the principles of Eduinformatics, we can support the resolution of common management issues faced by many institutions from a macro perspective, ultimately enhancing the sustainability of universities in the face of the challenges of the twenty-first century.

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## References

1. MEXT Reference material 1 collection of reference data. Special committee on the state of higher education (1st session)–distributed materials. <https://www.mext.go.jp/kaigisiryo/content/000262485.pdf>. Accessed 1 May 2024
2. Takamatsu K, Murakami K, Kirimura T, Bannaka K, Noda I, Wei LRJ, Mitsunari K, Seki M, Matsumoto E, Bohgaki M, Imanishi A, Omori M, Adachi R, Yamasaki M, Sakamoto H, Takao K, Asahi J, Nakamura T, Nakata Y (2018) “Eduinformatics”: a new education field promotion. Bull Kobe Toki Univ 11:27–44. <https://doi.org/10.20608/00000958>
3. Takamatsu K, Kozaki Y, Murakami K, Sugiura A, Bannaka K, Mitsunari K, Omori M, Nakata Y (2019) Review of recent eduinformatics research. IEEE/IIAI Int Congr Appl Inf Technol 2019:27–32. <https://doi.org/10.1109/AIT49014.2019.9144820>
4. Takamatsu K, Noda I, Bannaka K, Murakami K, Kozaki Y, Kishida A, Kabutoya H, Mitsunari K, Adachi R, Omori M, Nakata Y (2023) Sustainability of digital transformation (DX), institutional research (IR), and information and communication technology (ICT) in higher education based on eduinformatics. In: Intelligent sustainable systems selected papers of WorldS4 2022, vol 1. Springer Nature, pp 565–572. [https://doi.org/10.1007/978-981-19-7660-5\\_49](https://doi.org/10.1007/978-981-19-7660-5_49)
5. Takamatsu K, Noda I, Bannaka K, Murakami K, Kirimura T, Kunisaki T, Kozaki R, Matsumoto S, Kishida A, Ito H, Ito A, Imai S, Mitsunari K, Omori M, Mori M, Nakata Y (2024) Abduction, abstract degree and urgency matrix (abdu-m) for flexible/agile higher education reform based on eduinformatics. In: Intelligent sustainable systems selected papers of WorldS4 2023 (in press)
6. Takamatsu K, Gozu T, Kozaki R, Matsumoto S, Konso M, Nishiyama K, Ichikawa N, Murakami K, Kozaki Y, Mori M, Imai S, Noda I, Bannaka K, Mitsunari K, Nakata Y (2022) Combining key performance indicators and signs of changes in students to improve the quality of education in institutional research based on eduinformatics. IIAI Lett Inst Res 2:1–9. <https://doi.org/10.52731/lir.v002.052>
7. Takamatsu K, Noda I, Bannaka K, Murakami K, Kozaki Y, Mitsunari K, Omori M, Nakata Y (2023) A new concept of digital transformation,institutional research, and information and communication technology in higher education based on eduinformatics. In: Proceedings of seventh international congress on information and communication technology. Springer Nature, pp 233–224
8. Takamatsu K, Noda I, Bannaka K, Nakagawa T, Kozaki Y, Mitsunari K, Omori M, Adachi R, Nakata Y (2021) Concept of ICT on eduinformatics in higher education. In: Proceedings of sixth international congress on information and communication technology: ICICT 2021, London, vol 1 (Lecture Notes in Networks and Systems Book 235). Springer Nature, pp 693–700. [https://doi.org/10.1007/978-981-16-2377-6\\_64](https://doi.org/10.1007/978-981-16-2377-6_64)
9. Takamatsu K, Noda I, Bannaka K, Murakami K, Kozaki Y, Mitsunari K, Omori M, Nakata Y (2022) A new concept of digital transformation,institutional research, and information and communication technology in higher education based on eduinformatics.In: Intelligent sustainable systems: selected papers of WorldS4 2022. Nature Springer (in press)
10. Nakata Y, Bannaka K, Noda I, Murakami K, Kozaki Y, Mitsunari K, Omori M, Takamatsu K (2024) A new concept of data-driven education based on eduinformatics. In: Proceedings of eight International congress on Information and communication technology: ICICT2023, London,vol 4. Springer Nature, pp 729–735
11. Takamatsu K, Noda I, Sakai T, Kozaki Y, Bannaka K, Matsumoto S, Kozaki R, Itoh A, Gozu T, Nakata Y (2023) Novel QR code-based hybrid knowledge graph note (QrKno) system: transforming higher education with the knowledge network tag model and LMS, based on eduinformatics. In: Proceedings of 9th international congress on information and communication technology ICICT 2024. Springer Nature (in press)
12. Takamatsu K, Katsuhiko M, Kozaki Y, Bannaka K, Noda I, Mitsunari K, Omori M, Nakata Y (2022) Eduinformatics: a new academic field needed in the age of information and communication technology. intelligent sustainable systems: selected papers of WorldS4 2021, vol 1

- (Lecture Notes in Networks and Systems Book 333). Springer Nature, pp 139–147. [https://doi.org/10.1007/978-981-16-6309-3\\_15](https://doi.org/10.1007/978-981-16-6309-3_15)
- 13. United Nations (1998) Kyoto protocol to the United Nations framework convention on climate change. <https://unfccc.int/resource/docs/convkp/kpeng.pdf>. Accessed 1 May 2024
  - 14. United Nations (2015) Paris agreement. [https://unfccc.int/files/essential\\_background/convention/application/pdf/english\\_paris\\_agreement.pdf](https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf). Accessed 1 May 2024
  - 15. MEXT (2018) Grand design for higher education toward 2040. [https://www.mext.go.jp/component/b\\_menu/shingi/toushin/\\_icsFiles/afieldfile/2018/12/17/1411360\\_7\\_2.pdf](https://www.mext.go.jp/component/b_menu/shingi/toushin/_icsFiles/afieldfile/2018/12/17/1411360_7_2.pdf). Accessed 1 May 2024
  - 16. Takamatsu K, Matsumoto S, Shiratori N, Noda I, Tajiri S, Bannaka K, Kozaki Y, Ito H, Imai S, Nakata Y, Mori M (2024) Beyond silos: eduinformatics as a catalyst for dissolving faculty and staff boundaries in higher education. IIAI Lett Inst Res 5 (in press)
  - 17. UNESCO (2012) Learning analytics
  - 18. Norris D, Baer L, Leonard J, Pugliese L, Lefrere P (2008) Action analytics: measuring and improving performance that matters in higher education. EDUCAUSE Rev 43:42
  - 19. Campbell JP, DeBlois PB, Oblinger DG (2007) Academic analytics: a new tool for a new era. EDUCAUSE Rev 42:40

# The Impact of the Corporate Sustainability Reporting Directive (CSRD) on Software Companies—A Survey



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**Abstract** Today, companies face the growing challenge of not only achieving economic success but also assuming sustainability in the context of ESG (Environmental, Social, and Governance). The Corporate Sustainability Reporting Directive (CSRD), an initiative of the European Union (EU), aims to ensure that companies transparently disclose their sustainability efforts in annual reports. This survey study seeks to take a view on the perceptions of sustainability among software companies within the EU with a focus on their preparation status for the CSRD. For this purpose, we investigated 86 software companies from 19 different EU countries. Our findings show that software companies assess their current state of sustainability efforts as moderate and are yet barely acquainted with the CSRD. They recognize opportunities in sustainable development, particularly in adopting more sustainable business policies as well as the increase of business transparency and reputation in the public. However, they also identify challenges, especially in terms of potential additional financial and personnel costs as well as continuous changes in information and auditing standards.

**Keywords** Corporate sustainability reporting directive CSRD · Sustainability reporting · Sustainable software engineering · Software industry

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## 1 Introduction

In recent years, the convergence of technology and sustainability has emerged as a focal point of discourse within the global business community, catalyzing a paradigm shift towards more socially and environmentally sustainable practices [1]. At the forefront of this transition lie regulatory initiatives aimed at enhancing transparency, accountability, and stakeholder engagement in sustainability reporting [2]. Among these, the Corporate Sustainability Reporting Directive (CSRD),<sup>1</sup> introduced by the European Union (EU), stands as a pivotal intervention shaping the sustainability landscape for companies operating within its jurisdiction [3]. While the CSRD represents a landmark development in the EU's sustainability agenda, its implications for the software industry warrant particular attention. As engines of innovation and enablers of digital transformation across diverse sectors, software companies occupy a unique position because software systems become more and more embedded in socioeconomic and natural systems whereas the influences of those boundaries are not easy to identify [4].

This article explores the impact of the CSRD on software companies. Therefore, our research question (RQ) is: What impact does the implementation of the CSRD have on the sustainability endeavors of software companies? Our aim is to promote interdisciplinary dialogue and the exchange of knowledge between science, industry, and politics to contribute in finding ways towards a more sustainable digital future.

Our survey results reveal that software companies face significant changes in implementing the CSRD. While the CSRD is seen as a key driver for sustainable business practices, it leads to additional financial and personnel costs. The Haufe Group, a German B2B provider of integrated business and workplace solutions, estimates annual expenses of up to €100,000 per company that comes along with the CSRD [5]. It is estimated that by the year 2029, 50,000 companies will be required to write, review, and publish sustainability reports, compelling them to address sustainability issues comprehensively. Our findings underline that companies are still in a discovery phase, with increased awareness of the importance of sustainability in the business landscape.

## 2 Background

In this section, we first discuss current sustainability reporting practices followed by an overview of the challenges the software industry encounters when combining sustainability and software engineering.

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<sup>1</sup> <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022L2464> (last accessed 2024/06/09).

Currently, sustainability reporting experiences a shift from voluntary reporting standards towards mandatory standards. Two directives take center stage within the EU: the Sustainable Finance Disclosure Regulation (SFDR)<sup>2</sup> and the CSRD.

The SFDR was introduced by the EU in 2019 and aims to create transparency of financial products and their sustainability risks, which is particularly important for investors. The SFDR forces the obligation on the financial service sector to publish transparent information about sustainable financial services and sustainable financing [6]. The CSRD came into force in 2023 and is the further development of the Non-Financial Report Directive (NFRD), which was criticized for its lack of comparability, reliability and relevance of the non-financial information provided. CSRD is one of the cornerstones of the European Green Deal that was introduced to foster direct financial and capital flows to sustainable investment and should provide improved data availability and disclosure of non-financial information [7, 8]. CSRD emphasizes corporate sustainability reporting, providing investors and other stakeholders with a sound basis for their decisions. Companies have to include relevant, reliable, comparable and verifiable ESG (Environmental, Social, Governance) information and report based on double materiality—meaning that they have to report about their impact of the company and its value chain on environment, humans and society (impact materiality), as well as identifying and evaluating sustainability factors and its risk and opportunities that can impact the company and its value chain (financial materiality). ESG topics only need to be reported if they are identified as material in a materiality analysis. The materiality analysis is based on a dialogue with a company's internal and external stakeholders and is therefore the strategic core of sustainability reporting [9].

Currently, the CSRD covers all large EU companies that already had to report after NFRD. In the following years the reporting duties will be gradually expanded and will include all large companies, SMEs and certain non-European companies. It is estimated that 50.000 companies will be subject to reporting requirements in the EU after the completed introduction of CSRD, compared to 11.000 companies under NFRD requirements [8]. Reports will be checked by auditors or audit companies that already audit financial reports with the aim to ensure harmonization of financial and sustainability information [9].

The combination of both sets of rules, SFDR and CSRD, creates a comprehensive framework that improves both the transparency of financial products and the sustainability performance of companies. This shall support the EU's goals for a more sustainable economy and promotes responsible investment.

Numerous survey and interview studies reveal a lack of theoretical understanding within the software industry. For instance, Karita et al. show in a survey study within software companies that there is predominantly a non-existent or low level of sustainability concepts [10]. Similarly, Oyedeleji et al., in an interview-based study involving software practitioners, reveal a notable deficiency in holistic conceptualizations of sustainability, wherein none of the interviewees were able to articulate a definition

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<sup>2</sup> <https://eur-lex.europa.eu/eli/dir/2014/95/oj> (last accessed 2024/06/09).

encompassing social, ecological, and economic dimensions [11]. Consequently, findings suggest a selective perception of sustainability with respect to its constituent dimensions.

Accordingly, survey and interview studies also underscore a scarcity of practical methodologies within the software industry. For instance, we showed in a survey with software practitioners that the technically-oriented roles in software companies (e.g., software engineer) are comparatively reluctant when it comes to implementing sustainability [12]. Groher and Weinrich uncover, through interviews with software project team leads, a prevailing technical orientation that permeates sustainability discussions, at the expense of broader sustainability dimensions [13].

Software companies are faced with the dual task of meeting the requirements of both sustainability design and business plan design in order to achieve market success [14]. Academic discourse advocates for establishing a symbiotic relationship between these two facets. Notably within the EU, the publication of the Karlskrona Manifesto for Sustainability Design,<sup>3</sup> signed by a group of international academics as well as industrial software practitioners. The work around the manifesto supported the software industry in tackling the multi-dimensional and multi-layered impacts of software systems with the Sustainability Awareness Framework (SusAF) [15].

To summarize, insights into the challenges of the software industry with regard to linking software sustainability can be divided into three areas: comprehending software sustainability theoretically, addressing software sustainability practically, as well as establishing connections between software sustainability and business design.

### 3 Research Design

#### 3.1 Objectives and Content of the Survey

The decision to undertake a survey aimed at exploring the dynamics between the software industry and CSRD reporting stems from empirical evidence suggesting that practitioners in the software field exhibit knowledge gaps and lack methodological expertise in sustainable software development. Despite a burgeoning motivation within the industry to address sustainability concerns, the imposition of sustainability reporting obligations signifies a pivotal juncture. This juncture precipitates the central research question underpinning this paper: What impact does the implementation of the CSRD have on the sustainability endeavors of software companies?

The survey questionnaire comprises two primary sections. The initial section probes software companies on their perceptions and assessments of sustainability's relevance within their operations. The subsequent section delves into CSRD-specific

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<sup>3</sup> <https://sustainabilitydesign.org/> (last accessed 2024/06/09).

**Table 1** Overview of the country location of the respondents

| Country                                                                             | n (=86)          |
|-------------------------------------------------------------------------------------|------------------|
| Germany                                                                             | 33 (38%)         |
| Finland                                                                             | 10 (12%)         |
| France                                                                              | 8 (9%)           |
| Other country (from outside of the European Union but operating within the borders) | 8 (9%)           |
| Austria                                                                             | 5 (6%)           |
| Slovakia                                                                            | 3 (4%)           |
| Hungary, Italy, Poland, Spain, Sweden                                               | 2 each (2% each) |
| Croatia, Czechia, Estonia, Greece, Ireland Netherlands, Portugal, Romania, Slovenia | 1 each (1% each) |

inquiries, elucidating current knowledge levels, resultant implications, and associated challenges and opportunities encountered within the affected company.

### 3.2 Data Collection

The survey was conducted among 86 respondents from 19 EU countries in total (see Table 1). The survey could be completed for just over two weeks, between 24 April and 10 May 2024. It was placed on major professional social networks (especially LinkedIn). Mailings were also sent out within our industry network (particularly Furtwangen University).

Regarding company types, the survey categorized respondents based on their compliance timelines with the CSRD (see Table 2).

### 3.3 Data Analysis

In our data analysis, we adhere to Pfleeger and Kitchenham's three-step approach, encompassing data validation, response partitioning, and data coding [16].

Data validation involves meticulous checks for consistency and completeness, alongside the identification and rectification of responses to ambiguous questions. With this in mind, we discussed, tested and modified the questionnaire until a consensus was reached among us scientists.

Response partitioning categorizes the entirety of responses for subsequent analysis. Here, we differentiate the companies regarding their starting year of the report obligation as they have different levels of urgency to deal with the topic.

For data coding, the surveys incorporated three types of closed-ended questions: binary questions (with options for 'yes,' 'no,' or 'not sure'), a 5-point Likert scale,

**Table 2** Company types of the respondents

| Company type                                                                                                                                                                                                                                                                                   | n (=86)     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| CSRD from 2025: Capital market-oriented companies that are already required to report within the meaning of the CSR-RUG if this (2 of 3 characteristics must apply): balance sheet total at least € 25 million, net turnover at least € 50 million, number of employees at least 250 employees | 29<br>(34%) |
| CSRD from 2027: Listed SMEs: balance sheet total max € 350,000, net sales max € 700,000, employees max 0.10                                                                                                                                                                                    | 25<br>(29%) |
| CSRD from 2026: Large companies that are not yet required to report (2 of 3 characteristics must apply): balance sheet total of at least € 25 million, net sales of at least € 50 million, at least 250 employees                                                                              | 15<br>(17%) |
| CSRD from 2029: Non-EU companies with EU branches or EU subsidiaries: net turnover over €150 million within the EU and at least one EU branch or EU subsidiary                                                                                                                                 | 9<br>(11%)  |
| Company is smaller than a large company (according to EU directive) and can therefore report voluntarily (at least 2 of 3 characteristics must not apply): balance sheet total of at least €25 million, net sales of at least €50 million, average number of employees of at least 250         | 8 (9%)      |

and multiple-choice questions with provision for additional responses, which could be further elaborated upon in subsequent queries. To facilitate analysis aligned with our research questions, binary responses were assigned numerical values (e.g., yes = 1, no = 0), while Likert scale responses were allocated numerical values ranging from 1 to 5. This approach enabled the computation of average scores, normalization of responses onto standardized scales, and facilitated quantitative data analysis.

## 4 Results

### 4.1 *The Perception of Sustainability within the Software Company in General*

The survey assessed the perception of sustainability within software companies by evaluating three main dimensions: environmental, social, and governance (ESG) aspects. The overall average score across these dimensions was 3.0, indicating a moderate level of engagement and awareness regarding sustainability. The social aspect scored slightly higher at 3.1, reflecting a better but still moderate focus on social sustainability, which includes considerations such as employee welfare, diversity, and community impact. Governance (business conduct) was rated by 3.0 and Environment (includes climate change, pollution, water and marine resources, biodiversity and ecosystems, resource use and circular economy) by 2.9.

The statement that sustainability practices contribute to the long-term success of the software company was rated as ‘Average’ (3.0). The current sustainability efforts within the software company were also rated as ‘Average’ (2.9). Whether more

**Table 3** Main drivers for software companies to prioritize sustainability

| Answer                                                                                                                             | n (=86)          |
|------------------------------------------------------------------------------------------------------------------------------------|------------------|
| Market demand for sustainable software products and services                                                                       | 48 (56%)         |
| Acquire and bind employees                                                                                                         | 33 (38%)         |
| Image/reputation of the company                                                                                                    | 10 (12%)         |
| Long-lasting software system/service which refers to how well a piece of software system/service will be able to cope with changes | 8 (9%)           |
| Regulatory requirements                                                                                                            | 8 (9%)           |
| Receive fundings                                                                                                                   | 3 (4%)           |
| Reduce costs (examples: reduce resource wastage and process optimization for more efficiency)                                      | 2 each (2% each) |
| Reduce negative impacts on society and/or environment                                                                              | 1 each (1% each) |
| Other (please specify in the next question)                                                                                        | 1 (1%)           |

workload should be put into the topic of sustainability also achieved an average value with the answer ‘Neither agree nor disagree’ (2.9).

The respondents identified several main drivers for prioritizing sustainability within their software companies (see Table 3). Market demand for sustainable software products and services was the top driver, selected by 48 respondents (56%). This indicates that consumer preferences are pushing companies towards more sustainable practices. Reducing costs through resource optimization and process efficiency was another significant driver, noted by 43 respondents (50%).

Improving the company’s image and reputation was important for 32 respondents (37%). Long-lasting software systems, which can adapt to changes and maintain functionality over time, were also seen as crucial by 32 respondents (37%). Regulatory requirements were a key driver for 32 respondents (37%) as well, reflecting the growing legal pressure to adopt sustainable practices. Additionally, 31 respondents (36%) indicated that reducing negative impacts on society and the environment was a significant motivation.

The statement that sustainability will become more important in the coming years was given an average neutral rating of 3.2 (‘Neither agree nor disagree’).

## 4.2 Preparation for the CSRD

The statement as to whether the software company considers itself to be familiar with the content of the CSRD was answered in the negative: an average value of 2.0 was achieved here (‘Disagree’). In addition, the statement that the CSRD will have a positive impact on their own company is between ‘Neither agree nor disagree’ and ‘Disagree’ at 2.6. The survey explored the measures software companies have taken or plan to take to comply with the CSRD requirements (see Table 4). The most

**Table 4** Measures taken or planned to comply with the CSRD requirements

| Answer                                         | n (=86)  |
|------------------------------------------------|----------|
| Developing a sustainability strategy           | 44 (51%) |
| Introducing/updating reporting processes       | 34 (40%) |
| Training employees in sustainability practices | 30 (35%) |
| Investing in sustainability software           | 24 (28%) |
| Crafting a materiality analysis                | 23 (27%) |
| Other (please specify in the next question)    | 7 (8%)   |

common measure, taken by 44 respondents (51%), was developing a sustainability strategy. Introducing or updating reporting processes was another key measure, undertaken by 34 respondents (40%). Training employees in sustainability practices was also significant, with 30 respondents (35%) focusing on enhancing their workforce's sustainability knowledge and skills.

When asked about the opportunities presented by the implementation of the CSRD (see Table 5), 34 respondents (40%) saw the potential for more sustainable business policies. Increasing business transparency and improving public reputation were important for 32 respondents (37%). Other opportunities included reduce costs and increase revenues by 20 respondents (23%).

Respondents also identified several challenges in implementing the CSRD in their software company (see Table 6). The most significant challenge, noted by 49 respondents (57%), was the potential for additional financial and personnel costs. Continuous changes in information and auditing standards were a concern for 31 respondents (36%), while 20 respondents (23%) highlighted the underdeveloped network of auditors as a challenge.

**Table 5** Opportunities for the software company through the implementation of the CSRD

| Answer                                                      | n (=86)  |
|-------------------------------------------------------------|----------|
| More sustainable business policies                          | 34 (40%) |
| More sustainable business policies                          | 34 (40%) |
| Increase business transparency and reputation in the public | 32 (37%) |
| Reduce costs and increase revenues                          | 20 (23%) |
| Minimize regulatory and legal interventions                 | 18 (21%) |
| Discover new business opportunities                         | 14 (16%) |
| Financial risk management                                   | 13 (15%) |
| Facilitate access to commodity and capital markets          | 12 (14%) |
| Other (please specify in the next question)                 | 4 (5%)   |

**Table 6** Challenges for the software company through the implementation of the CSRD

| Answer                                                                                                  | n (=86)  |
|---------------------------------------------------------------------------------------------------------|----------|
| Possible additional financial and personnel costs                                                       | 49 (57%) |
| Continuous changes in information standards and auditing standards                                      | 31 (36%) |
| Underdeveloped network of auditors                                                                      | 20 (23%) |
| Insufficiently elaborated relationship between financial and sustainability reports                     | 18 (21%) |
| Unclear regime of sanctions in case of publication of low-quality reports or non-publication of reports | 14 (16%) |
| Decrease in global competitiveness                                                                      | 12 (14%) |
| Other (please specify in the next question)                                                             | 6 (7%)   |

## 5 Discussion

### 5.1 *The Perception of Sustainability within the Software Company in General*

In companies, different departments are responsible for sustainability, which often indicates how sustainability is perceived within the organization [17]. For instance, sustainability officers may be found in the marketing department, HR department, or at the strategic management level where one could argue the topic ideally belongs in the future because of the interface position between all departments [17]. Our questionnaire did not address this issue. Sustainable customer segments are generally perceived as higher-paying customers [18]. Whether this will remain the case is uncertain, as alongside customers who voluntarily prioritize sustainability, there could develop the situation that having a sustainability report and with it sustainability metrics and practices, is the new standard due to reporting obligations. However, the market for companies that value sustainability and are willing to invest in it is likely to grow, driven by the increasing interconnection between financing, sustainability, and public interest [18]. Despite this, companies are not anticipating new markets. This may be due to the nature of the industry, where it is challenging to distinguish between customers interested in sustainability and those who are not, making it difficult to offer separate software products or services.

The second major topic is efficiency gains through sustainability, which could lead to cost reductions. Efficiency strategies have the advantage that managers can demonstrate the amortization of costs far more easily than compared to consistency or sufficiency strategies. This suggests that many companies addressing this are at the beginning of their transformation. Sustainability is also perceived as a compliance issue. One factor contributing to this perception is the multitude of current regulations, such as the Supply Chain Act, CSRD, EU Taxonomy that were implemented concurrently with or prior to the survey [19]. Another factor could be the increasing pressure from financiers, which are approaching companies to evaluate their sustainability stance that could directly impact refinancing options and loans

if sustainability rating is lacking. Surprisingly, compliance does not overshadow all other issues. This indicates that sustainability is perceived as more than just a compliance matter. The strategy of doing only the minimum necessary, associated with the notion that sustainability is a cost burden and should therefore be minimized in a profit-oriented organization, may be diminishing in importance. This suggests that sustainability is increasingly being recognized as a serious strategic issue. Image gains are not among the top responses. This suggests that sustainability as a purely marketing topic is losing traction. Sustainability is now perceived as a multifaceted issue that extends beyond the marketing department. This is further evidenced by the fact that most companies agree or strongly agree that sustainability is becoming increasingly important. Consequently, greenwashing as an avoidance strategy could diminish in importance. This perception is reinforced by the categorization of sustainability as a transparency issue. The significance of sustainability in employee recruitment is rather low compared to the other points, especially in an industry characterized by fierce competition for talent, which is expected to intensify due to demographic and labor market developments. Sustainability is generally seen as an important factor in attracting new employees, particularly high potentials. The results could be interpreted to mean that employees in this sector do not consider sustainability to be a decisive factor in their job choice.

## ***5.2 Preparation for the CSRD***

Companies do not appear to be prepared for CSRD reporting. This is not surprising, given that important elements of CSRD reporting have only been finalized relatively recently. Additionally, a standardized practical audit procedure has not yet emerged. The first CSRD reports from capital market-oriented companies will not be submitted until 2025. As a result, companies are currently in a discovery process – particularly those that have not previously been required to report are only beginning to engage with the topic. It is evident that there is a significant need for consultancy and a growing market for employees with expertise in sustainability (e.g., ESG managers). Companies are critical of the new compliance rules, most of which are unfamiliar to them, and they assume that these rules will have little impact on actual sustainability. However, given the general unpreparedness for the CSRD directive, this could be interpreted as a broader skepticism towards new regulations. On the other hand, there remains an expectation that the CSRD will lead to more sustainable business practices. However, an important element of the regulation, ‘financial risk management,’ is not considered particularly important. Thus, sustainability reporting is not yet understood as part of a company’s risk management, which is the intention of the CSRD regulation. This disconnect also impacts access to capital markets, which evaluate companies based on risks. The actual implications of CSRD via SFDR do not yet seem to affect companies, or it is not yet understood as a sustainability issue. The overview of sustainability measures reveals that very few companies have already implemented the so-called centerpiece of CSRD regulation. Few have conducted a

materiality analysis, which is essential for a CSRD report and a well-founded sustainability strategy. The response behavior regarding training, strategy, and updating reporting processes indicates that companies have taken measures based on other standards or have adopted a non-standardized approach. Software companies have identified possible additional financial and personnel costs as the primary challenge in implementing the CSRD. As stated, it is estimated that each company will have to invest €100,000 annually [5]. These costs encompass various aspects of compliance, including the adaptation of reporting systems, training of staff, and potential hiring of specialized personnel. Such financial burdens pose significant hurdles for companies, especially for SMEs, and underscore the practical challenges associated with aligning with the regulatory requirements of the CSRD. Other risks currently in focus are typical implementation risks, such as an underdeveloped network of auditors and evolving guidelines. While both are assumed, they are not considered long-term risks. The EU is mitigating these concerns by initially conducting only limited assurance audits with the plan to switch to reasonable assurance audits in the future [20].

### 5.3 *Limitations*

*Construct validity:* There is a risk that some participants may have understood the survey only partially or even not at all. This would inevitably lead to a misinterpretation of the analysis and interpretation of the results. To minimize this risk, we made a point of repeating the survey several times in advance and taking feedback into account in the form of adjustments to the questions. However, the potential further risk that our questionnaire does not fully do justice to the complexity of the topic cannot be completely dismissed. This is also because individual survey elements, in particular the scales used, limit the validity of the results. In this respect, it makes sense to supplement our quantitative study with qualitative studies, for example in the form of interviews.

*Internal validity:* Additional variables could influence the relationship between the independent and dependent variables in our survey. These include factors such as the location. Although we tried to distribute the questionnaire throughout the EU, a country-specific bias cannot be ruled out. This is made more difficult by the fact that the two countries Germany and Finland account for around fifty percent of the responses. Furthermore, there could be a risk that those software companies in particular were willing to participate in our survey that already have a greater existing interest in sustainability issues, although we took care to use commonly used platforms to distribute the survey in order to minimize selection bias.

*External validity:* Although we have made every effort to collect a large and diverse data set during the participant recruitment process, there is a risk that certain characteristics of our sample may limit the applicability of the results to the software industry in general. The biggest issue here is that the sample is comparatively small, so it cannot be considered representative of the EU-wide software industry. In

particular, industry-specific circumstances cannot be ruled out. For example, there may be differences between software companies that can be attributed to the type of IT products and services or their customer groups. Future survey studies should take these nuances into account in order to improve the generalizability of the results. A further bias results from the fact that it is not always clear who from the company answered the questionnaire. This is also due to the fact that the topic of sustainability is located in different business areas at the companies or is not allocated. It is common for sustainability officers to be in marketing, human resources or management assistance. As a result, there is a bias depending on the perspective or focus of the person completing the questionnaire. This is balanced out somewhat by random sampling. Furthermore, we are facing a situation where the CSRD is still a relatively new topic for many SMEs. As a result, numerous companies that are either not yet involved with the topic or have not begun to address it are unlikely to respond to the questionnaire, as it is currently not relevant to them.

*Reliability:* All authors of this study were equally involved in the evaluation process. This ensured that any inconsistencies in the classification could be discussed and resolved by consensus. To avoid potential reactive bias, where participants give answers that are influenced by social desirability, the surveys were conducted anonymously. This results in the difficulty that it cannot be ruled out that two or more employees of a company have completed a questionnaire.

## 6 Conclusion

Following the SFDR, the CSRD represents a significant shift from voluntary to mandatory reporting. Our study confirms that sustainability reporting is not yet firmly established within the software industry. The results indicate that these software companies are not yet adequately prepared to meet the new requirements. This lack of preparedness is expected at this stage, as there has not been sufficient time to develop standardized practical audit procedures. Software companies currently assign moderate to low importance to sustainability while also agreeing that the topic of sustainability will become more important for them in the coming years. Additionally, they expect to face additional workloads, leading to increased costs, the need for additional staff, and/or training of existing staff. These challenges contrast with the opportunities that sustainability presents, which are not only mandated by policymakers but also demanded by the market, as recognized by the majority of the surveyed software companies. However, the survey study has its limitations in using a random sampling method. Future surveys should involve a larger number of software companies to allow for a more detailed analysis, particularly by country and sector. Additionally, qualitative studies, such as interviews, are essential to explore how software companies can be supported in addressing the challenges posed by the CSRD.

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## References

1. Bocken N (2024) Business models for sustainability. SSRN Electron J. <https://doi.org/10.2139/ssrn.4731205>
2. Şahin Z, Çankaya F (2020) The importance of sustainability and sustainability reporting. In: Çalıyurt K (ed) New approaches to CSR, sustainability and accountability. Accounting, finance, sustainability, governance & fraud: theory and application vol 1. Springer, Singapore. [https://doi.org/10.1007/978-981-32-9588-9\\_4](https://doi.org/10.1007/978-981-32-9588-9_4)
3. Odobaša R, Marošević K (2023) Expected contributions of the european corporate sustainability reporting directive (csrd) to the sustainable development of the european union. EU and comparative law issues and challenges series (ECLIC) 7:593–612. <https://doi.org/10.25234/ecli/27463>
4. Becker C, Betz S, Chitchyan R, Duboc L, Easterbrook SM, Penzenstadler B, Seyff N, Venters CC (2016) Requirements: the key to sustainability. IEEE Softw 33:56–65. <https://doi.org/10.1109/MS.2015.158>
5. Müller S Unternehmensberichterstattung durch CSRD im Wandel, [https://www.haufe.de/finance/jahresabschluss-bilanzierung/csr-richtlinie-umsetzungsgesetz-berichterstattung/csr-rflug-unternehmensberichterstattung-im-wandel\\_188\\_409066.html](https://www.haufe.de/finance/jahresabschluss-bilanzierung/csr-richtlinie-umsetzungsgesetz-berichterstattung/csr-rflug-unternehmensberichterstattung-im-wandel_188_409066.html). Accessed 05 May 2024
6. Opferkuch K, Caeiro S, Salomone R, Ramos T (2021) Circular economy in corporate sustainability reporting: a review of organisational approaches. Bus Strat Env 30(8):4015–4036. <https://doi.org/10.1002/bse.2854>
7. Hahnkamper-Vandenbulcke N (2021) Non-financial reporting directive. European parliamentary research service. [https://www.europarl.europa.eu/thinktank/en/document/EPRS\\_BRI\(2021\)654213](https://www.europarl.europa.eu/thinktank/en/document/EPRS_BRI(2021)654213). Accessed 18 May 2024
8. Birkmann M, Funke J, Gulbin J, Meyer LM, Sauer M, Wegmann L (2024) CSRD-burdening regulation or opportunity for CSR communication? A qualitative study on the influence of the corporate sustainability reporting directive on large German companies. In: Sound or silence? Current developments in organizational communication, pp 10–41
9. Kirchhoff K, Niefund S, von Pressentin J (2024) ESG: Nachhaltigkeit als strategischer Erfolgsfaktor. Wiesbaden: Springer Fachmedien Wiesbaden; Imprint Springer Gabler (SDG - Forschung, Konzepte, Lösungsansätze zur Nachhaltigkeit)
10. Karita L, Mourão BC, Machado I (2019) Software industry awareness on green and sustainable software engineering: a state-of-the-practice survey. In: Proceedings of the XXXIII Brazilian symposium on software engineering (SBES '19). Association for Computing Machinery, New York, NY, USA, pp 501–510. <https://doi.org/10.1145/3350768.3350770>
11. Oyedeleji S, Shamshiri H, Porras J, Lammert D (2021) Software sustainability: academic understanding and industry perceptions. software business: 12th international conference. ICSOB 2021:18–34. [https://doi.org/10.1007/978-3-030-919832\\_3](https://doi.org/10.1007/978-3-030-919832_3)
12. Lammert D, Betz S, Porras J, Oyedeleji S (2024) Sustainability in the software industry: a survey study on the perception, responsibility, and motivation of software practitioners. In: Digital ecosystems, blockchain evolution, and sustainable transformation (DEBEST) 2023
13. Groher I, Weinreich R (2017) An interview study on sustainability concerns in software development projects. In: 2017 43rd Euromicro conference on software engineering and advanced applications (SEAA), pp 350–358. <https://doi.org/10.1109/SEAA.2017.70>

14. Bomfim C, Nunes W, Duboc L, Schots M (2014) Modelling sustainability in a procurement system: an experience report. In: IEEE 22nd international requirements engineering conference (RE), pp 402–411. <https://doi.org/10.1109/RE.2014.6912291>
15. Penzenstadler B, Duboc L, Koçak SA, Becker C, Betz S, Chitchyan R, Easterbrook SM, Leifler O, Porras J, Seyff N, Venters CC (2020) The SusAF workshop—improving sustainability awareness to inform future business process and systems design. <https://doi.org/10.5281/zenodo.3676514>
16. Pfleeger SL, Kitchenham BA (2001) Principles of survey research: part 1: turning lemons into lemonade. SIGSOFT Softw Eng Notes 26(6):16–18. <https://doi.org/10.1145/505532.505535>
17. Carollo L, Guerci M (2018) ‘Activists in a suit’: paradoxes and metaphors in sustainability managers’ identity work. *J Bus Ethics* 148:249–268. <https://doi.org/10.1007/s10551-017-3582-7>
18. Goedertier F, Weijters B, van den Bergh J (2024) Are consumers equally willing to pay more for brands that aim for sustainability, positive societal contribution, and inclusivity as for brands that are perceived as exclusive? Generational, gender, and country differences. *Sustainability* 16(9):3879. <https://doi.org/10.3390/su16093879>
19. Mittwoch AC, Bremenkamp FL (2023) The German supply chain act—a sustainable regulatory framework for internationally active market players? *Rev Eur Comp Law* 55(4):189–219. <https://doi.org/10.31743/recl.16677>
20. European Commission (2021) Questions and answers: corporate sustainability reporting directive proposal. [https://ec.europa.eu/commission/presscorner/detail/PT/qanda\\_21\\_1806](https://ec.europa.eu/commission/presscorner/detail/PT/qanda_21_1806). Accessed 18 May 2024

# A Hybrid Tabu Search and Multi-objective Evolutionary Framework for Virtual Machine Placement in Cloud Computing



Montassar Riahi, Fatma Hachmi, and Nejla Rouissi

**Abstract** The emergence of Cloud Computing (CC) has rapidly changing the thinking of IT service providers, which propose actually a proliferation of services based on virtualization technology. This paradigm contributes to the built of multiple data centers across the world housing millions of Virtual Machines (VMs). In this context, Virtual Machine Placement (VMP) is considered as one of the greatest challenges to overcome by cloud providers in order to optimize their platforms by improving power efficiency, resource utilization, and Quality of Services (QoS). In this paper, we propose a multi-objective framework based on hybrid Tabu Search (TS) and Genetic Algorithm (GA) for the VMP problem. The proposed approach is tested on real cloud platforms and compared with some existing methods from the literature. Evaluation results show that the proposed technique is more efficient and fully competitive than other methods in the literature.

**Keywords** Cloud computing · Virtual machine placement · Tabu search · Genetic algorithm · Multi-objective framework

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## 1 Introduction

CC technology provides a range of services through three basic models, namely: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) [1]. In cloud environment, computing resources are provided according to some predefined SLA [2]. SLA is a contract negotiated between the service provided and the service consumer. However, as computing resources are shared between customers and cloud subscribers seem to grow steadily in the presence of heterogeneous and irrelevant platforms problem [3], it will clearly lead to resource wastage in case where shared resources are not distributed properly. Therefore, how to efficiently and dynamically satisfy the needs of cloud subscribers and how to manage computing resources without waste become the issues to be solved. In fact, a cloud data center consumes on average the same energy consumed by twenty-five thousand houses [4]. Thus, green CC is a field that must be taken into account to reduce energy consumption and resource wastage. Virtualization Technology (VT) represents an efficient solution to manage CC platforms. By deploying cloud services in VMs and mapping them to physical servers, the problems of heterogeneity and hardware platforms irrelevance of cloud customers' needs can be better solved. In addition, VT allows a dynamic remapping process between VMs and Physical Machines (PMs) according to the workload amount of each VM. In this paper, we propose a multi-objective and hybrid VMP approach that aims to minimize simultaneously: power consumption and resource wastage in a dynamic scenario. Our proposal is based on the combination of GA and TS metaheuristics in the context of solving the VMP problem. The development of our hybrid approach aims to enhance the strengths and compensate the weakness of our proposed technique in [5]. To validate our approach, we compared our experimental results by using real-world workload coming from: the private cloud platform of the Délice Holding company in Tunisia. To achieve this work, we developed a decision support system (DSS) based on the proposed framework using Java J2EE programming language [6].

## 2 Related Works

The energy efficiency in cloud data center was further more improved upon [7, 8]. In these works, the researchers proposed a scheduling algorithm with a dynamic voltage frequency scaling (DVFS) technique to ensure an energy-efficient scheduling approach which gives the priority to select the suitable VM for the executing job, according to the SLA level required by the cloud clients [9]. On the other hand, many efforts focused on the task scheduling which led to greater advocacy of green computing. In fact, [10] proposed an DVFS energy-saving workflow tasks scheduling algorithm within, leverages the useful slack time after the merging of servers. This proposed work can be applied in a heterogeneous environment with parallel applications without violating the SLA's constraints. The use of the DVFS technique

continues with [11]. Their proposal combined a reactive DVFS policy with a proactive frequency-aware consolidation in order to reduce the power consumption, avoid the SLA violations and maintain a good QoS. Their approach minimized the global energy peak in the cloud data center as it speed up the elastic scale out. Recently, many approaches still apply the DVFS method but in different ways. As a result, [12] exploit the analysis of large scale data, by developing energy-efficient Hadoop clusters. The proposed approach is based on DVFS with Ant Colony Optimization (E-Ant) which improved the energy consumption and the performance. Their approach was applied in heterogeneous Hadoop clusters where they connected the DVFS controller to dynamic scaling of the CPU frequency of the slave machine. The research community felt the necessity to provide an efficient solution that reduces the aforementioned challenges. The consolidation technique represents another alternative in order to decrease the power consumption and the violation of the SLA. As a matter of fact, many researchers [13, 14] adopts new strategies based on prediction model or provisioning approach to solve the problem of SLA violation in cloud data center. So that, authors in [15] proposed a task scheduling strategy based on genetic algorithm to allocate and execute application tasks to reduce task completion time called LBNP. The delay capacity scheduling algorithm can ensure that most tasks can achieve localization scheduling, improve resource utilization, improve load balance and speed up job completion time.

The proposed approach in [16] aims to conduct a complete systematic mapping analysis on the impact of high energy consumption in cloud data centers and its effect on the environment.

On another side, a good VMP algorithm plays an important role to perform a correct live migration. Authors in [17] proposed a workload algorithms which permits to predict the future overloaded/underloaded hosts in cloud data center to avoid the inefficient VMs migration, and reduce the extra utilization of energy.

Compared to the cited state-of-the-art approaches, our proposal is based on the combination of two metaheuristics, which are TS and GA. Our approach is also based on a Bernoulli simulation in order to simulate the achievement of the TS moves in such a way that we can use the same genetic operators proposed in [5]. In addition, our optimization model adopts a pure multi-objective optimization using the concept of Pareto dominance where the goal is to obtain the non-dominated solutions that minimize simultaneously: Energy consumption and resource wastage. In this work, we proposed to minimize three objective functions which are detailed in the rest of this paper. Our proposal was implemented on a real cloud platform. The efficiency of our VMP solution is challenged in terms of four metrics namely: number of active PMs, power consumption, resource wastage and number of VMs' migration.

### 3 Problem Formulation

In this section, we propose a multi-objective formulation for the VMP problem where the goal is to minimize simultaneously energy consumption and resource wastage.

### 3.1 Energy Consumption Modeling

To model energy consumption in a cloud data center we propose to formulate two objective functions that aim to model an energy-efficient framework in cloud environment, namely:

1. **Minimizing the number of active PMs:** Turning off PMs that are not needed or in idle state is an important issue that should be taken into consideration to decide which PMs can be powered off in order to save energy in cloud environment [18–20], especially during the dynamic process of VMs to PMs allocation. Thus, a simplified on/off objective function is used, trying to minimize the number of active PMs instead of the overall power consumption. In this situation, we propose the same objective function proposed in [5], which is defined as follows:

$$\text{Minimize} \sum_{j=1}^m p_j, \quad p_j \in \{0, 1\} \quad (1)$$

such as  $m$  corresponds to the number of available PMs in the cloud platform and  $p_j$  is a binary variable that equals 1 if server  $P_j$  is active, otherwise it is equal to 0.

2. **Minimizing the total power consumption:** As explained above, according to this objective function, we can consider the proposals of [21, 22], which state that energy consumption of PMs is directly connected with their computing resources and illustrated that servers' energy consumption has a linear relationship with their computer processing unit (CPU) workload. Hence our second objective function is based on the formula defined in [18] as follows:

$$PC_j = (PC_j^{busy} - PC_j^{idle}) \times U_j^{cpu} + PC_j^{idle} \quad (2)$$

where  $PC_j$  denotes the power consumption value of server  $j$ ,  $PC_j^{busy}$  and  $PC_j^{idle}$  correspond to the average power values when server  $j$  is overloaded and idle, respectively. In this work, their respective values are fixed to 215 and 162 Watt according to [23, 24].  $U_j^{cpu}$  denotes the normalized CPU resource used by server  $j$ .

### 3.2 Resource Wastage Modeling

In this section, we propose to use the same formula presented by [5, 23] as follows:

$$W_j = \frac{|L_j^{cpu} - L_j^{ram}| + \varepsilon}{U_j^{cpu} + U_j^{ram}} \quad (3)$$

In this case, when an active PM has untapped resources, we can say that those resources are wasted and are not used by any VM. Thus,  $W_j$  represents the percentage of wasted resource at PM  $j$ .

### 3.3 Mathematical Formulation

As the goal consists of minimizing simultaneously: the total energy consumption and the total resource wastage in a cloud environment, our VMP problem can be formulated based on the three objective functions defined in Eqs. 1, 2, and 3.

$$\text{Minimize} \sum_{j=1}^m p_j, \quad p_j \in \{0, 1\} \quad (4)$$

$$\text{Minimize} \sum_{j=1}^m PC_j = \sum_{j=1}^m \left[ p_j \times \left( (PC_j^{busy} - PC_j^{idle}) \times \sum_{i=1}^n (r_i^{cpu} \cdot v_{ij}) + PC_j^{idle} \right) \right] \quad (5)$$

$$\text{Minimize} \sum_{j=1}^m W_j = \sum_{j=1}^m \left[ p_j \times \frac{\left| (C_j^{cpu} - \sum_{i=1}^n (r_i^{cpu} \cdot v_{ij})) - (C_j^{ram} - \sum_{i=1}^n (r_i^{ram} \cdot v_{ij})) \right| + \varepsilon}{\sum_{i=1}^n (r_i^{cpu} \cdot v_{ij}) + \sum_{i=1}^n (r_i^{ram} \cdot v_{ij})} \right] \quad (6)$$

Subject to:

$$\sum_{i=1}^n r_i^{ram} v_{ij} \leq C_j^{ram} p_j, \quad \forall j = 1, \dots, m \quad (7)$$

$$\sum_{i=1}^n r_i^{cpu} v_{ij} \leq C_j^{cpu} p_j, \quad \forall j = 1, \dots, m \quad (8)$$

$$\sum_{j=1}^m v_{ij} = 1, \quad \forall i = 1, \dots, n \quad (9)$$

The Constraints above define the capacity constraints, where  $r_i^{ram}$  and  $r_i^{cpu}$  correspond respectively to the ram and cpu resources necessary for the VM  $v_{ij}$ .  $C_j^{cpu}$  and  $C_j^{ram}$  correspond respectively to the fixed CPU and RAM thresholds for the host  $p_j$ .

The third Constraint guarantees that each VM  $v_{ij}$  is assigned in exactly one PM  $p_j$ . Once this VMP problem is solved, the binary values (1 or 0) of PM  $p_j$  will indicate if it will be activated for hosting VMs or not, while the binary values of  $v_{ij}$  will present the VMs to PMs mapping schema that states if  $v_{ij}$  can be affected to server  $p_j$  or not.

## 4 Proposed Multi-objective and Hybrid Approach

Our **Hybrid** approach represents an extension of the GAVMP-BO algorithm presented in [5] and is based on the combination between **TS** and **GA** metaheuristics. The goal is to find an ameliorated solution for the **VMP** problem in cloud environment. Hence, throughout this paper our proposed multi-objective algorithm will be called **HTSGAVMP** and is detailed in Algorithm 1.

## 5 Experimental Results

To evaluate the proposed HTSGAVMP algorithm, we conducted our experimental results on a real experimental environment, which corresponds to the Délice's private cloud platform. The goal is to validate the feasibility of our approach in a real scenario. Also, we compared our approach with methods of the Literature namely:

1. **GAVMP-BO**: presented in [5]. The goal is to compare our solution versus a similar approach based on multi-objective optimization and GA.
2. **RVMP**: presented in [18], which represents also a recent and innovative contribution in the research domain of VMP in CC. Hence, the efficiency of our proposal is more challenged.
3. **CBP**: a Class-Based Placement technique, proposed in [25]. This solution is also inspired from the naive BP approach. In this manner, our multidimensional and vector BP technique can be evaluated versus a similar one.
4. **VMPACS**: an evolutionary approach based on ACO and proposed in [23]. In this way, we can compare HTSGAVMP against another evolutionary metaheuristic where the objectives are close to our VMP formulation.
5. **DVFS-Enabled**: presented in [7].

Table 1 summarizes the values of the input parameters given to HTSGAVMP. We note that these features remain the same for all the presented experiments.

**Algorithm 1** HTSGAVMP: Hybrid TS and GA approach for VMP in CC

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1: Input: Set of VMs: V and set of PMs: P with their associated resource demand (ram, cpu) and
 their thresholds capacities (RAM, CPU) respectively.
2: $TLsize$: the TL's max size
3: N : the number of generation defined as an integer
4: p : crossover rate, q : mutation rate
5: Output: S^* : a chromosome corresponding to the best non-dominated VMP solution
6: /* Initialization */
7: $S^{(t-1)}$: the last recorded VMP solution given by HTSGAVMP
8: S : a feasible VMP solution encoded as a chromosome and given from the hypervisor
9: $neighborhoodsList$: the list of neighborhood solution as set of chromosomes
10: TL : the tabu list as a set of chromosomes
11: t : a timer counter on which will be stored the computation time of HTSGAVMP
12: $S^* \leftarrow S$
13: $TL \leftarrow TL.add(S^*)$ /* add S^* to TL */
14: $t \leftarrow$ Set Up a Timer() /* start the timer counter */
15: $j \leftarrow 1$ /* a counter j that starts by 1 */
16: /*End Initialization*/
17: If $Migrate_VMs (S^{(t-1)})$ Then /*The load-balancing algorithm proposed in [23]*/
18: While ($j < N$) Do /* while stopping criterion not met */
19: $neighborhoodsList \leftarrow getNeihbors (S^*, p, q)$ /* see Algorithm 1 */
20: For each Neighboring Solution NS in $neighborhoodsList$ do
21: If $NS \notin TL$ Then
22: $S \leftarrow NS$
23: If $fitnessDominate (S, S^*, S^{(t-1)}, RAM, CPU, t)$ Then /*see Algorithm 4*/
24: $S^* \leftarrow S$
25: End If
26: End If
27: End For
28: $TL \leftarrow pushTLaspiration (TL, S^*, TLsize)$ /* see Algorithm 5 */
29: $j \leftarrow j + 1$
30: End While
31: $S^{(t-1)} \leftarrow S^*$
32: End If
33: Return S^*

```

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**Table 1** The features of HTSGAVMP

| Feature                             | Value |
|-------------------------------------|-------|
| $N$ : Generation number             | 3000  |
| $p$ : Crossover rate                | 0.7   |
| $q$ : Mutation rate                 | 0.1   |
| $TLsize$ : Tabu list size           | 200   |
| $RAM$ : RAM threshold for active PM | 90%   |
| $CPU$ : CPU threshold for active PM | 90%   |

**Table 2** Comparison of HTSGAVMP versus VMPACS, CBP, RVMP, DVFS Enabled, and GAVMP-BO in the real case study

| $ P $<br>$ V $ | Algorithm    | # of active PMs | Power consumption (KW) | % Resource wastage | # of VMs migrations | Time (s) |
|----------------|--------------|-----------------|------------------------|--------------------|---------------------|----------|
| 10             | VMPACS       | 6               | 229.34                 | 4.93               | 11                  | 0.069    |
| 30             | CBP          | 6               | 225.12                 | 5.26               | 9                   | 0.0654   |
|                | RVMP         | 5               | 223.28                 | 4.02               | 6                   | 0.059    |
|                | GAVMP-BO     | 5               | 222.35                 | 3.33               | 4                   | 0.052    |
|                | DVFS Enabled | 5               | 221.9                  | 3.10               | 3                   | 0.0529   |
|                | HTSGAVMP     | 5               | 220.78                 | 2.98               | 3                   | 0.0514   |
| 50             | VMPACS       | 26              | 499.52                 | 3.34               | 55                  | 1.27     |
| 150            | CBP          | 27              | 549.74                 | 3.47               | 46                  | 1.26     |
|                | RVMP         | 24              | 414.62                 | 3.08               | 32                  | 1.02     |
|                | GAVMP-BO     | 23              | 368.64                 | 2.95               | 24                  | 0.96     |
|                | DVFS Enabled | 22              | 331.9                  | 2.90               | 22                  | 0.98     |
|                | HTSGAVMP     | 22              | 323.94                 | 2.83               | 21                  | 0.91     |

### 5.1 Evaluation and Analysis of HTSGAVMP on the Real Délice's Cloud Platform

As explained above, HTSGAVMP is firstly evaluated on the Délice's private cloud platform. This real cloud environment is composed of 10 PMs and 30 VMs. HTSGAVMP is triggered when at least one active PM reaches the RAM or CPU threshold fixed in Table 1. This command provides a detailed look at how each active host in the given platform uses resources such as RAM and CPU in real time. Thus, during a period of one month, we recorded the values given by each compared algorithm including those given by HTSGAVMP in terms of four metrics as presented in Table 2. These values correspond to the mean of the recorded metrics in order to take into consideration all the daily activities of Délice Holding.

By referring to the experimental results presented in Table 2, following is our analysis based on the studied objectives:

- In terms of energy consumption:** HTSGAVMP outperforms all the compared algorithms for both test cases( PMs=10 and PMs= 50), since it gives the same number of active PMs as GAVMP-BO, DVFS Enabled, and RVMP but it gives one less server compared to CBP and VMPACS. However, in terms of power consumption, the results showed that HTSGAVMP solution is the non-dominated one because it gives up to 9 KW fewer power consumption. Compared to GAVMP-BO, we note a gain of 1.57 KW and with DVFS enabled we observe a gain of 1.12 KW. Against RVMP, our solution allows to economize 2.5 KW of

power consumption which is more observed compared to CBP with an improvement of 4.34 KW in less. Nevertheless, the improvement is well seen if we compare our solution versus that given by VMPACS where we observed an amelioration of 8.56 KW.

2. **In terms of resource wastage:** We observe that CBP and VMPACS achieve the worst performance results while those given by RVMP, DVFS, and GAVMP-BO are considerably better but remain inferior to the solution given by HTSGAVMP. In our case, the resulting resource wastage caused respectively by CBP, VMPACS, RVMP, GAVMP-BO and DVFS enabled is 5.26%, 4.93%, 4.02% , 3.33%, and 3.10% while that resulting from HTSGAVMP is 2.98% when the number of PM is 10. Even when the number of PMs has increased to 50, HTSGAVMP still the best among the remaining methods.

## 6 Conclusion

In this paper, we proposed a new VMP algorithm called HTSGAVMP, which is based on the combination between TS and GA. The first objective of the proposed approach consists of minimizing the whole energy consumption in cloud data centers. Our second objective consists of minimizing the resource wastage of the cloud platform. Finally, the proposed technique has been evaluated with some recent state-of-the-art approaches including our contribution proposed in [5] and this in terms of different performance metrics. The experimental analysis was conducted on the real cloud platform of Délice Holding. The simulation results demonstrate that our approach outperforms the compared method and gives an improvement up to 23.5% in terms of VMs' migration number. It reduces the energy consumption by 5% considering both PMs' number and power consumption. Similarly, as regards the percentages of resource wastage, the proposed approach gives a significant reduction corresponding to 8%. The scalability of our algorithm was also proved since its computation time expands linearly whenever the size of the cloud platform increases.

## References

1. Singh S, Jeong Y, Park JH (2016) A survey on cloud computing security: issues, threats, and solutions. *J Network Comput Appl* 75:200–222
2. Hussain W, Hussain FK, Hussain OK, Damiani E, Chang E (2017) Formulating and managing viable SLAs in cloud computing from a small to medium service provider's viewpoint: a state-of-the-art review. *Inform Syst* 71:240–259
3. Hu J, Gu J, Sun G, Zhao T (2010) A Scheduling Strategy on Load Balancing of Virtual Machine Resources in Cloud Computing Environment. 2010 3rd International symposium on parallel architectures, algorithms and programming
4. Kaplan J, Forrest W, Kindler N (2008) Revolutionizing data center energy efficiency. McKinsey & Company

5. Riahi M, Krichen S (2018) A multi-objective decision support framework for virtual machine placement in cloud data centers: a real case study. *J Supercomput* 74(7):2984–3015
6. Krishnaiyer K, Chen FF (2017) A cloud-based kanban decision support system for resource scheduling & management. Proceedings of the 27th International conference on flexible automation and intelligent manufacturing, FAIM2017 11, 1489–1494
7. Hagraas T, El-Sayed GA (2024) Maintaining the completion-time mechanism for Greening tasks scheduling on DVFS-enabled computing platforms. *Cluster Comput*
8. Hassan HA, Salem SA, Saad EM (2020) A smart energy and reliability aware scheduling algorithm for workflow execution in DVFS-enabled cloud environment. *Future Generation Comput Syst* 112:431–448 November
9. Ghafari R, Hassani Kabutarkhani F, Mansouri N (2022) Task scheduling algorithms for energy optimization in cloud environment: a comprehensive review. *Cluster Comput* 25(2), 10351093. <https://doi.org/10.1007/s10586-021-03512-z>
10. Tang Z, Qi L, Cheng Z, Li K, Khan SU, Li K (2016) An energy-efficient task scheduling algorithm in DVFS-enabled cloud environment. *J Grid Comput* 14:55–74
11. Mao J, Peng X, Cao T, Bhattacharya T, Qin X (2022) A frequency-aware management strategy for virtual machines in DVFS-enabled clouds. *Sustain Comput Inform Syst* 33
12. Cheng D, Zhou X, Lama P, Ji M, Jiang C (2018) Energy efficiency aware task assignment with DVFS in Heterogeneous hadoop clusters. *IEEE Trans Parallel Distrib Syst* 29(1):1–14
13. Bashir S, Mustafa S, Ahmad RW, Shuja J, Maqsood T, Alourani A (2023) Multi-factor nature inspired SLA-aware energy efficient resource management for cloud environments 26:1643–1658
14. Mustafa S, Bilal K, Malik SUR, Madani SA (2018) SLA-aware energy efficient resource management for cloud environments. *IEEE Access* 6:15004–15020
15. Fu W, Wang L (2022) Load balancing algorithms for hadoop cluster in unbalanced environment. *Comput Intell Neurosci* 1545024, <https://doi.org/10.1155/2022/1545024>
16. Bharany S, Sharma S, Ibrahim Khalaf O, Muttashar Abdulsahib G, Al Humaimedy AS, Aldhyani THH, Maashi M, Alkahtani H (2022) A systematic survey on energy-efficient techniques in sustainable cloud computing 14(10):6256, <https://doi.org/10.3390/su14106256>
17. Melhem SB, Agarwal A, Goel N, Zaman M (2018) Markov prediction model for host load detection and VM placement in live migration. *IEEE Access* 6:7190–7205
18. Gupta MK, Amgoth T (2018) Resource-aware virtual machine placement algorithm for IaaS cloud. *J Supercomput* 74:122–140
19. Zhang B, Qian Z, Huang W, Li X, Lu S (2012) Minimizing communication traffic in data centers with power-aware VM placement. Sixth International conference on innovative mobile and internet services in ubiquitous computing
20. Mosa A, Paton NW (2016) Optimizing virtual machine placement for energy and SLA in clouds using utility functions. *J Cloud Comput*, 5–17
21. Satpathy A, KantiAddya S, KumarTuruk A, Majhi B, Sahoo G (2018) Crow search based virtual machine placement strategy in cloud data centers with live migration. *Comput Electr Eng* 69:334–350
22. Ravandi B, Papapanagiotou I (2018) A self-organized resource provisioning for cloud block storage. *Future Gen Comput Syst* 89:765–776
23. Gao Y, Guan H, Qi Z, Hou Y, Liu L (2013) A multi-objective ant colony system algorithm for virtual machine placement in cloud computing. *J Comput Syst Sci* 79:1230–1242
24. Kasture H (2017) A Hardware and Software Architecture for Efficient Datacenters. PhD Thesis in the Department of Electrical Engineering and Computer, MIT
25. Canali C, Lancellotti R (2016) Scalable and automatic virtual machines placement based on behavioral similarities. *Computing* 99:1–21

# Ontology Based Legal Knowledge System for Cheque Bounce Cases in India



Varsha Naik and K. Rajeswari

**Abstract** Legal systems are often confusing and require expertise to answer questions related to it. One such tricky section is Cheque Bounce Case i.e., Section 138. This section deals with the causes and consequences of issuing a cheque and not honoring to pay that amount. This study focuses on simplifying the complexities of Section 138 of the Negotiable Instrument Act, a challenging legal provision often poorly understood by the general public. The aim is to make the information accessible to individuals with limited legal knowledge, as well as aid law stakeholders in comprehending the nuances of this section. The system employs a unique approach, transitioning from unsupervised machine learning models to a custom-built ontology based on Section 138, significantly improving the accuracy of answers to user queries. The originality lies in the creation of a comprehensive ontology, encompassing multiple classes and their attributes. The research implications are noteworthy, as the system proves instrumental in addressing intricate questions related to Section 138, empowering individuals with limited knowledge to make informed decisions and better understand their legal situations.

**Keywords** Ontology · Section 138 · Machine Learning · Unsupervised Learning

## 1 Introduction

Cheques constitute a crucial element in our banking system, providing a convenient means of transferring money without the hassle of physical currency. Prior to 1988, there was a significant gap in legal measures to penalize individuals engaging in

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fraudulent activities related to issuing cheques without sufficient funds. This loophole resulted in numerous instances of goods being exchanged for cheques that later bounced due to insufficient funds. In response, Section 138 was introduced in 1988 under The Negotiable Instruments Act. This legal provision aims to address the issue by imposing penalties, including imprisonment for up to two years and a fine equivalent to twice the amount of the offense. In an effort to enhance understanding and provide a reliable system for answering queries related to Section 138, we are developing an ontology based on a comprehensive analysis of various cases and legal documents. By discerning patterns and rules from these materials, the system will learn to respond to questions, ranging from specifics about individual cases to general inquiries related to Section 138. Our ultimate goal is to create a user-friendly platform that not only educates individuals on the challenges and consequences of cheque bouncing but also humanizes the legal intricacies surrounding Section 138, making the information more accessible and relatable to the public.

## 2 Literature Survey

The field of legal informatics has witnessed significant advancements through the exploration of legal ontologies, semantic analysis, expert systems, information retrieval systems, and user-centric design principles. The development of legal ontologies, as demonstrated by Arbaaeen et al. [1] and V. G. D. Gupta et al. [2], underscores the importance of structured frameworks for representing legal knowledge. These ontologies serve as the cornerstone for systems that aim to enhance the accessibility and comprehension of legal information for various user groups. The key learning from this research is the foundational role that legal ontologies play in organizing and presenting legal knowledge, facilitating a more systematic and structured approach to understanding complex legal concepts [1, 2].

Furthermore, semantic analysis techniques applied to legal texts, as discussed by Arbaaeen et al. [1], contribute to a deeper understanding of complex legal documents by extracting meaningful information and relationships. The application of semantic analysis in legal contexts offers valuable insights into the interpretation and implications of legal texts, fostering a more nuanced comprehension of legal content. This approach enables the extraction of meaningful information and relationships within legal documents, enhancing the capacity to derive accurate and contextually relevant insights from legal texts [1]. Expert systems in legal decision-making, as highlighted by Estival [3] and Elfadil et al. [4], leverage rule-based approaches and ontologies to provide valuable insights into legal implications and potential outcomes, improving the efficiency and accuracy of legal processes. The development and integration of expert systems in legal decision-making contribute to a more streamlined and informed decision-making process. These systems utilize rule-based approaches and ontologies to provide valuable insights into legal implications and potential outcomes, thereby enhancing the overall efficiency and accuracy of legal decision-making processes [3, 4].

Legal information retrieval systems, as seen in the work of Büchter et al. [5], emphasize the importance of tailoring systems for legal databases with natural language processing, streamlining the search process for legal professionals. The design and implementation of legal information retrieval systems catered to legal databases are pivotal for facilitating efficient access to relevant legal information. By incorporating natural language processing and tailored search mechanisms, these systems enhance the effectiveness of legal research, providing legal professionals with a more streamlined approach to accessing pertinent information [5].

Additionally, user-centric legal information systems, explored by Shamsfard et al. [6], address the accessibility gap between legal professionals and laypersons by presenting information in a digestible format. The development of user-centric legal information systems aims to bridge the accessibility gap between legal professionals and non-experts. By presenting legal information in a digestible format, these systems empower individuals with limited legal expertise to navigate and comprehend legal matters. This user-centric design approach ensures that legal information is presented in a manner that is accessible and comprehensible to a broader audience [6].

These collective learnings underscore the interdisciplinary nature of legal informatics, emphasizing collaboration between legal experts and information scientists, and the importance of human-centered design principles. Moreover, ethical considerations, such as privacy, security, and bias, need thorough exploration as legal information systems continue to advance. These insights not only contribute to a more nuanced understanding of legal informatics but also pave the way for future research and innovation in creating accessible, comprehensible, and ethically sound legal information systems.

## 2.1 Data Extraction

This paper [7] discusses a method called RETRO is a method discussed by Borgeaud et al. [7], which aims to enhance language models by retrieving document chunks from a large corpus based on local similarity with preceding tokens. By utilizing a 2 trillion token database, RETRO achieves comparable performance to GPT-3 and Jurassic-1 on the Pile, while using significantly fewer parameters. RETRO combines a frozen BERT retriever, a differentiable encoder, and a chunked cross-attention mechanism to predict tokens based on a larger amount of data than traditional training methods. This approach introduces the potential for improving language models through explicit memory on an unprecedented scale.

Unstructured Multi-Layout Invoice Documents Collection: Positive Aspects  
Cross attention chunked dependable reformatting

Research Gap/Limitation: Preprocessed data is used to create tokens, which lean more towards regressive datasets.

The use of the OKAPI BM25 model in text mining is discussed by Tinega, Gesare [8] to enhance relevance ranking in digital libraries. The study compares the performance of the OKAPI BM25 model with the Boolean and vector space models for

data retrieval. The findings indicate that the OKAPI BM25 model performs better than the other models in terms of relevance ranking.

Positives we can infer from this are that taking relative word frequency into account and also the normalization of document length.

Research Gaps/Limitation are that it is based on probabilistic theory, this research does not apply to a broad range of situations.

## 2.2 *Ontology Based QA Systems*

The paper authored by Arbaaeen et al. [1] constitutes a comprehensive review centered around an ontology based approach to semantically enhanced question answering within closed domains. The authors delve into the intricate challenges associated with acquiring concise, accurate, and precise answers to questions in natural language processing (NLP). They underscore the vital role that question answering systems can play in mitigating these challenges. One noteworthy benefit highlighted in the review is the semantic improvement achieved through the integration of ontologies. By structuring knowledge within a semantic framework, question answering systems can offer more contextually accurate and nuanced responses. Additionally, the review emphasizes the harmonization of diverse information facilitated by ontological approaches, enabling the integration of heterogeneous data sources for a more comprehensive understanding. The notion of a semantically reusable vocabulary is also discussed, highlighting the potential for ontologies to establish a standardized language for communication across different entities and domains. Moreover, the paper underscores the advantages of reasonable thinking and observation, suggesting that ontologies contribute to enhancing the reasoning capabilities of question answering systems.

Despite the benefits identified, the review acknowledges certain research omissions and restrictions. Notably, there is a discussion about the challenge of expression mapping to ontology components, emphasizing the need for further exploration in effectively translating expressions into ontological structures. Furthermore, the limited adoption of ontological approaches and the necessity for specialized training are recognized as areas of concern in the broader application of this methodology.

Similarly, the document authored by J.M.G.R.Jayabahu et al. [9] presents a thorough examination of an ontology based approach to semantically enhanced question answering within closed domains. The challenges associated with obtaining concise, accurate, and precise answers in NLP are discussed in-depth, with a focus on how question answering systems can address these challenges. The benefits outlined in this review align closely with those in the Arbaaeen et al. [1], emphasizing semantic improvement, harmonization of diverse information, semantically reusable vocabulary, and the enhancement of reasonable thinking and observation.

Expanding upon the insights gleaned from these reviews, it is evident that ontology based approaches hold substantial promise in advancing question answering systems within closed domains. The semantic enhancement achieved through ontological

frameworks provides a more nuanced understanding of natural language queries. The harmonization of diverse information promotes a holistic view of knowledge, contributing to more accurate responses. The notion of a semantically reusable vocabulary not only standardizes communication but also fosters interoperability across varied data sources. However, the recognition of research omissions, such as the challenge of expression mapping and the limited adoption of ontological approaches, highlights the need for ongoing exploration and refinement. Moreover, addressing training needs becomes crucial for the broader integration of ontological approaches in question answering systems. These reviews collectively underscore the potential of ontology based methods while pointing towards areas that merit further attention for the continued advancement of semantically enhanced question answering in closed domains.

### 3 Dataset Description

The dataset was manually created by downloading sample documents from Indian kanoon.com, this data is publicly available in the form of Case judgments. Each file was individually assessed to extract relevant data. Prominent features were very determined after Brain-Storming and in accordance with the ontological concepts and relationships. After thorough Brain-Storming, the resulting dataset had the following columns (Table 1).

**Table 1** Sample data from e-judgements

| Dataset columns        | Example                                       |
|------------------------|-----------------------------------------------|
| Case No                | M.C. 702                                      |
| Plaintiff              | Galaxy Datamatics Pvt. Ltd                    |
| Defendant              | Dinesh Sehgal & Harsh Sehgal                  |
| Payee                  | Delhi State                                   |
| Drawer                 | Galaxy Datamatics Pvt. Ltd                    |
| Bank                   | Union Bank Of India                           |
| Payment instruments    | Cheque                                        |
| Evidence               | Undue Delay in resolving Cheque Dishonor case |
| Penalties/Consequences | Deposition of Fine                            |
| Filing date            | 2nd March 2022                                |
| Decision date          | 13th May 2022                                 |
| Reason                 | Section 138 of the Negotiable Instruments Act |

## 4 Methodology

This section describes the processing of user queries based on the legal proceedings of specific scenarios of Section 138.

The main idea of this proposed work is to introduce advancement in semantic analysis within a legal ontology framework, the system extracts relevant legal concepts and relationships, delivering optimal and user-friendly answers. The overarching goal is to democratize legal knowledge, making it more transparent and accessible, ultimately allowing individuals to navigate Section 138 cases with enhanced understanding and confidence.

### 4.1 Preprocessing

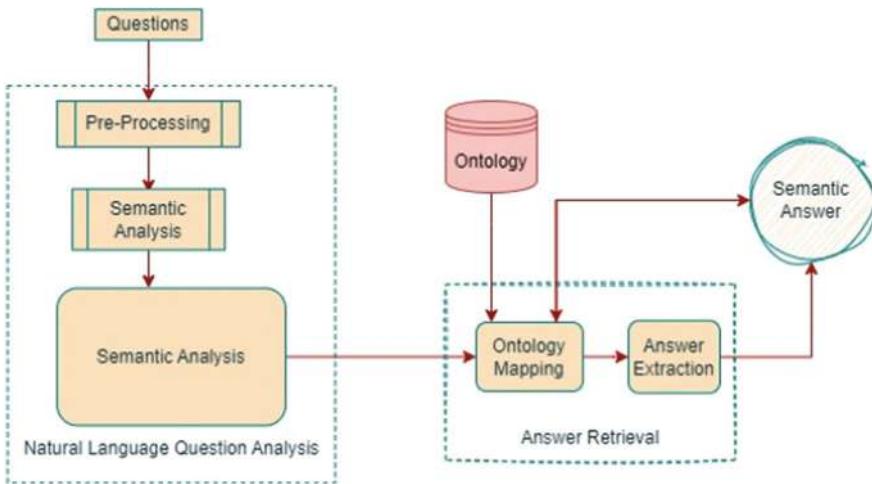
As shown in Fig. 1 the input to the model is user given query in the form of unstructured text, it is then processed using Natural Language Processing(NLP) preprocessing techniques. Multiple preprocessing steps were performed to ensure the text data was both clean and consistent. The text was initially converted to lowercase to maintain uniformity and avoid issues related to case sensitivity. Punctuation and common stop words were removed to retain only the most relevant terms, thereby minimizing noise in the data. Subsequently, the text was broken into smaller units, or tokens. Lastly, lemmatization was applied, particularly focusing on verbs, to transform words into their root or base forms, ensuring that different variations of the same term were handled consistently. After preprocessing, various methods were explored to represent the textual data numerically, including approaches such as TF-IDF, n-grams, and Word2Vec embeddings.

### 4.2 Ontology Modeling

In the initial iterations, our ontology included classes such as ‘party’ with subclasses like ‘plaintiff,’ ‘defendant,’ ‘payer,’ and ‘payee,’ each equipped with data properties such as ‘name’ and ‘age.’ However, this approach began resembling a database structure rather than an abstract ontology, deviating from our intended conceptualization.

**Transition to Abstract Ontology:** Prior to advancing the abstract ontology, we deliberated on the formulation of competency questions.

1. Tell me all the reasons for dishonor of a cheque
2. What follows notice issuance?
3. Give the names and descriptions of all possible resolutions
4. Give me the details of some stages of proceedings

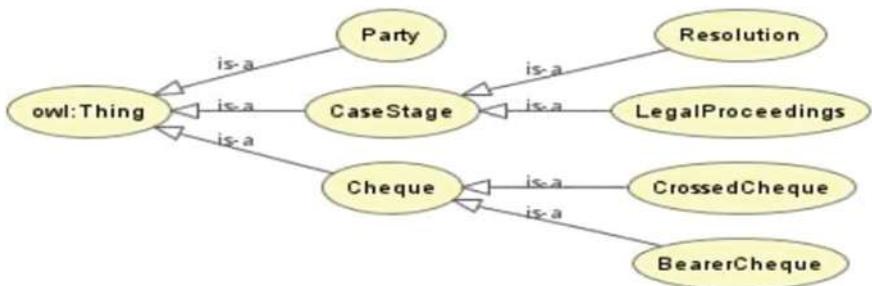


**Fig. 1** Architecture of the proposed legal system

5. Fetch the names and descriptions of 5 stages within the legal proceedings concerning cheque dishonor.

Recognizing the need for increased abstraction, particularly in the context of ontological design, we refined our approach. As shown in Fig. 2, the subsequent abstract ontology centered around Section 138, introducing classes like ‘cheque’ with logically named instances elucidating reasons for cheque dishonor. Additionally, classes like ‘case stage’ were introduced, further subdivided into ‘legal proceedings’ and ‘resolution.’ The ‘party’ class featured two instances: ‘payer party’ and ‘payee party.’

**Abstract Instances and Data Properties:** To enhance precision, instances of ‘legal proceedings’ were abstract, explicating each stage through pertinent data properties. Importantly, our ontology embraced a shift towards a more user-centric approach, focusing on data properties deemed essential for end-user inquiries. As a result, we



**Fig. 2** Abstract ontology for section 138

**Fig. 3** Abstract instances and data properties in the Protégé editor



streamlined to include only universally relevant data properties, such as ‘Reason for Cheque Dishonor’ and ‘Case Stage Description.’ This decision aimed to optimize the ontology for question answering, prioritizing user-centric information.

**Focus on User-Centric Queries:** Unlike the previous iteration that addressed specifics like party names, the refined ontology prioritizes answering broader questions, such as predicting post-notice issuance events. While the ontology remains a work in progress, this strategic shift aligns with our commitment to maintaining abstraction while catering to end-user query requirements.

This abstraction-oriented ontology forms the basis for our question answering system, with ongoing efforts directed towards its expansion and refinement.

Recognizing its complexity, we opted to initially construct a system based on our ontology that could respond to predefined queries, albeit hardcoded ones, as a preliminary step.

At this stage, our system addresses a predetermined set of queries by associating them with a dictionary that contains hardcoded natural language questions. It retrieves the corresponding answers from the .rdf files within our dataset (Fig. 3).

## 5 Experimental Setup

In the system, we have a frontend that acts as a means to connect with the ontology. Using the textbox we get the queries and process them which is sent to the backend to fetch the relevant output, upon getting the output it is sent to the frontend interface where it is eventually displayed as shown in Figs. 4 and 5.

**Section 138 FAQ**

**Enter your query:**

**Submit**

**Example Queries:**

1. Tell me all the reasons for dishonor of a cheque.
2. What follows after issuance?
3. Give me the names and descriptions of all possible resolutions.
4. Give me the details of some stages of proceedings.
5. Fetch the names and descriptions of 5 stages within the legal proceedings concerning cheque dishonor.

---

**Fig. 4** Front end for legal queries

**Section 138 FAQ**

**Enter your query:**

**Submit**

**Example Queries:**

1. Tell me all the reasons for dishonor of a cheque.
2. What follows after issuance?
3. Give me the names and descriptions of all possible resolutions.
4. Give me the details of some stages of proceedings.
5. Fetch the names and descriptions of 5 stages within the legal proceedings concerning cheque dishonor.

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**Compensation**  
Upon the court's judgment favoring the spouse or the aggrieved party due to a bounced cheque this stage involves enforcing the payment of compensation by the drawer. The court-ordered compensation aims to reimburse the aggrieved party for the bounced cheque amount and may include additional damages or costs as deemed appropriate by the court.  
<http://www.semanticweb.org/comikit/owlontologies/2012/11/chequeDishonour#compensation>

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**Imprisonment**  
Its severe reprimand or sentence of repeated offences related to bounced cheques this stage involves on the court's verdict of imprisonment against the drawer. The court may order imprisonment as a punitive measure aiming to hold the drawer legally accountable for the offence and deter future instances of defaulting on payments.  
<http://www.semanticweb.org/comikit/owlontologies/2012/11/chequeDishonour#imprisonment>

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**Mortuary Penalties**  
As part of the court's judgment this stage encompasses the imposition of a monetary penalty or fine upon the drawer due to the

**Fig. 5** Result of a legal query

Using an ontology as the knowledge base gives us an advantage as the accuracy of the answers increases drastically while remaining consistent.

All the times the queries were run we got the same answer telling us about the accuracy we attained was above 95% accurate through the runs.

## 6 Limitations and Future Work

The current iteration of our ontology, focused on Section 138 of the Negotiable Instruments Act, is acknowledged to have limitations stemming from the absence of comprehensive legal details due to the authors' lack of legal expertise. The

ontology's restricted size poses constraints on the spectrum of questions it can effectively address. Attempts to enhance its capabilities by incorporating language models such as GPT-3.5 and finetuning GPT-2 encountered integration challenges, proving to be ineffective. Furthermore, the usage of Protege has revealed limitations in managing complex knowledge graphs, hindering substantial progress in the ontology's development without guaranteed impact.

Moving forward, we recognize the need to strengthen the ontology by collaborating with legal experts. The plan involves merging the existing iteration with a more abstract one, intending to create a robust system capable of addressing a wider array of queries related to Section 138 of the Negotiable Instruments Act. In ontology development annotation is the first step, we need legal experts who can help develop the manual set of rules for annotation with their domain expertise. An in-depth annotation and curation of gold standard text corpus helps to automate the system accurately. After building an ontology legal professionals validate the ontology, ensure compliance with legal standards, and refine the system's responses. This collaboration aims to infuse legal expertise into the ontology, ensuring a more accurate representation of legal nuances. Involving legal experts to review and validate the ontology and the system's responses is the qualitative measure of ontology evaluation. On the other hand quantitative ontology evaluation measures include accuracy metrics, error rates, semantic metrics, and query performance.

To overcome the challenges faced, we propose transitioning the ontology to a graph database like Neo4j. This shift aims to leverage the strengths of graph databases in managing intricate knowledge structures efficiently. Considering the complexity of legal documents, Neo4j is an advanced graph data model that offers robust data integrity, flexible schema, efficient performance, scalability, built-in graph algorithms, and powerful query capabilities. The integration of these characteristics enhances the system's capacity to handle intricate legal information, deliver precise and prompt solutions, and expand to accommodate changing requirements, ultimately resulting in a more reliable and effective legal ontology system. Additionally, we plan to expand the ontology to incorporate legal precedents derived from earlier iterations. This expansion will contribute to a more comprehensive knowledge base, enriching the ontology with a historical perspective and enhancing its ability to handle a broader range of legal queries. In line with technological advancements, we intend to invest in the latest APIs, such as GPT-4 or Gemini. By finetuning these advanced language models on our enriched knowledge graphs, we seek to develop a sophisticated querying mechanism. The goal is to retrieve natural language responses directly from the core information within the knowledge graph. This approach aims to enhance the system's ability to provide detailed and contextually relevant answers to diverse legal inquiries. Through this iterative process of collaboration, technological adaptation, and knowledge enrichment, we aspire to overcome the current limitations of ontology. The learnings from past challenges underscore the importance of interdisciplinary collaboration, emphasizing the need for domain-specific expertise in legal ontology development. By embracing evolving technologies and leveraging legal insights, we aim to create a more robust and effective system for addressing complex legal queries related to Section 138 of the Negotiable Instruments Act.

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## References

1. Arbaaeen A, Shah A (2021) <https://doi.org/10.3390/info12050200>
2. Gupta D, Anil A (2019) An ontology driven question answering system for legal documents. In: 2019 2nd international conference on intelligent computing
3. Estival D, Nowak C, Zschorn A. <http://www.ontoknowledge.org/oil/>
4. Elfadil SSAN, Jarajreh M, Algarni S (2021) Question answering systems: a systematic literature review. Int J Adv Comput Sci Appl 12(3)
5. Büchter RB, Weise A, Pieper D (2020) Development, testing and use of data extraction forms in systematic reviews: a review of methodological guidance. BMC Med Res Methodol 1:20–20
6. Shamsfard M, Barforoush AA (2004) Learning ontologies from natural language texts. Int J Hum Comput Stud 60(1):17–63
7. Borgeaud S, Mensch A, Hoffmann J, Cai T, Rutherford E, Millican K, Driessche GVD, Lespiau JB, Damoc B, Clark A, De D, Casas L, Guy A, Menick J, Ring R, Hennigan T, Huang S, Maggiore L, Jones C, Sifre L, Tinega G, Mwangi RW, Rimiru RM (2018) Text mining in digital libraries using OKAPI BM25 model. Int J Comput Appl Technol Res 7
8. Jayabahu JMGR, Rajapaksha UUS (2019)

# Comparative Analysis of Grade Distributions in Team-Taught Introductory Data Science Courses for First-Year Students



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**Abstract** The increasing importance of mathematical and data science education in Japanese higher education has led to its integration into general education curricula. This study examines the design and implementation of a university-wide information literacy education course at Hokuriku University, focusing on the integration of data science and AI education. As part of the university's general education curriculum, the compulsory first-year course aims to equip students with essential information literacy and data science skills. This study analyzes the fairness of evaluation among course instructors, considering the challenges of delivering uniform content to several students. These findings highlight the importance of regular communication and collaboration among instructors to ensure consistent grading practices. The innovative approach of the course to integrate data science and AI education into information literacy education serves as a model for other higher education institutions in Japan. By sharing the lessons learned from this experience, this study contributes to the development of best practices for designing and delivering university-wide general education courses that effectively prepare students for an increasingly data-driven world.

**Keywords** University-wide education · Higher education · Information literacy education · Data Science · AI education

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## 1 Introduction

In recent years, mathematical and data science education has received significant attention as part of general education in Japanese higher education. General education, which refers to compulsory courses for all first-year students, has traditionally included well-known subjects, such as first-year education and self-education. Mathematical and data science education has also been added to this list.

The growing need for mathematical and data science education can be attributed to societal changes such as Society 5.0 and digital transformation (DX). The advancement of information and communication technology (ICT) has led to the emergence of Society 5.0, a human-centered society that balances economic advancement with the resolution of social problems through a system that integrates cyberspace and physical space [1]. The Japanese government has positioned artificial intelligence (AI) as a fundamental technology for realizing Society 5.0 and is working on AI strategies to achieve this goal [2].

Furthermore, DX, which is closely related to Society 5.0, has been increasingly discussed in Japan since 2018, when it was highlighted in the reports of the Ministry of Internal Affairs and Communications and the Ministry of Economy, Trade, and Industry [3]. DX refers to the improvement in people's lives in all aspects owing to the use of IT [4].

Consequently, mathematical and data science education has been introduced as general education subjects in many Japanese universities. This development necessitates the delivery of uniform course content to several students. The on-demand format of classes in higher education prevalent during the COVID-19 pandemic, has led to an increase in the number of universities offering mathematical and data science education in this format.

However, exercises and practical sessions require small class sizes, which implies that many instructors must teach the same content. In this context, ensuring fair evaluation among instructors is crucial.

At Hokuriku University, the mathematical and data science education program comprises lectures and practical sessions conducted in small class sizes in the classrooms. This study focuses on the fair evaluation among instructors of mathematical and data science education program at Hokuriku University, aiming to contribute to the improvement of such programs in Japanese higher education.

## 2 Practice

Hokuriku University, a private institution in the Ishikawa Prefecture, Japan, has made significant strides in integrating data science and AI education into its curriculum. With approximately 2,400 students, the university has four faculties: Pharmaceutical Sciences, Health and Medical Sciences, Economics and Management, and International Communication. In 2020, the university implemented a Bring Your Own

Device (BYOD) policy for its two humanities faculties, requiring students to bring personal notebook computers and smartphones to campus. Concurrently, the university adopted Google Workspace for Education and Office 365 Education platforms to enhance collaboration, learning, and research.

The “Information Literacy” course has been a compulsory subject for first-year students since the establishment of two faculties in 2017. At that time, the course focused on acquiring basic skills in Microsoft Office applications. However, from 2020, both faculties fundamentally redesigned the content of the “Information Literacy” course to align with the introduction of BYOD and cloud platforms, standardizing the course content across the two faculties.

The updated curriculum emphasizes practical applications and data-driven problem solving, incorporating the analysis of student typing scores and survey data collected through web forms. All course materials were freely accessible on the university’s website, promoting open education and knowledge sharing. The course content aligns with the “Literacy Level Certification System for Mathematical, Data Science and AI Education Programs,” a model curriculum outlined by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). Moreover, it fulfills the criteria set forth by the Private University Reform Comprehensive Support Project Type 1 and the Ordinary Expense Subsidy (Special Subsidy) “4 Enhancement of Mathematical, Data Science, and AI Education” Category 1 initiatives.

The “Information Literacy” course adopted a pedagogical approach rooted in active learning, critical thinking, and practical applications. This curriculum nurtures statistical thinking and conceptual understanding, and encourages the use of real-world data in meaningful contexts. The integration of cutting-edge technologies and tools enhances the learning experience, allowing students to explore complex concepts and conduct data analysis in a supportive environment.

The “Information Literacy” course serves as a cornerstone of Hokuriku University’s “Data Science and AI Education Program,” which aims to cultivate data literacy among students across all faculties. This program equips learners with the skills and knowledge necessary to understand, analyze, and extract insights from vast amounts of data. Upon successful completion of the “Information Literacy” course and the complementary “Introduction to Statistics” course, students are awarded an open badge to recognize their achievement.

Hokuriku University places a strong emphasis on the evaluation of student comprehension and learning outcomes to ensure continuous improvement of its educational initiatives. The university employs a range of assessment strategies, including formative and summative, to gather feedback and insights into the effectiveness of its programs. The assessment practices align with the principles outlined in the “Guidelines for Assessment and Instruction in Statistics Education (GAISE)” report published by the American Statistical Association in 2016.

Hokuriku University's strategic implementation of the "Data Science and AI Education Program," anchored by the "Information Literacy" course, demonstrates its commitment to delivering cutting-edge education in an increasingly data-driven world. By leveraging existing resources and expertise, the university has created a comprehensive and interdisciplinary program that engages students across all faculties. As Hokuriku University continues to adapt to the demands of the twenty-first century, its dedication to nurturing data-literate graduates positions it as a leader in shaping the future of education and society.

### 3 Materials and Methods

#### 3.1 Class Organization

As a result of being positioned as a constituent subject in the "Data Science and AI Education Program" at Hokuriku University, which began in 2022, "Information Literacy" is now offered in all departments across all faculties. As presented in Table 1, Hokuriku University ensures equal access to high-quality information literacy education by organizing classes of 40–60 students among faculty members. Each class is assigned an instructor and a senior student serving as a student assistant to provide technical support.

The course operation is managed by a faculty member who serves as the program coordinator. The coordinator is responsible for preparing the course materials and convening weekly online meetings with other instructors and student assistants in all departments. In online meetings, instructors share successful tips and challenges with their respective classes and collaborate on the content for the upcoming week's class. The instructors assigned to each class come from diverse backgrounds and

**Table 1** Number of students registered and passed in each faculty

| Year | Faculty                | # of Classes | # of Registrations | # of Passes | Passing rate (%) |
|------|------------------------|--------------|--------------------|-------------|------------------|
| 2022 | Pharmacy               | 1            | 67                 | 67          | 100.0            |
|      | Health & Medical       | 1            | 68                 | 68          | 100.0            |
|      | Economics & management | 4            | 219                | 166         | 75.8             |
|      | Int'l communication    | 3            | 123                | 116         | 94.3             |
|      | <i>Subtotal</i>        | 9            | 477                | 417         | 87.4             |
| 2023 | Pharmacy               | 1            | 62                 | 61          | 98.4             |
|      | Health & medical       | 2            | 126                | 126         | 100.0            |
|      | Economics & management | 5            | 241                | 207         | 85.9             |
|      | Int'l communication    | 2            | 98                 | 92          | 93.9             |
|      | <i>Subtotal</i>        | 10           | 527                | 486         | 92.2             |

are not necessarily experts in informatics or data science. The teaching staff varies slightly from year to year. By teaching this course, instructors acquire updated knowledge related to digital technologies that they can apply to their own courses and research, effectively serving as a form of professional development [4]. In cases where novice instructors continue to experience difficulties in their classes, a coordinating faculty member will observe the classroom to identify the underlying causes of the challenges. The coordinator will then provide guidance and recommendations to the novice instructor on strategies for improving their teaching effectiveness. This mentoring approach aims to support the professional development of new data science education and ensure that students receive high-quality instruction.

### ***3.2 Course Contents and Evaluation***

The “Information Literacy” course, which began in 2017, initially focused on teaching basic skills in using Microsoft Office applications. However, in 2019, prior to the launch of the Data Science and AI Education Program, the course content underwent significant changes. Students were required to design web surveys, collect data, and analyze them using MS Excel. Moreover, they had to analyze the weekly typing score data recorded by all first-year students and compile their findings into a term paper using MS Word. Additionally, the course included hands-on experience with basic machine learning and AI using tools such as Google Teachable Machine.

Beginning in 2022, with the commencement of the Data Science and AI Education Program, the 90-min class was restructured to compress the previous year’s content to two-thirds of the allotted time. The remaining 30 min were dedicated to a data science section where students learned to use the visual analytics tool Tableau for data analysis and visualization. During this data science section, students watch approximately 30-min hands-on videos in the classroom over the course of four weeks to learn the basic operations of Tableau. Following this, the university provides real-world data, such as sales data from campus bookstores and cafeteria, as well as student survey response data. In conjunction with the course, a Tableau analysis competition is held, where students are encouraged to freely visualize and analyze the provided data [6, 7].

As presented in Table 3, the grading criteria for the “Information Literacy” course were standardized across all classes to ensure consistency in the evaluation.

## 4 Results and Discussions

### 4.1 *Grading Difference by Classes*

This introductory “Information Literacy” course was taught by four instructors (A, B, C, and D) across four classes in 2022. In 2023, the course was taught by five instructors (A, B, C, E, and F) across five classes. Among these instructors, Instructors A, B, and C taught the course for two consecutive years. The course was taught using the same materials, assignments, grading criteria, and rubrics for both years, as presented in Tables 2 and 3. Students were assigned to classes by a university registrar. If the students were randomly assigned to classes without regard to their abilities, and each instructor taught the same content and graded it using the same criteria, it would be expected that the grade distributions for each class would be similar.

Figure 1 illustrates the actual grade distribution by class. The upper portion displays histograms of the grades for each class in 2022 and 2023, whereas the lower portion displays bar graphs of the pass/fail ratios. Grades were given on a 100-point scale, with 60 points or more considered a passing score. Examining the pass/fail ratios, it is evident that in 2022, they were nearly identical across classes, whereas in 2023, there were significant differences between classes. In 2023, excluding the newly appointed Instructor E, the proportion of students who failed the course decreased considerably. The average pass rate increased from 76.2 in 2022 to 86.04% in 2023.

Figure 2 presents the grade distribution percentages for the passing students in each class, where “S” represents scores from 90 to 100 points, “A” represents scores from 80 to less than 90 points, “B” represents scores from 70 to less than 80 points, and “C” represents scores from 60 to less than 70 points. In contrast to solely considering the pass/fail ratios, the grade composition percentages in 2023 appear to be similar across instructors, with the exception of Instructor A. However, in 2022, Instructor A graded more leniently, whereas Instructor D graded more strictly.

To investigate this further, Fig. 3 presents box-and-whisker plots of first-year students’ placement test scores in Japanese and English for each class. The score distributions for 2022 appear to be scattered within a similar range for both Japanese and English. In contrast, students in Class E in 2023 appear to have lower academic abilities. However, the reason for the discrepancy remains unclear.

**Table 2** Information literacy course contents from [7]

|                                           |         | Information literacy section              |                                        | Data science section                              | Apps & service used        |
|-------------------------------------------|---------|-------------------------------------------|----------------------------------------|---------------------------------------------------|----------------------------|
| Unit 1–Getting started                    | Week 01 | Introduction                              | Basic PC skills and typing             |                                                   | Teams                      |
|                                           | Week 02 | Online communication                      | PC settings and email                  |                                                   | Teams and Gmail            |
|                                           | Week 03 | Short essay                               | Formal email and writing a short essay | Video lecture: “Everyone is data people”          | Word, printing on campus   |
|                                           | Week 04 | Collaborative presentation                | Fieldwork                              | Tableau exercise I                                | Powerpoint                 |
| Unit 2–Understanding the computer         | Week 05 | How a PC works                            | Setting up PC and cloud drive          | Tableau exercise II                               | Google Drive               |
|                                           | Week 06 | Information ethics & information security |                                        | Tableau exercise III                              | Windows defender           |
|                                           | Week 07 | Information to AI                         | Experiencing AI                        | Tableau exercise IV                               | Bard and teachable machine |
| Unit 3–Information Gathering and Analysis | Week 08 | Web survey                                | Short Questionnaire                    | Video lecture: “How to analyze supermarket sales” | Google forms               |
|                                           | Week 09 | Freshman public opinion survey I          | Creating a web survey form             | Tableau analysis competition I                    | Google forms               |
|                                           | Week 10 | Freshman public opinion survey II         | Analysis of survey data                | Tableau analysis competition II                   | Excel                      |
|                                           | Week 11 | Freshman public opinion survey III        | Creating a presentation                |                                                   | Powerpoint                 |
| Unit 4–Data Analysis and report writing   | Week 12 | Typing data analysis I                    | Analysis Typing data                   | Tableau analysis competition award ceremony       | Excel                      |
|                                           | Week 13 | Typing data analysis I                    | Analysis Typing data                   |                                                   | Excel and tableau          |

(continued)

**Table 2** (continued)

|  |         | Information literacy section | Data science section           | Apps & service used |
|--|---------|------------------------------|--------------------------------|---------------------|
|  | Week 14 | Writing a term paper         | Writing a data analysis report | Word                |
|  | Week 15 | Using a proofreading tool    | Peer Review, Final typing test |                     |

<https://hokuriku-unv.hokuriku-u.ac.jp/up/faces/up/km/Kms00802A.jsp>

**Table 3** Grading criteria

| Points | Main category                                  | Subcategory                                                                        |
|--------|------------------------------------------------|------------------------------------------------------------------------------------|
| 40     | Submission of mini assignments in each session | Submission of screenshots, sending emails, responding to surveys, etc              |
| 30     | Evaluation of task sets based on rubrics       | Week 10: tableau analysis competition                                              |
|        |                                                | Week 11: freshman public opinion survey powerpoint                                 |
|        |                                                | Week 13: excel analysis of typing data                                             |
| 20     | Evaluation of the term paper based on a rubric | Week 15: term paper of typing data analysis                                        |
| 10     | Final typing test score                        | Week 15: An additional 1 point for every 10 points above 100, maximum to 10 points |

When Kruskal–Wallis tests were performed on the 0–100 point grades of “Information Literacy” for each year, the results revealed no significant differences in 2022, however, significant differences were found in 2023. Consequently, multiple comparisons using Dunn’s test with Bonferroni Correction were conducted for only 2023 data points. The results revealed significant differences between three pairs of classes: Classes A and B, Classes B and E, and Classes A and F.

It is not surprising that differences in grade distributions emerged, although the same materials and grading methods were used, considering the disparities in students’ prior academic abilities across the assigned classes. It is crucial for instructors to share information during the course rather than discover the differences between classes after the course has ended and been graded. In the case of the “Information Literacy” course, weekly online meetings were held with all the instructors. However, the extent of the disparities remains unknown. To effectively share information about such disparities between classes during the course and adapt teaching methods for each class accordingly, it is essential to establish a system that enables the real-time visualization and sharing of weekly assignment submission statuses and rubric-based assessment results. Such a system would allow instructors to promptly identify and address differences in student performance across classes, thereby facilitating timely adjustments to their teaching approaches. By accessing updated data on student progress and assessment outcomes, instructors can collaborate more effectively, discuss potential issues, and develop targeted strategies to support students

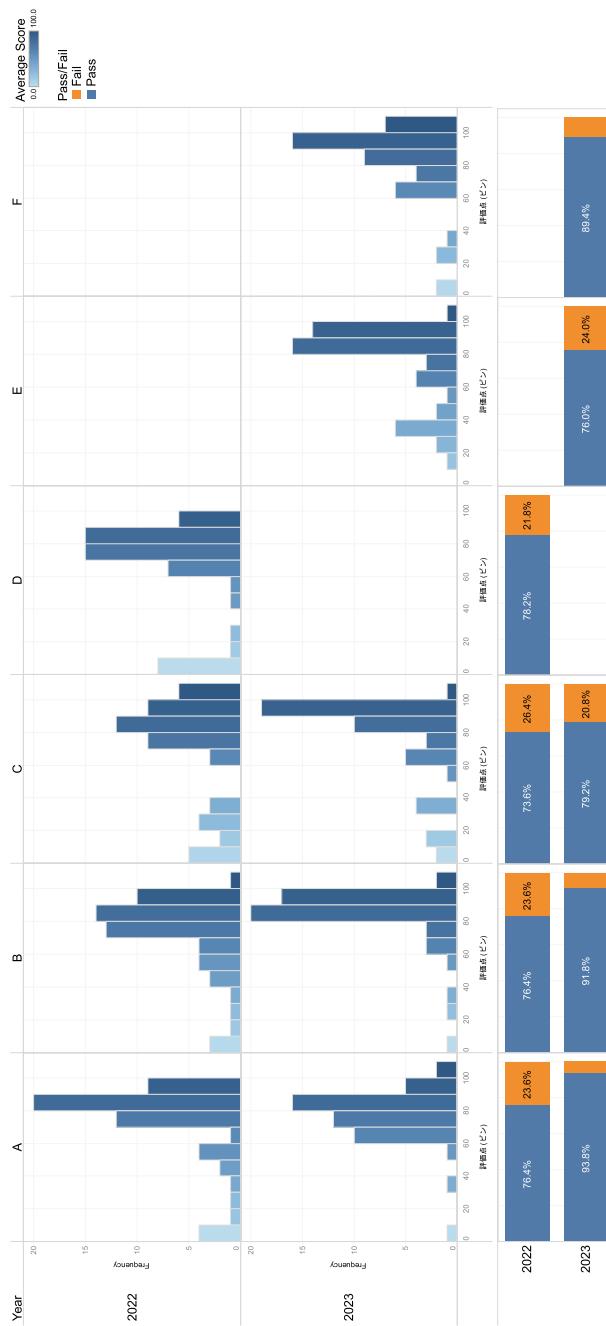
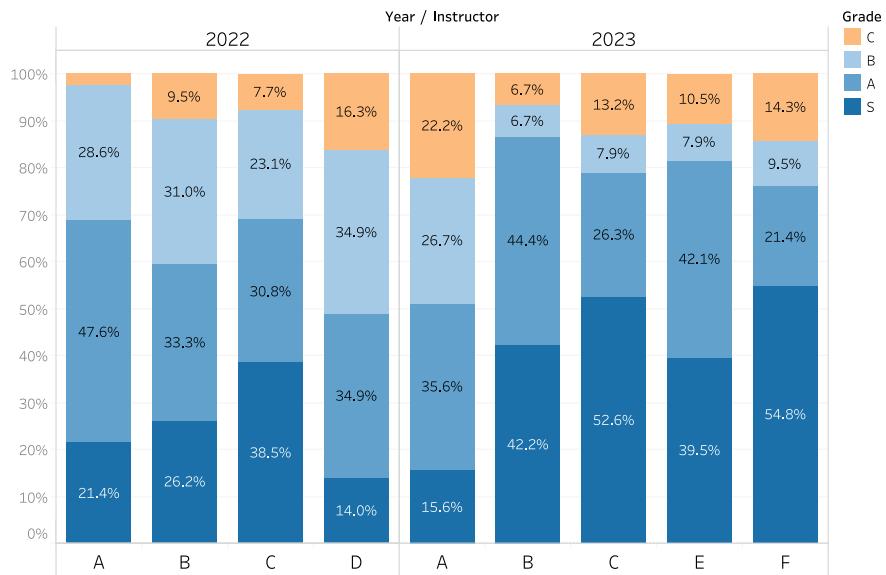
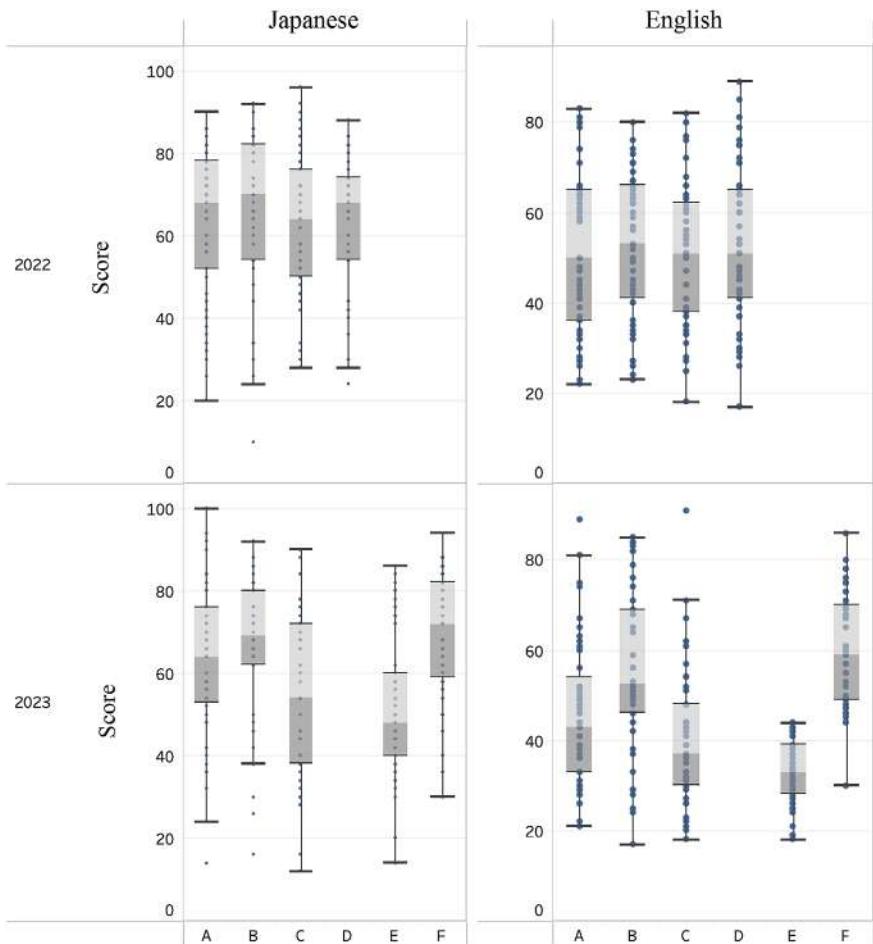


Fig. 1 Class-specific grade distributions and pass/fail ratios



**Fig. 2** Class-specific grading result

based on their specific needs. This proactive approach to information-sharing and data-driven decision-making can contribute to a more equitable and effective learning experience for all students, regardless of their assigned class or instructor.



**Fig. 3** Placement test scores

## 5 Conclusion

This study analyzed grading differences among instructors in a “Data Science and AI Education Program” course, a compulsory subject for first-year students at Hokuriku University. By treating the grades given by each instructor as sampling data and performing a test for the difference in population means, we found a significant difference in grading among instructors. Although such differences may be perceived negatively, it is essential to consider that the true nature of students in each class may vary, leading to justifiable differences in grading.

A crucial aspect of teaching a course with multiple instructors is the regular sharing of classroom experiences and reflections among teaching staff. This practice

enables instructors to understand whether differences in grading are owing to their grading methods or genuine differences in student characteristics. By fostering open communication and collaboration, instructors can ensure that their grading practices are fair, consistent, and aligned with course objectives.

Although this study focused on the results of a general education course at a single university, its findings have the potential to serve as a model for a growing number of general education courses in higher education. Therefore, the impact of this study on higher education in other universities is expected to be significant. By sharing our experiences and insights, we aim to contribute to the development of best practices for the design and delivery of general education courses, particularly in the context of data science and AI education.

Currently, “Data Science and AI Education Program” courses employ detailed grading criteria and rubrics, however, these are only available to individual instructors and are not shared among the teaching staff. In the future, we plan to develop a system that allows instructors to share, visualize, and compare fine-grained grading values in real-time. We aim to enhance the quality and consistency of education in the classroom by creating a collaborative platform for instructors to access and analyze grading data.

This study highlights the importance of monitoring and addressing grading differences among general education instructors. By fostering a culture of open communication, collaboration, and data-driven decision-making, universities can ensure that their general education programs provide students with high-quality and equitable learning experiences. As Hokuriku University continues to innovate and refine its “Data Science and AI Education Program,” we will continue to share our findings and contribute to the advancement of higher education in Japan and beyond.

## References

1. Cabinet office in Japan (2016) Society 5.0
2. Integrated innovation strategy promotion council decision (2019) AI strategy. <https://www8.cao.go.jp/cstp/ai/aistratagy2019en.pdf>. Accessed 1 Apr 2024
3. Ministry of internal affairs and communications (2018) The current status and challenges of digital transformation in business activities (Japanese). [https://www.soumu.go.jp/johotsusinto\\_kei/whitepaper/ja/r03/pdf/n1200000.pdf](https://www.soumu.go.jp/johotsusinto_kei/whitepaper/ja/r03/pdf/n1200000.pdf). Accessed 1 Apr 2024
4. Stolterman E, Fors AC (2004) Information technology and the good life. In: Kaplan B, Truex DP, Wastell D et al (eds) Information Systems Research: Relevant Theory and Informed Practice. Springer, US, Boston, MA, pp 687–692
5. Tajiri S (2024) University-wide data science education program selected for literacy level plus in MDASH. Educational academic newspaper
6. Tajiri S, Sugimori K (2024) Implementation of a data science & AI education program through in- classroom flipped learning and corporate collaboration. JSiSE research report 38:75–77
7. Tajiri S, Takamatsu K, Shiratori N, et al (2024) Integrating tableau into a first-year information literacy course: a practical approach to enhancing data science education. In: 16th international conference on data science and institutional research (DSIR 2024). p in press

# Data Analysis of the Factors Affecting Cryptocurrency by Using Machine Learning



Kazunori Minetaki

**Abstract** The rapid development of financial technology brings convenience to our society but may also create risks. Based on the e-SQ (electronic service quality) framework, this study aims to investigate how cryptocurrency's ease of use, reliability, responsiveness, and security affect customer satisfaction in Japan. The number of respondents is 1967. The methods of data analysis are SHAP (SHapley Additive ExPlanations), a cooperative game theoretic approach, and Random Forest using Lasso Regression, which enables feature selection. It was found that ease of use and reliability impacted customer satisfaction. It is noteworthy that security did not affect customer satisfaction. Blockchain technology enhances the security of cryptocurrency. Two-factor authentication and Cold Wallet were introduced as the security measurements of cryptocurrency in the questionnaire. The result of the data analysis implied that the customers possibly have little interest in such security measurements in Japan. The factors of reliability were the reasonableness of fees and validity of the spread, which is the difference between bid and offer prices. Putting all this together, the results suggested that the customers were less concerned with risk and more concerned with benefits in Japan.

**Keywords** e-SQ (electronic service quality) · Cryptocurrency · SHAP (SHapley Additive ExPlanations)

## 1 Introduction

The security, trust, and reliability of internet-based financial transactions form the backbone of our e-society. Information and Communication Technology has been influencing our society for several decades. However, harnessing the power of these technologies is not always straightforward. Rapid advancements bring about new threats. Through internet-based financial transactions, customers can save on transaction costs and avoid trips to the bank. Additionally, they can make inquiries and

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receive information via social media platforms like LINE. While these transactions offer convenience, they also come with inherent risks. Cryptocurrencies have revolutionized the financial landscape, offering a decentralized and secure method for transactions. Understanding customer satisfaction with cryptocurrency in this domain has become increasingly important.

This study explores cryptocurrency's distinctive nature, which leverages blockchain technology's decentralized power. As a peer-to-peer electronic monetary system, it operates beyond the control of governments and public financial institutions.

Consequently, unlike most other financial assets, cryptocurrencies are not associated with any central authority [6]. While blockchain technology has evolved from the initial digital currencies to current smart contracts, it still relies on cryptography for security. It's important to note that, due to a lack of underlying assets and other factors, the price of cryptocurrencies tends to be highly volatile, influenced by various elements such as user supply and demand dynamics.

Cryptocurrency presents both opportunities and risks. This study aims to investigate how cryptocurrency's ease of use, reliability, responsiveness, and security impact customer satisfaction.

## 2 Literature Review

Electronic Service Quality (e-SQ) constitutes a conceptual framework designed to evaluate the quality of online services provided by businesses, with a particular emphasis on e-commerce and digital transactions. This framework assesses multiple service quality dimensions essential for customer satisfaction in the online environment. The following section provides a detailed explanation of the key components and dimensions of e-SQ.

The key components of Electronic Service Quality (e-SQ) encompass several critical dimensions. Efficiency pertains to the ease and speed with which customers can access and utilize a website, necessitating a user-friendly interface, quick loading times, and straightforward navigation. Reliability evaluates the accuracy and dependability of the service, ensuring that customers receive products or services as described and on time, with minimal errors. Fulfillment measures the extent to which a website's promises regarding order delivery and item availability are met, including accurate product descriptions, stock availability, and timely delivery. Privacy addresses protecting customer information, emphasizing the importance of customers feeling secure about their personal and financial data. Responsiveness assesses how well the service handles customer inquiries and issues, focusing on the speed and effectiveness of responses to emails, chats, or calls and the ability to resolve problems satisfactorily. Compensation evaluates the mechanisms in place for addressing service failures and customer complaints, including policies for returns, refunds, and compensations for any inconvenience caused.

Notable among them are E-S-QUAL and E-RecS-QUAL, developed by Parasuraman et al. [13], which measure e-SQ in two stages—service encounter and recovery. The E-S-QUAL scale includes Efficiency, Fulfillment, System Availability, and Privacy, while the E-RecS-QUAL focuses on Responsiveness, Compensation, and Contact. Another significant model is WebQual, proposed by Branes and Vidgen [3], which evaluates e-SQ based on four dimensions: Usability, Information Quality, Service Interaction, and Website Design. Additionally, Yoo, and Donthu [20] introduced SITEQUAL, emphasizing ease of use, aesthetic design, processing speed, and security [14]. Various methodologies have been employed to assess e-SQ, including surveys and questionnaires, web analytics, and experimental designs. Structured surveys are commonly used to gather customer perceptions of e-SQ dimensions. Tracking user behavior on websites through web analytics provides insights into the practical aspects of e-SQ. Controlled experiments help understand the impact of specific e-SQ attributes on customer satisfaction.

Researchers employ various methodologies to assess e-SQ, ensuring a robust and multidimensional understanding of electronic service quality. Structured surveys and questionnaires are commonly utilized to gather customer perceptions and evaluations of e-SQ dimensions. These tools allow researchers to collect large-scale quantitative data, providing insights into the overall effectiveness and areas for improvement in e-SQ. Web analytics, which involves tracking website user behavior, offers a practical perspective on e-SQ by analyzing user interactions and experiences. This method helps identify patterns and issues that surveys may not capture. Furthermore, controlled experimental designs are employed to understand the specific impacts of individual e-SQ attributes on customer satisfaction. Through experiments, researchers can isolate and test the effects of variables such as website speed, user interface design, and security features, thereby understanding their influence on customer perceptions and behaviors.

Empirical studies consistently demonstrate that high e-SQ positively influences customer satisfaction, trust, and loyalty. For instance, Zeithaml et al. [21] found that efficient and reliable website performance significantly increases customer retention, highlighting the critical role of technical and functional aspects of e-SQ. Furthermore, research by Madu and Madu [11] underscored that security and privacy in building customer trust in e-commerce platforms is essential. These studies emphasize that customers are more likely to remain loyal and satisfied with online services that prioritize their security and privacy concerns and provide responsive and reliable service. This body of literature underscores the multifaceted nature of e-SQ and its profound impact on customer relationships in the digital marketplace.

As the cryptocurrency market continues to expand and evolve [17], understanding the factors that influence customer satisfaction becomes increasingly critical. Several key elements shape users' experiences and perceptions of cryptocurrency platforms. This review examines these factors, including security, usability, trust, volatility, and demographic variations, to provide a comprehensive overview of what drives customer satisfaction in the context of cryptocurrency.

Security is a concern for cryptocurrency users, given the prevalence of cyber threats and the irreversible nature of most blockchain transactions. Studies such as

those by Lee and Chung [10] highlight that perceived security significantly affects user satisfaction and trust in cryptocurrency platforms. Encryption and multi-factor authentication have enhanced user confidence and satisfaction [5].

The usability of cryptocurrency platforms is another critical factor influencing customer satisfaction. The Technology Acceptance Model (TAM) has been used to the context of cryptocurrency, indicating that ease of use and perceived usefulness are vital determinants of user acceptance and satisfaction [7]. Intuitive interfaces, clear transaction processes, and accessible customer support contribute to a positive user experience, increasing overall satisfaction [18].

Trust in cryptocurrency platforms and the broader ecosystem is crucial in shaping customer satisfaction. Trust is fundamental in online transactions, influencing user intentions and satisfaction [8]. In the context of cryptocurrency, trust can be derived from the perceived reliability of the platform, transparency in operations, and the reputation of the cryptocurrency itself. Trust in the technology and the organization behind the cryptocurrency significantly impacts user satisfaction and loyalty.

The inherent volatility of cryptocurrencies poses a unique challenge to customer satisfaction. Studies by Yermack [19] and Baur et al. [4] explore the effects of price volatility on user satisfaction, suggesting that while some users may appreciate the potential for high returns, others are deterred by the associated risks. Managing expectations and providing educational resources about volatility can help mitigate dissatisfaction related to price fluctuations.

Cryptocurrency adoption and satisfaction levels vary across different demographic groups. Younger, tech-savvy individuals are more likely to adopt and express satisfaction with cryptocurrencies than older demographics [16]. Additionally, as Karame et al. [9] explored, regional differences highlight how regulatory environments and cultural factors influence user satisfaction and adoption rates.

### 3 Data Analysis of Customer Satisfaction with Cryptocurrency

#### 3.1 Data Set

This study uses the data of the “Oricon dataset,” including cryptocurrency in Japan [12]. The number of respondents is 1967. This dataset provides customer satisfaction using cryptocurrency, specifically, “Overall, how satisfied are you with your experience?” and variables that possibly affect customer satisfaction, considering previous studies. All variables are on a 10-point Likert scale (10 points: Very satisfied ← → 1 point: Very dissatisfied), which was collected in 2021.

**Table 1** Category and item

|                       |                                                                                                         |
|-----------------------|---------------------------------------------------------------------------------------------------------|
| Ease of use/usability | Ease of account opening procedures                                                                      |
|                       | Smooth account opening process                                                                          |
|                       | Ease of viewing the application and website (charts, trading screens, etc.)                             |
|                       | Ease of use of the application and website (charts, trading screens. etc.)                              |
|                       | Variety of currencies                                                                                   |
|                       | Smoothness of transactions                                                                              |
|                       | The functionality of the application and site in transactions (alerts, point redemption function, etc.) |
|                       | Abundance of information provided (market information, etc.)                                            |
|                       | Quality of information of campaign details (market information, etc.)                                   |
|                       | Ease of understanding of campaign details (e.g., eligibility requirements)                              |
| Reliability           | Full campaign content                                                                                   |
|                       | Ease of understanding how to contact us                                                                 |
| Responsiveness        | Relevance of the spread (difference between bid and offer prices)                                       |
|                       | Reasonableness of fees (transactions, deposits, withdrawals, etc.)                                      |
|                       | Clarity of information disclosed (currency handled, fees, security system, etc.)                        |
|                       | Company Credibility                                                                                     |
| Security              | Responding to inquiries                                                                                 |
| Security              | Stability of system and Internet connection                                                             |
|                       | Security measures (two-step verification, cold wallets, etc.)                                           |

### 3.2 Conceptual Framework

This study is based on e-SQ because our target variable is customer satisfaction, which e-SQ has mostly researched. This study investigates the effects of six dimensions: (1) Ease of use/usability, (2) Reliability, (3) Responsiveness, and (4) security (Table 1).

### 3.3 Methodology

As mentioned, many previous studies have used PLS-SEM with a small sample. One of the criticisms of PLS-SEM is this point. PLS is misunderstood to handle small sample sizes and non-normality [15]. SEM, which utilizes maximum likelihood, is distorted with a small sample and non-normality; therefore, PLS-SEM is often used instead of SEM. The problem with PLS, however, is that it cannot test systems of equations causally (i.e., overidentifying restrictions cannot be tested), nor can it directly estimate standard errors of estimates [2]. SEM and PLS-SEM are not appropriate when the explanatory variables may have endogeneity. PLS-SEM could be

sensitive to sample size. PLS-SEM tends to be more lenient in its assumptions about measurement models. While this flexibility can be advantageous in some cases, it can also lead to oversimplification or misspecification of measurement models. First, this study adopted Machine learning such as SHAP (SHapley Additive exPlanations).

SHAP (SHapley Additive exPlanations) is a cooperative game theoretic approach that explains the output of any machine learning model. SHAP (SHapley Additive exPlanations) is the unified approach for model interpretation proposed. Machine learning and deep learning Machine learning (ML) and deep learning (DL) have become more prevalent in data analysis because they can identify patterns in the data. ML and DL models can continuously learn and adapt from new data, improving their performance over time. This capability is essential in dynamic environments where patterns and trends evolve. However, those methods are criticized due to their black-box nature. Explainable Artificial Intelligence (XAI), including SHAP, is expected to improve the transparency of the model based on Machine learning and deep learning.

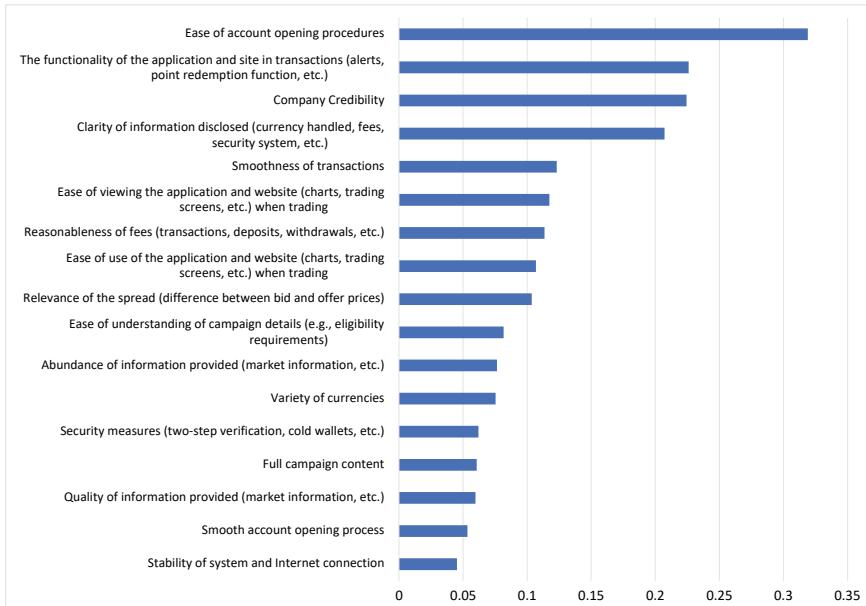
This study aims to examine the factors that support the infrastructure of an e-society; therefore, it mainly focuses on the security, trust, and reliability of the services in Internet-based financial transactions, referring to the e-SQ mentioned above. This study categorizes each item into (1) ease of use/usability, (2) reliability, (3) responsiveness, and (4) security in analyzing the effects on customer satisfaction of cryptocurrency usage.

Customers can trade cryptocurrency at a crypto asset exchanger, a platform or service that allows users to buy, sell, trade, and manage various cryptocurrencies and digital assets.

Ease of account opening procedures has the highest impact on customer satisfaction (Fig. 1). Items for which the absolute value of the mean SHAP value is above 0.2 are ease of account opening procedures, the functionality of the application and site in transactions, company credibility, and clarity of information disclosed. The former three are included in the ease of use/usability factor, and the latter are included in the reliability factor.

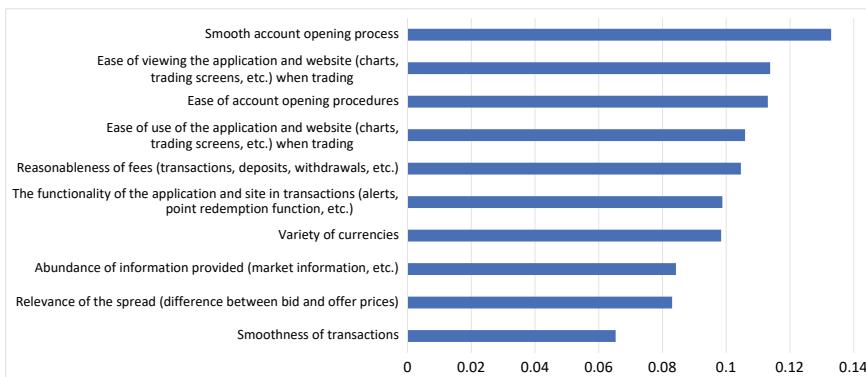
Next, feature selection was meticulously performed using both Random Forest and LASSO regression as embedded methods. This hybrid approach capitalizes on the distinctive strengths of each technique. Random Forest, with its ensemble learning nature, excels in capturing intricate interactions and non-linear relationships among the features, thereby providing a comprehensive understanding of the variable importance. On the other hand, LASSO regression, known for its regularization properties, adeptly manages multicollinearity and performs effective variable selection by shrinking less important feature coefficients to zero. By combining Random Forest and LASSO for variable selection, we harness the synergy of these two methods, resulting in a robust and efficient feature selection process that enhances model performance and interpretability.

SHAP did not indicate which explanatory variables should be selected. The results of the feature selection suggest the optimal combination of factors as follows: smooth account opening process, ease of viewing the application and website, ease of account opening procedures, ease of use of the application and website, reasonableness of fees, functionality of the application and site in transactions, variety of currencies,



**Fig. 1** Absolute value of mean of SHAP value

abundance of information provided, relevance of the spread, and smoothness of transactions. It was found that factors related to ease of use/usability and reliability were selected. The results of calculating feature importance are shown in Fig. 2.



**Fig. 2** Feature importance

## 4 Discussions

The results of SHAP, Random Forest, and Lasso Regression for feature selection indicated that (1) ease of use/usability and (2) reliability impacted customer satisfaction. Notably, (3) security did not affect customer satisfaction. It is important to investigate further why security did not impact customer satisfaction in Japan. Future studies should also explore the effects of user attributes, such as age, frequency of use, and length of experience in cryptocurrency transactions, as these factors may influence customer satisfaction. Teenagers, for instance, are more receptive to new technologies and adapt easily to cryptocurrency [1].

The data analysis in this study was based on the theoretical framework of e-SQ. However, the factors used in e-SQ have varied in prior literature. Therefore, it is necessary to develop a framework that accurately captures the unique characteristics of cryptocurrency.

## 5 Conclusion

Based on the e-SQ (electronic service quality) framework, this study aims to investigate how cryptocurrency's ease of use, reliability, responsiveness, and security affect customer satisfaction in Japan. The results showed that ease of use and reliability significantly impacted customer satisfaction, while security did not. Although blockchain can strengthen the security of cryptocurrencies, this study found that customers might have little interest in these security measures in Japan.

Blockchain technology offers many features that significantly enhance the security of cryptocurrencies. It operates on a decentralized network managed by numerous nodes, ensuring that the entire network remains unaffected even if a single node is attacked or fails. Transactions are protected by public key cryptography, which ensures that only those with the private key can approve transactions, preventing unauthorized access. The blockchain network is also monitored in real time, with immediate alerts triggered for any suspicious activities or abnormal transactions.

The questionnaire introduced two-factor authentication and Cold Wallet as security measures for cryptocurrency. Despite these measures, the data analysis suggested that customers in Japan may not prioritize security. Instead, the factors of reliability, such as the reasonableness of fees and the validity of the spread (the difference between bid and offer prices), were more significant. Overall, the results suggested that Japanese customers are more concerned with the benefits of cryptocurrency rather than the risks.

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## References

1. Alaeddin O, Altounji R (2018) Trust, technology awareness and satisfaction effect into the intention to use cryptocurrency among generation Z in Malaysia. *Int J Eng Tech.* 7 (4.29): 8–10
2. John A, Bendahan S, Jacquart P, Lalive R (2010) On making causal claims: a review and recommendations. *Leadersh Q* 21(6):1086–1120
3. Barnes SJ, Vidgen RT (2002) An integrative approach to the assessment of e-commerce quality. *J Electron Commer Res* 3(3):114–127
4. Baur DG, Hong K, Lee AD (2018) Bitcoin: medium of exchange or speculative assets? *J Int Financ Mark Inst Money* 54:177–189
5. Chen Y, Lai M (2017) The effects of security and usability on customer satisfaction in mobile banking. *Int J Inf Manag* 37(2):108–117
6. Corbet S, Lucey B, Urquhart A, Yarovaya L (2019) Cryptocurrencies as a financial asset: a systematic analysis. *Int Rev Financ Anal* 62:182–199
7. Davis FD, Bagozzi RP, Warshaw PR (1989) User acceptance of computer technology: a comparison of two theoretical models. *Manag Sci* 35(8):982–1003
8. Gefen D, Karahanna E, Straub DW (2003) Trust and TAM in online shopping: an integrated model. *MIS Q* 27(1):51–90
9. Karame GO, Androulaki E, Capkun S (2015) Double-spending fast payments in bitcoin. *Proceedings of the 2012 ACM conference on computer and communications security*
10. Lee D, Chung J (2009) Understanding factors affecting trust in and satisfaction with mobile banking in Korea: a modified DeLone and McLean's model perspective. *Interact Comput* 21(5–6):385–392
11. Madu CN, Madu AA (2002) Dimensions of e-quality. *Int J Qual Reliab Manag* 19(3):246–258
12. Oricon ME Inc.: Customer satisfaction survey data. Informatics research data repository. National institute of informatics. (2023) <https://doi.org/10.32130/idr.10.1>
13. Parasuraman A, Zeithaml VA, Malhotra A (2005) E-S-QUAL: a multiple-item scale for assessing electronic service quality. *J Serv Res* 7(3):213–233
14. Rotchanakitumnuai S (2008) Measuring e-government service value with the E-GOVSQUAL-RISK model. *Bus Process Manag J* 14(5):724–737
15. Mikko R, McIntosh CN, Antonakis J (2015) On the adoption of partial least squares in psychological research: caveat emptor. *Personality Individ Differ* 87:76–84
16. Schuh S, Shy O (2016) U.S. consumers' adoption and use of Bitcoin and other virtual currencies. *Federal Reserve Bank of Boston Working Paper Series*
17. Singh AK, Kumar M (2024) Navigating the digital gold rush: An in-depth analysis of crypto currency markets through machine learning techniques
18. Yang H, Lee H, Zo H (2015) User acceptance of smart home services: an extension of the technology acceptance model. *Ind Manag Data Syst* 115(6):1130–1147
19. Yermack D (2013) Is Bitcoin a real currency? An economic appraisal, National Bureau of economic research working paper
20. Yoo B, Donthu N (2001) Developing a scale to measure the perceived quality of an internet shopping site (SITEQUAL). *Q J Electron Commer* 2(1):31–46
21. Zeithaml VA, Parasuraman A, Malhotra A (2002) Service quality delivery through web sites: a critical review of extant knowledge. *J Acad Mark Sci* 30(4):362–375

# Performance Comparisons of Private AI Chatbot and Public AI Chatbot



Pavan Sai Bolliboina and John Jenq

**Abstract** In this paper, we develop an AI chatbot portal using Python Flask server. LangChain was used for setting up the backend process. For phase one, we load and process our PDF documents and use LangChain's text splitter, RecursiveCharacterTextSplitter, to break up these documents into smaller chunks. HuggingFaceEmbeddings is then used to create embeddings for each chunk and we use Facebook AI Similarity Search (FAISS) to index the embeddings. For phase two, the Question and Answer, FAISS is used to retrieve relevant chunks. CTransformers is used for language model interactions and uses these chunks to generate the answer. The answer is then displayed on the browser screen. For comparison purposes, we develop three versions of this system. The first version utilizes data and knowledge from a pdf on the local store. The second version uses Google search engine AI APIs to send the query and receive the query result. The third one is a hybrid form which uses the local bot to handle the query. If it is unable to do so, it will then fall back to use the search engine AI bot. This paper will only examine and compare the results of version 1 and version 2. We will also briefly discuss the advantages and disadvantages of public and private AI bots, as well security concerns. According to our experimental results, the search engine AI outperforms the private local AI bots.

**Keywords** Chatbot · LangChain · HuggingFaceEmbeddings · LLM · FAISS · CTransformers

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## 1 Introduction

Research in the field of conversational AI has evolved rapidly due to advancements in natural language processing (NLP) and deep learning. Real time communication has experienced a transformation, with the introduction of chatbot technology enabling interactions across different locations. While chatbots have been around for some time, they have recently gained recognition after ChatGPT became viral in 2022.

The effectiveness in human-like communication of chatbots encourages humans to use them to search for solutions in daily life. In [1], Devlin et al. introduced Bidirectional Encoder Representations from Transformers (BERT) which revolutionized the field of NLP by demonstrating that pre-trained transformers can achieve great performance in various tasks, such as answering questions and conversational AI. In [2], Brown et al. presented GPT-3, a large-scale transformer model capable of understanding and generating human-like text. It showed the potential of large language models for creating conversational agents and QA systems. [3] FAISS home is the home for Facebook AI Similarity Search (FAISS) and is described in its documentation [4] as a library for efficient similarity search and clustering of dense vectors, and it has the ability to search k-nearest neighbors. In [5], Janakiram described LangChain as an SDK which simplifies the integration of large language models (LLMs) and applications by chaining together components and exposing a simple and unified API. LLMs have become increasingly significant in many areas, as it provides natural language processing capabilities, prediction analysis, and help in the decision-making process. LangChain is a framework that integrates with external tools to form an ecosystem. It makes the life of a software developer easier by collecting all the required components for creating private chatbots.

Chatbots and the technology behind them are widely used in many places and in various ways. For example, in [6], Athikkal and Jenq implement a hospitality chatbot to answer various questions related to the hospitality industry. In [7], Aguinis et al. used generative AI as a human resource management assistant to help users finish tasks faster. The authors of [8] investigated LLMs in food science application, while the authors of [9] investigated the use of LLMs in the areas of clinical and anatomic pathology.

## 2 System Design and Implementation

The frontend design of our system involves creating the user interface and handling interactions to ensure a user-friendly experience. The chatbots visual layout is crafted using HTML for structure and uses JavaScript for features. Flask session management enables the chatbot to sustain context across interactions offering users a seamless and natural experience.

For the backend design: (1) Flask is utilized to establish the web server and define where the chatbot communicates. It handles HTTP requests and sets up the structure

for backend operations. (2) The system incorporates FAISS for information retrieval. The backend is responsible for managing the loading of data vectors and ensuring retrieval based on user queries. (3) For the language model processing, the chatbot utilizes CTransformers to handle queries and formulate responses. The backend oversees interactions with the language model and deals with context requirements. (4) Through Flask's session management, the chatbot can retain conversation context across user engagements.

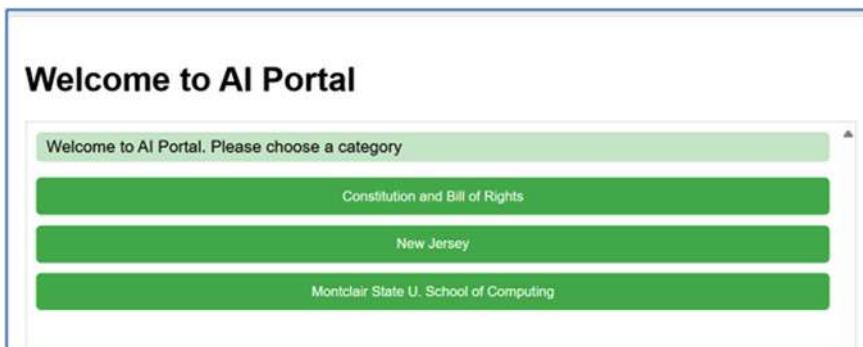
For the data management, the system utilizes FAISS (Facebook AI Similarity Search) to establish a vector-based storage mechanism. This involves storing embeddings generated from text data for access, during user query processing. The vector store is pivotal for the chatbot's capability to provide responses.

### 3 Experimental Results

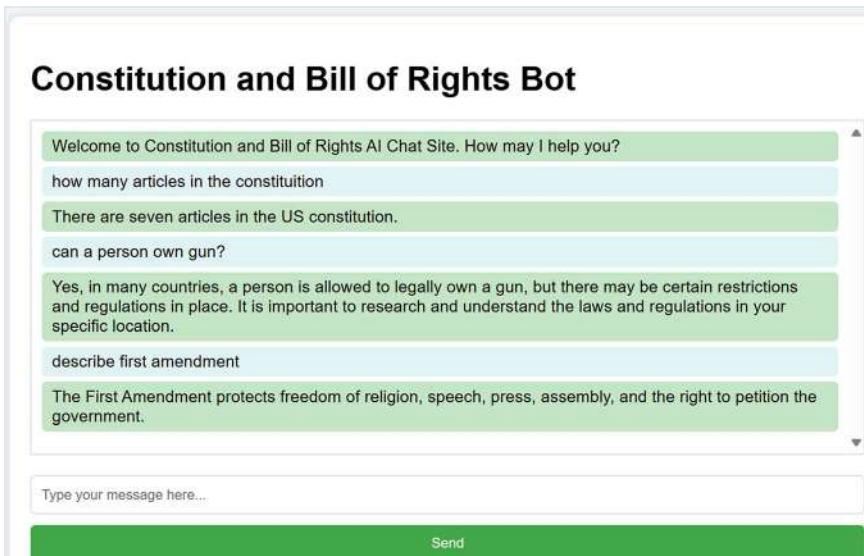
Figure **Fig.1** shows the landing page of our portal. Clicking on each button will redirect users to a different chatbot.

Figure **Fig. 2** shows a screenshot of the Constitution and Bill of Rights chatbot interacting with the user where three questions are asked and answers are displayed.

**Table 1** shows the results of our experiment. It lists the questions, response time and answers from private bot and public bot. The public bot used was the Google search engine AI API.



**Fig. 1** The AI portal home page



**Fig. 2** System and user interaction of constitution and bill of rights chatbot

**Table 1** Comparison of response time and answers of private AI bot and public AI bot

| Question                                                                                | Local AI answer                                                                                                                                                                                      | Time       | Search engine answer                                                                                                      | Time      |
|-----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|---------------------------------------------------------------------------------------------------------------------------|-----------|
| How many articles in the constitution<br><i>(a typo but still get the right answer)</i> | The constitution of the united states of America contains 7 articles.                                                                                                                                | 9.28 sec.  | Seven                                                                                                                     | 5.27 sec. |
| Can a person own gun?                                                                   | Yes, a person can own guns under the constitution and laws of most states.                                                                                                                           | 9.51 sec.  | Yes, a person can own a gun in New York City, but they must have a license or permit issued by the NYPD license division. | 3.77 sec. |
| Describe first amendment                                                                | The first amendment protects freedom of speech, religion, assembly, petition, and the press. It also protects against self-incrimination (the right to remain silent or refuse to answer questions). | 12.25 sec. | The first amendment protects freedom of religion, speech, press, assembly, and the right to petition the government.      | 3.80 sec. |

## 4 Concluding Remarks

We implement chatbots on local machine and compare their usage with the public AI chatbots. In our preliminary testing, the results indicated that public AI bot outperform all private bots with regards to the turnaround time, which we define as the time it takes from making the request to getting the response back. We will discuss the correctness of the query below. There are both pros and cons of using private AI bots.

One of the advantages of using private AI bots is that we can shorten the query in certain situations. For example, in our New Jersey chatbot, we can simply ask *where is the capital* rather ask *where is the capital of New Jersey* because we are using NJ bot. During our testing, we also asked the NJ bot for the percent of the population that speaks Spanish, and it returned a numerical value. On the other hand, asking the Google search engine AI using API for the percentage of Spanish speakers gives the following response: “Observation: Native Spanish speakers make up 6.3 percent of the world’s population. Spanish speakers in general (including non-native speakers and Spanish language learners) make up 7.5 percent of the world’s population. Spanish is the 2nd most spoken native language after Mandarin Chinese.” Since the goal is to get the percentage of the NJ population who speaks Spanish, the answer given by the public AI bot is not what we were looking for.

However, there are also disadvantages to using local private AI bots. It has a slower response time compared with the public bot. There is potential for this to change in the future if computer processing speed improves rapidly and outperforms network communication speed. But if not, then public bots have better performance in terms of response time. Private bots also have a narrower scope, so they may not be able to keep up to date as new technologies keep developing. However, some may argue that this is an advantage rather than a disadvantage, because this means public bots may be more susceptible to being polluted with false information data, in which case the private bot would contain more accurate information.

We believe private AI bots will become increasingly important for industries. Some may wonder why private AI bots would still be useful even though its performance is not significantly better when compared with that of directly using public AI bots on browser. Why wouldn’t we just use publicly available AI bots? There are reasons, two of which we will discuss below.

The first is to prevent leakage of business secrets and proprietary data. Although ChatGPT can be a valuable tool to help banks to serve their customers better, reduce operational costs and reduce risks [10], several major banks have restricted their employees’ use of ChatGPT. These banks include Bank of America, Deutsche Bank, JPMorgan Chase, Citigroup, Goldman Sachs, and Wells Fargo. Employees at such institutions may encounter limitations on using ChatGPT [10–13] as these institutions have a responsibility to protect sensitive business information and to prevent them from being publicly available.

The second is that we can customize our local private AI. For example, we can add private information that public AI chatbots may not be aware of. In our implementation, this means adding more PDF files which contains information, data or knowledge. Doing this makes the local private AI more powerful than open AI bots as the results can be refined further.

## 5 Future Improvement of the System and Work

There are various ways the system can be improved and enhanced. We consider some of the possible future work below:

- (a) The current prototype uses CPU, so we can use GPU to speed up the process. As the newly AI-powered NPU is similar to GPU, we expect using GPU might help it run even faster.
- (b) Apply concept of caching to store questions and answers for quick reply. This can be implemented using data structure like Python dictionary and we can consider pre-processing the questions by removing stop words and special chars, converting to all lowercase, etc.
- (c) Since chunks of data are embedded into embeddings so that FAISS can select the best relevant chunks, which in turn will feed into LLM in order to generate the output as the answer for the query, we can consider tuning the chunk size by modifying the parameters of LangChain Splitter to find the best possible chunk size.
- (d) Implement multi-turn conversation capabilities, enabling the bot to handle more complex queries and scenarios.

The current system retrieves information from a collection of PDF documents using FAISS. Future improvements could also involve: (i) Advanced Embeddings: experiment with different embedding techniques to increase retrieval accuracy, or (ii) Larger Document Corpus: expand the document collection to include a broader range of sources, allowing for more comprehensive answers.

Looking beyond to a larger scale, with regards to future work on chatbots in general, another question to consider is how to manage historical information and knowledge. How would we efficiently embed changes or updates on data, information or knowledge so that a query can be correctly answered? For example, we asked Microsoft Co-Pilot for the names of faculty who were in the Computer Science Department at Montclair State University in the year 1999. Instead, it listed all the current faculty members and falsely identified them all as faculty from 1999. This is due to the lack of record keeping of past information. Another area to consider is the management of chatbots. Is there a way for large organizations, companies or the government to organize a repository to gather these AI bots that developers want to share to the public? These are all questions and problems that would be worthwhile to investigate in the future.

## References

1. Devlin J, Chang MW, Lee K, Toutanova K (2018). BERT: pre-training of deep bidirectional transformers for language understanding. arXiv preprint [arXiv:1810.04805](https://arxiv.org/abs/1810.04805)
2. Brown TB, Mann B, Ryder N, Subbiah M, Kaplan J, Dhariwal P, Neelakantan A, Shyam, P, Sastry G, Askell A, Agarwal S, Herbert-Voss A, Krueger G, Henighan T, Child R, Ramesh A, Ziegler DM, Wu J, Winter C, Radford A (2020) Language models are few-shot learners. arXiv preprint [arXiv:2005.14165](https://arxiv.org/abs/2005.14165)
3. FAISS home, <https://github.com/facebookresearch/faiss/wiki>, last accessed 2024/5/20
4. Welcome to FAISS documentation, <https://faiss.ai/>, last accessed 2024/5/20
5. Janakiram MSV (2023) A brief guide to LangChain for software developers. <https://www.infoworld.com/article/3705097/a-brief-guide-to-langchain-for-software-developers.html>, Accessed 2024/5/20
6. Sagina A, John J (2022) An implementation of voice assistant for hospitality. Signal Image Processing: An Int J (SIPIJ) 13(2/3/4)
7. Aguinis H, Beltran JR, Cope A (2024) How to use generative AI as a human resource management assistant. Organizational Dynamics, ORGDYN 53:101029
8. Peihua M, Shawn T, Yiyang H, Xiaoxue J, Dongyang Z, Ning Y, Qin W, Ahuja JKC, Cheng-I W (2024) Large language models in food science: innovations, applications, and future. Trends Food Sci Technol 148(104488)
9. Hart SN, Hoffman NG, Peter G, Chancey C, Clintock DSM, Miller LJ, Jackups R, Vahid A (2023) Nicholas Spies, Victor Brodsky, Organizational preparedness for the use of large language models in pathology informatics. J Pathol Inform 14(100338)
10. Understanding (and using) ChatGPT in banking. 10-13 was used in prevent secrets leak <https://bankingjournal.aba.com/2023/04/understanding-and-using-chatgpt-in-banking/> , Accessed 2024/5/20
11. Brian B (2023) Workers' ChatGPT Use restricted at more banks—including goldman, citigroup, on Forbes. <https://www.forbesmiddleeast.com/innovation/technology/workers-chatgpt-use-restricted-at-more-banksincluding-goldman-citigroup>, last accessed 2024/5/20
12. Major banks restricting use of ChatGPT | Visbanking. <https://visbanking.com/major-banks-restricting-use-of-chatgpt/>, last accessed 2024/5/20
13. Banking majors join JP Morgan in barring use of ChatGPT. <https://www.retailbankerinternational.com/news/banking-majors-bar-chatgpt-use/>, last accessed 2024/5/20

# Exploring the Landscape of Digital Transformation in Small and Medium Enterprises: A Bibliometric Analysis



Nawal Ilahiane , Abdellatif Aziki , Moulay Hachem Fadili , Olivier Colot , and Jonathan Bauweraerts

**Abstract Purpose:** The study aims to investigate the digital transformation of small and medium enterprises (SMEs) by analyzing research articles published between 2014 and 2024 in the field of business. **Method:** A total of 102 studies were selected based on inclusion criteria like containing keywords related to digital transformation and SME concepts, being published in English, and falling within the specified timeframe. **Results:** The bibliometric analysis revealed a growing trend of SMEs adopting digital technologies, particularly in the manufacturing sector. Key technologies highlighted include, artificial intelligence, big data analytics, internet of Things and cloud computing. The study also emphasized the benefits of digital tools in enhancing operational functions, addressing challenges like the COVID-19 crisis, and improving productivity. **Conclusion:** The findings underscore the increasing importance of digital transformation for SMEs, offering opportunities for efficiency gains, cost reduction, and enhanced customer interactions. Embracing digital technologies not only modernizes businesses but also empowers employees to develop digital skills and adapt to the evolving digital landscape, ultimately positioning SMEs for sustainable growth and competitiveness in the digital era.

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**Keywords** Digital transformation · Bibliometric analysis · Small and medium enterprises

## 1 Introduction

During the last decade, the concept of digital transformation (DT) has sparked the interest of researchers from different disciplines. This amounts to the evolution of digital technologies that are fundamentally changing processes, relationships, products and services [1], and pushing companies to radically change the organization of work and rebuild a new balance in its ecosystem [2]. Digital transformation is a process leading to the rebuilding of an organization's business ecosystem through the use of digital technologies and capabilities [3]. It became a necessity not just a technological opportunity [4]. Digital transformation aims to bring a positive change to the properties of organizations from the creation of combinations of information technologies, computing, communication and connectivity [5]. In fact, the definitions of digital transformation differ from the practice of technologies to improvements in processes, customer relations, operations, and performance to contribute to the creation of new business models [4]. Digital transformation is empowered by two cores: technology and organizational change. In terms of technology, it means the application of information technology in a business's production process. In terms of organizational change, digital transformation is mainly based on changes in business models and organizational processes to enhance business performance [3].

The future of any country's economy rely on the capacity of companies and businesses to successfully transform in a digital business environment [6]. Actually, digital transformation has become a critical factor of new business strategy, which plays an essential role in the creation, resilience, success, and sustainability of organizations, particularly for small and medium-sized enterprises (SMEs) [7]. For this reason, fostering digital transformation (DT) of business includes new operating, new competencies and a new organizational structures [8]. However, the implementation of DT has proven to be a complex and difficult process for many companies, especially for SMEs [9, 10]. Due to limited resources and insufficient capacity, SMEs are the category most facing difficulties in successfully implementing the digital transformation [1].

In light of the significance of digital transformation for small and medium enterprises over the past decade, a comprehensive bibliometric analysis was conducted to systematically assess the evolution of research in this domain. This bibliometric analysis delves into the evolution of research in digital transformation of small and medium enterprises over the past ten years. The study aims to elaborate an overview of the global literature on DT and its applications in small and medium enterprises, focusing on the period from 2014 to 2024. It tries to examine the current state, the advancements, and the impact of digital transformation on SME by exploring the most technologies adopted by SMEs, the field in which SMEs have most adopted

DT, the internal/external factors promoting DT of SMEs, the main obstacles encountered by SMEs in implementing this process. So to make a detailed overview to our study, we will try to answer the ensuing research question: **What is the current state of SMEs regarding digital transformation?**

## 2 Methodology

### 2.1 Protocol and Research Framework

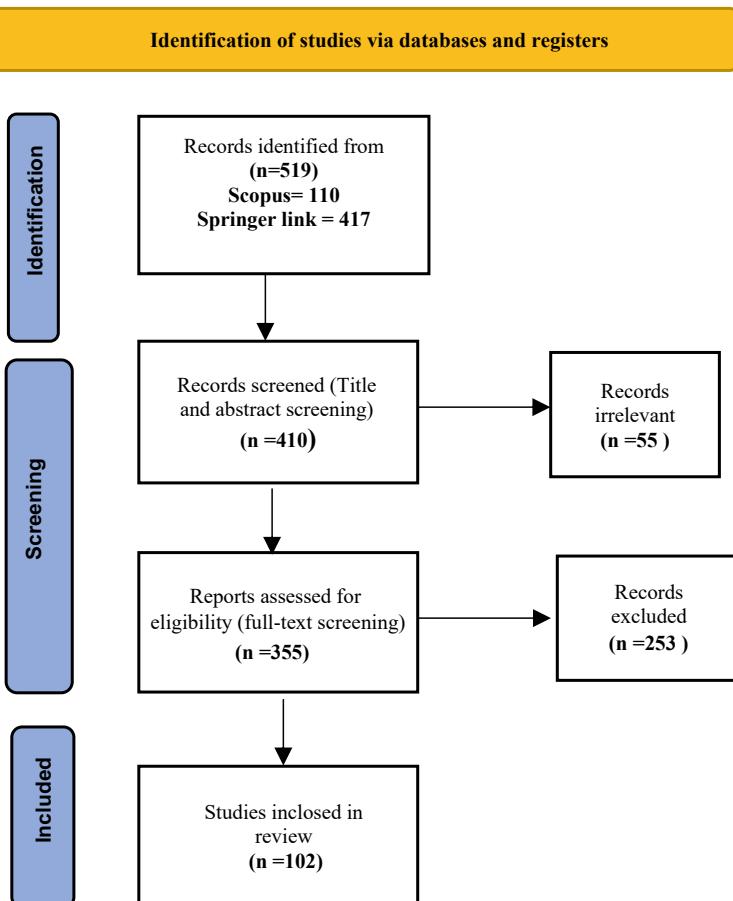
To address the research question, the study used a bibliometric approach and content analysis. It aims to understand the development of the topic. Bibliometric provides a helpful technique and it is one of the best approach to evaluate research because it's a unprejudiced way that saves time compared with estimating articles by reading them. This bibliometric analysis is conducted by following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) introduced by [11], Fig. 1 exposes the PRISMA flowchart that illustrates the steps followed in this study. The next section demonstrates the methodology process used to conduct the study tests.

### 2.2 Information Gathering

The study used a sample of research publications collected by Scopus and Springer Link, these databases known by its quality and its credibility, which ensures the quality of the relevant scientific studies gathered. Then, as a tools used to research, analyze and interpret the data collected and address the research question accurately, the study is based on Microsoft Excel and covariance. The study used online refinements and cursory examination from six researchers of each article to verify that the articles are related to the research question. Also, the research focused on research published between 2014 and 2024. To collect an important number of relevant studies, we created a data extraction sheet including keywords related to digital transformation and small and medium enterprises.

### 2.3 Inclusion and Exclusion Criteria

Each selected paper was examined manually, ultimately resulting in a total number of 519 relevant searches. This number of studies was focused on inclusion criteria chosen by reviewers as shown in (Table 1). In fact, the selection was carried out only



**Fig. 1** PRISMA flow diagram of the study, processed results

on english open access articles published in the areas of business and management during the period (2014–2024).

To make an exhaustive examination of the existing literature, we used the following boolean function as demonstrated in Table 2.

**Table 1** Inclusion/ exclusion criteria

| Articles were included:                                                                                                                                              | Articles were excluded:                                                                                                                              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| Contains keywords related to the digital transformation and SME concepts<br>Articles published in area of business and management<br>Published between 2014 and 2024 | Published in the other languages<br>Identified as duplicates<br>Not published into the specified timeframe<br>Deemed irrelevant to the study's focus |

**Table 2** Boolean research

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“Digital transformation” OR “Digitalization” OR “Digital transition” OR “Industry 4.0” OR “Technology” OR “Technology adoption” OR “Digital technologies” AND “SME” OR “small and medium enterprises” OR “small and medium business” OR “small and medium companies”

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## 2.4 Screening and Data Abstraction

To make an exhaustive examination, we were passed to screening and data abstraction stage via Covidence tool. Two phases carried out at this level as follows; (1) screening of the title and abstract: by looking at the title and the abstract, we can identify if the article could be relevant to our research question or not. In our case, we kept 355 article. (2) Screening the full text: in this phase, we examined the full texts that included at the first phase. at the end, we kept 102 articles.

## 3 Results

### 3.1 Bibliometric Analysis

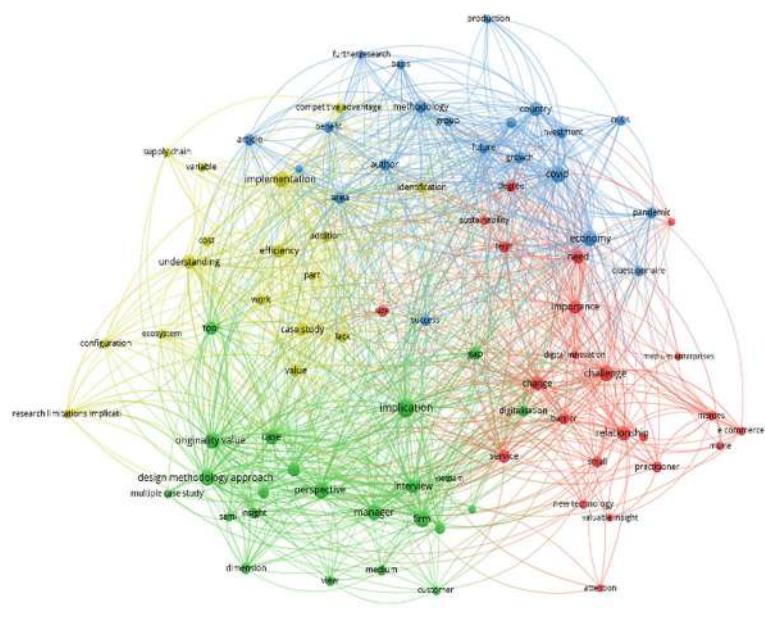
Bibliometric analysis is a quantitative method used to evaluate patterns of publication, citation, and collaboration within a specific field of study [12]. By examining these patterns, researchers can gain valuable insights into the scholarly landscape, identifying influential authors, highly cited papers, key journals, and trends that have emerged over time. This type of analysis plays a crucial role in understanding the impact and reach of research within a particular discipline [12].

The results of a keyword co-occurrence analysis and title/abstract terms mapping were presented in the bibliometric analysis conducted as part of this review using the WOSviewer software.

The study focused on investigating the connections and structures among keywords derived from author-provided keywords, titles, and abstracts. Through the examination of keyword co-occurrence and the visualization of relevant terms' distribution, valuable insights were gained into the thematic groupings, prevalent topics, and emerging trends present in the literature under review.

Authors meticulously select keywords to succinctly encapsulate the essence of their papers. By examining the map of keyword co-occurrence, researchers can discern the interrelationships and patterns among different keywords. In this visual representation, nodes symbolize the keywords themselves, while the edges that link them signify the connections or associations between these terms. The keyword network, as illustrated in Fig. 2, offers a comprehensive view of these relationships.

Challenge, implication, originally value and implementation are the most frequent keywords used by authors within the domain of digital transformation and SME intersection.



**Fig. 2** Keywords linked to DT of SME

*Cluster 1—Digital Transformation Challenges for Small and Medium Enterprises (SMEs) (red):* implementing digital transformation in small and medium enterprises (SMEs) poses several challenges that need to be addressed for successful integration. One significant challenge is limited resources, both concerning of budget and skilled personnel. SMEs often operate on tighter budgets compared to larger corporations, making it difficult for them to invest in expensive digital technologies essential for digital transformation, putting SMEs at a disadvantage in today's competitive market. Another key challenge is resistance to change within SMEs. Employees may be accustomed to traditional ways of working and reluctant to hold new digital tools and processes. Overcoming this resistance needs clear communication and transform change management strategies about the digital transformation's advantages, and proposing adequate coaching to ensure employees are comfortable with the new technologies being implemented.

**Cluster 2—Enhancing Value and Perspective for Small and Medium Enterprises:** Digital transformation has significantly impacted small and medium enterprises (SMEs) by revolutionizing their operations, customer interactions, and overall business models. Initially, SMEs faced challenges in adopting digital technologies due to limited resources and expertise. However, as the digital landscape evolved, SMEs began to recognize the immense value that digital transformation could bring to their businesses.

### *Cluster 3—Digital Transformation Efficiency and Cost Considerations for SMEs.*

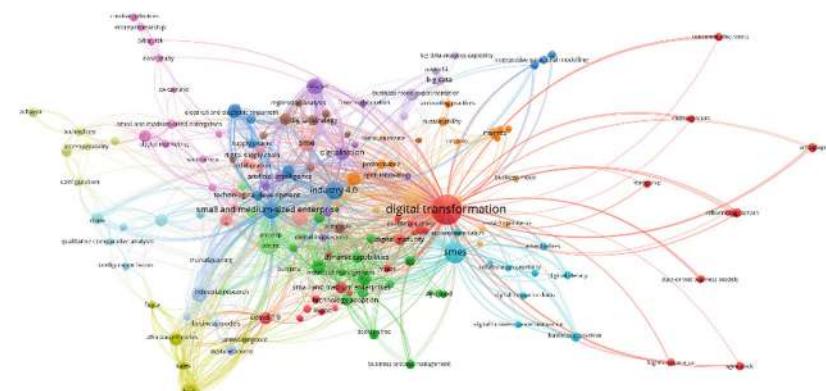
(yellow). Digital transformation can significantly increase the efficiency of small and medium-sized enterprises (SMEs) by streamlining processes, improving communication, and increasing productivity. By leveraging digital tools and technologies, SMEs could minimize manual errors, automate repetitive tasks, and accelerate decision-making processes. The cost of digital transformation for SMEs varies depending on the scale of implementation, complexity of technologies adopted, and ongoing maintenance expenses. While investing in digital tools can yield long-term advantages namely improved competitiveness and efficiency, SMEs must carefully evaluate the return on investment (ROI) to justify the costs involved.

*Cluster 4—Digital Transformation Driving Growth, Success, and Benefits for Small and Medium Enterprises (blue).* In the contemporary business landscape, digital transformation has emerged as a critical driver of growth, success, and benefits for small and medium enterprises (SMEs). By embracing digital technologies and integrating them into their operations, SMEs can boost their streamline processes, competitiveness, and unlock new opportunities for expansion.

The use of digital tools enables SMEs to improve efficiency, increase productivity, and better serve their customers in an increasingly digital world. Moreover, digital transformation empowers SMEs to access valuable data insights that can inform strategic decision-making and drive innovation within their organizations.

**Title and abstract terms mapping.** The purpose is to observe the most relevant terms employed by the authors in the title and abstract of their research papers. Title.

and abstract are what is read first by most. Figure 3 present the network of the largest connected terms used by the authors.



**Fig. 3** Title and abstract terms mapping

The largest set of terms used by the authors include Digital transformation and SME, industry 4.0, digital strategy, artificial intelligence, highlighting a great connection between Digital transformation and SME.

### **3.2 Content Analysis**

The results revealed that the number of SMEs adopting and using digital technologies is growing, especially those operating in the manufacturing sector. The Artificial intelligence, big data analytics, cloud technology, Internet of Things, autonomous robots, simulation, additive manufacturing, augmented reality, business intelligence are the most technology treated by researchers followed. Indeed, companies that undertake the journey to become digital businesses and compete with digital businesses open themselves to a range of opportunities [13]. The use of digital tools allows companies to free staff from daily work and allow them to concentrate on missions with more added value, improve commercial and operational functions, enable solutions to remedy the negative impacts of the COVID-19 crisis [14]. Also, the implementation of an automated system makes it possible to reduce labor costs, reduce execution time, improve product quality, and increase labor productivity. Also, this commitment makes it possible to expand the capacity to interact with customers for a better understanding of needs and identification of new products/services, to manage and use the data collected effectively to make the right decisions [13]. The digital transformation offers staff the opportunity to develop their digital skills and give the image of a modern company. Likewise, [15] highlight that it offers benefits, such as improved transparency and control of operations, expansion of IT systems, data collection and analysis, increased integration of business applications transforms analog processes into streamlined and efficient digital processes. In short, SMEs are often able to implement the digital transformation more quickly than large companies and they are more likely to be the big winners from this digital transformation, because they can easily develop new structures from scratch [16].

Of course, the application of DT is a sophisticated process, associated with a set of factors that can conduct to the success of this process or not (1). So, identify the main factors that tend to increase opportunities for success is a necessary preliminary condition for successful DT. In this sense, the majority of the studies that have worked on this issue have assigned factors to the dimensions of the Technology, Organization and Environment framework. As example, (1) identified a set of key factors from these three dimensions: technology (information technology management capabilities and information technology infrastructure), environment (governmental support, partnership) and organization (top management and digital strategy). Technological and environmental resources positively and indirectly impact TFD through the upgrade of organizational resources.

However, although the digital transformation brings many advantages, several difficulties and limitations can be noted. According to studies, it was revealed that companies could face internal and external challenges when executing the digital

transformation [17]. Using digital technologies can respond to three main internal challenges; firstly, financing (insufficient resource investment, high transformation costs)[17]. Second, human resources in terms of skills, cultural traditions, resistance to change [18]. Third, unclear transformation pathways, complexity and the attempt to achieve the level of privacy and security [17]. Certainly, the implementation and success of the digital transition of companies requires the commitment of its external environment. At this level, challenges arise before SMEs, which are mainly: the lack of awareness on the part of stakeholders (customers/suppliers/investors/governments...), the desire of these parties who demand perfect innovative changes from the company [14].

## 4 Conclusion

In conclusion, the current study gives a comprehensive analysis of the digital transformation landscape within small and medium enterprises (SMEs) from 2014 to 2024. The research sheds light on the challenges, advancements, and implications of digital transformation for SMEs, offering valuable insights for researchers, academics and practitioners.

The findings reveal a growing trend of SMEs adopting digital technologies, particularly in the manufacturing sector. Key technologies like cloud computing technology, big data and artificial intelligence are driving digital transformation initiatives.

While the study provides a comprehensive review of the current state of digital transformation in SMEs, there are certain gaps that warrant further exploration. Future research could delve deeper into the specific challenges faced by different industry sectors within the SME landscape and investigate the long-term impacts of digital transformation on organizational performance and innovation.

In order to recognize the constraints of this research, it is essential to highlight certain aspects that may impact the validity and reliability of the findings. These limitations encompass the reliance on existing literature and the potential bias in the selection of research articles.

The scope of the analysis may not capture all nuances of digital transformation in SMEs, and further empirical studies are needed to validate the findings and explore additional factors influencing digital adoption in SMEs.

Looking ahead, future research in the field of digital transformation for SMEs should focus on addressing the identified gaps and exploring emerging technologies and strategies that can drive successful digital initiatives in SMEs. Collaboration between academia, industry, and policymakers is essential to facilitate knowledge exchange and support SMEs in navigating the complexities of digital transformation. By embracing innovation and leveraging digital capabilities, SMEs can position themselves.

## References

1. Zhang X, Xu Y, Ma L (2022) Research on Successful Factors and Influencing Mechanism of the Digital Transformation in SMEs. *Sustainability* 14(5):2549. <https://doi.org/10.3390/su14052549>
2. Li L, Su F, Zhang W, Mao J-Y (2018) Digital transformation by SME entrepreneurs : A capability perspective. *Inf Syst J* 28(6):1129–1157. <https://doi.org/10.1111/isj.12153>
3. Wu Y, Li Z (2024) Transformation numérique, entrepreneuriat et innovation de rupture : preuves de la numérisation des entreprises en Chine de 2010 à 2021. *Humanit Soc Sci Commun* 11:163. <https://doi.org/10.1057/s41599-023-02378-3>
4. Kraus, S., Durst, S., Ferreira, J. J., Veiga, P., Kailer, N., & Weinmann, A. (2022). Digital Transformation in Business and Management Research: An overview of the current status quo. *International Journal of Information Management*, 63(August 2020)). <https://doi.org/10.1016/j.ijinfomgt.2021.102466>
5. Vial G (2019) Understanding digital transformation: A review and a research agenda. *J Strateg Inf Syst* 28(2):118–144
6. Barmuta KA, Akhmetshin EM, Andryushchenko IE, Tagibova AA, Meshkova GV, Zekiy AO (2020) Problems of business processes transformation in the context of building digital economy. *Entrepreneurship and Sustainability Issues* 8(1):945–959
7. Jose Antonio Clemente-Almendros, J. A., Nicoara-Popescu, D., Pastor-Sanz, I. (2024). Digital transformation in SMEs: Understanding its determinants and size heterogeneity. *Technology in Society*, Volume 77,102483, ISSN 0160-791X, <https://doi.org/10.1016/j.techsoc.2024.102483>.
8. Markovitch S, Willmott P, P. (2014) Accelerating the Digitization of Business Processes. *McKinsey Corporate Finance Business Practise* 2014:1–4
9. Kane, G.C. et al., (2015). «Strategy, Not Technology, Drives Digital Transformation». *MIT Sloan Management Review*, P.1–25.(19)
10. Mia Mahmudur R., Samuel O.I. (2015). Social Audit Regulation. Development, Challenges and Opportunities. Springer Cham. <https://doi.org/10.1007/978-3-319-15838-9>
11. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, Moher D, Peters MDJ, Horsley T, Weeks L (2018) PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann Intern Med* 169(7):467–473
12. Donthu N, Kumar S, Mukherjee D, Pandey N, Lim WM (2021) Comment effectuer une analyse bibliométrique : un aperçu et des lignes directrices. *Journal de recherche commerciale* 133:285–296
13. Busulwa, R. et Evans, N., (2021) : Digital Transformation in Accounting , Australy.
14. Minh, L. (2021). A Journey of Digital Transformation of Small and Medium-Sized Enterprises in Vietnam: Insights from Multiple Cases . *Journal Asian Finance Economics and Business*, Vol°1, n° 10, p.77- 85
15. Fehér, P., Szabó, Z., et Varga, K. (2017). « Analysing Digital Transformation among Hungarian Organizations ». *BLED 2017 Proceedings*. 40
16. Dominik T, Vladimír M., Helmut Z. (2020). Industry 4.0 for SMEs Challenges, Opportunities and Requirements .
17. Tarutè, A., Duobienè, J., Klovienè, L., Vitkauskaitè, E. et Varaniütè V., (2018). Identifying factors affecting digital transformation of SMEs . *La 18ème Conférence internationale sur le commerce électronique*, p. 373- 383
18. Schwertner, K. (2017). DIGITAL TRANSFORMATION OF BUSINESS.

# Implementing a Knowledge Sharing System for Course Development in Higher Education



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**Abstract** The integration of Information Communication and Technology (ICT) coupled with innovative advancements from the internet has emerged as more than just a passing trend in organizational settings, serving as a means to enhance business processes. Notably, in the field of education, the adoption of applications, particularly Learning Management Systems (LMS) such as Moodle, Blackboard, and Google Classroom, has made learning more accessible and practical. This transformation in education, driven by disruptive forces, presents an opportunity for institutions to strategically enhance their approach to foster innovative learning experiences. However, it also raises the challenge of consolidating academic and business processes into a unified body of knowledge that can be comprehended by both the organization and its stakeholders. With the primary objective of introducing a pedagogical administration mechanism known as the Knowledge Sharing System (KSS), this research is conducted in XYZ University, a privately-held academic institution in Indonesia. The KSS will be utilized by the instructional faculty to curate a comprehensive repository of scholarly resources and instructional endeavors tailored to specific subjects. The implementation process consists of a procedural flow, which utilizes a Moodle-based Learning Management System (LMS), to systematically track the development of content and detect any modifications or variations in the amassed scholarly resources. By the end of 2023, XYZ University has mapped digital learning

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materials into 3,352 subjects and developed training and certification products as strategic initiatives to enhance the use of KSS.

**Keywords** Knowledge Sharing System (KSS) · Learning Management System (LMS) · Collection of learning materials

## 1 Introduction

Leveraging Information Communication and Technology (ICT) with massive innovation from the internet has become more than a trend in the organization to improve the business process. Taking into account, for example, in the education sector, the use of applications to accommodate the necessity of learning has become more practical with the implementation of the Learning Management System (LMS) using Moodle, Blackboard, Google Classroom. One can argue that it is the outcome of the disruption in education, which the institution has to see as an opportunity to enhance their strategy to produce innovative learning for their fundamental activity and business [1–3] but left another issue in how all the processes between academic and business can be gathered as a single entity of knowledge that is understandable for the organization and the consumer.

The use of knowledge comes from the perspective of academic knowledge as the primary process for the institution in producing learning and teaching activities and organizational knowledge concerned with achieving profit to continue the business. How these processes in different dimensions can be collaborated strategically in capitalizing the opportunity and settling the continuity of the business process, and practically to have the learning activities can be delivered through the use of ICT with desired outcomes. Several studies in the context of Knowledge Sharing (KS) practices are pointing to the adoption of several tools to create knowledge, collaborate, and share for the approach [4, 5].

The primary objective of this study is to introduce the Knowledge Sharing System (KSS) at XYZ University in Indonesia. The KSS, managed by the instructional faculty, aims to compile scholarly resources and instructional materials for specific courses. The implementation will involve designing a procedural flow using a Moodle-based LMS as the frontend and Microsoft SharePoint as the backend repository. This approach aligns with the university's strategic plan to enhance business processes by digitizing content for a more effective learning design. The research will detail the organizational structure, technical development process, and the final compilation of materials and their variations.

## 2 Literature Review

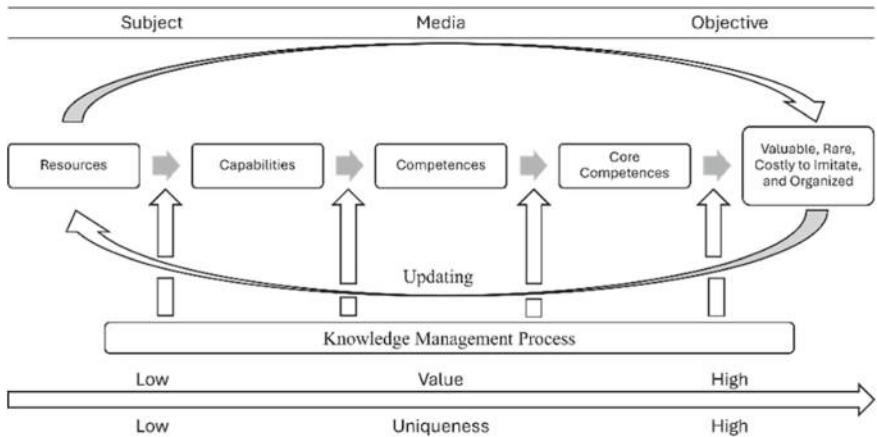
### 2.1 *Overview of Knowledge Sharing System and Its Role in Organizations*

Knowledge can be defined as the comprehension or information possessed by individuals or organizations as a result of their experiences, studies, or learning endeavors. It encompasses a deep understanding, interpretation, and practical application of information within a specific context. This understanding is based on what some scholars refer to as the tripartite account of knowledge, which comprises three essential conditions: the truth condition, the belief condition, and the justification condition [6]. From an organizational standpoint, enhancing employee performance can be achieved by providing them with valuable and pertinent knowledge [7, 8].

This aspect is considered a primary source of competitive advantage [9] and plays a crucial role in ensuring long-term sustainability for the organization [10]. Higher education institutions not only serve as repositories of knowledge but also adopt information management practices and learning strategies known as knowledge sharing within educational settings [11]. These institutions effectively manage, integrate, and facilitate knowledge sharing among their faculty members. Consequently, knowledge sharing has become a significant challenge and a fundamental concept in higher education, as evidenced by the allocation of grants to implement Knowledge Sharing (KS) practices in numerous universities, particularly in developed nations.

### 2.2 *Introduction to Moodle as a Knowledge Sharing System (KSS)*

As per the developers of Moodle, they describe it as a Course Management System (CMS) that is free and open source. It has been designed based on pedagogical principles to assist educators in creating engaging online learning communities. Moodle offers a comprehensive platform for managing and delivering learning materials, organizing courses, and facilitating interaction between teachers and students [12]. This versatile virtual environment is suitable for various educational institutions, such as schools, colleges, and training institutes, that aim to provide remote education and training. The integration of information and communication technology, facilitated by Moodle, brings about enhanced effectiveness and efficiency in the education sector [13].



**Fig. 1** Four important points of sustainable competitive advantage according to Mahdi

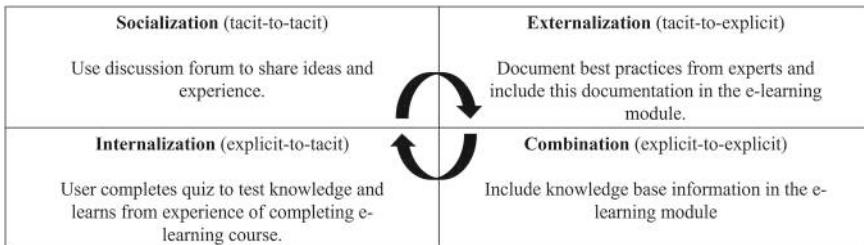
### 2.3 Knowledge Sharing System (KSS)

Knowledge sharing involves the exchange of experiences, events, thoughts, or understanding on any subject matter, with the aim of acquiring additional insights and comprehension for temporary curiosity. According to [14], Knowledge Sharing (KS) refers to the process of distributing and providing access to existing knowledge, while knowledge utilization entails integrating acquired knowledge into the organization's practices and processes.

Knowledge sharing occurs between a minimum of two participants known as actors [15] and cannot exist independently from the human mind [16]. To achieve that knowledge can be sustainable, competitive, and advantage (see Fig. 1) there are four important points that can be looked at: subjects, media, objective, and updating [17].

### 2.4 Review of Relevant Studies and Research on Implementing KSS Using Moodle

Moodle, as an educational platform, is software or a collection of software that is located on or can be accessed through a network, and its purpose is to facilitate teaching and learning for educators and students. Knowledge Sharing (KS) is essential because businesses are not harnessing the potential of their existing information, and by neglecting this issue, they run the risk of decreased efficiency and profitability [18]. The continuous fluctuations and transformations encountered by most organizations highlight the necessity of knowledge sharing.

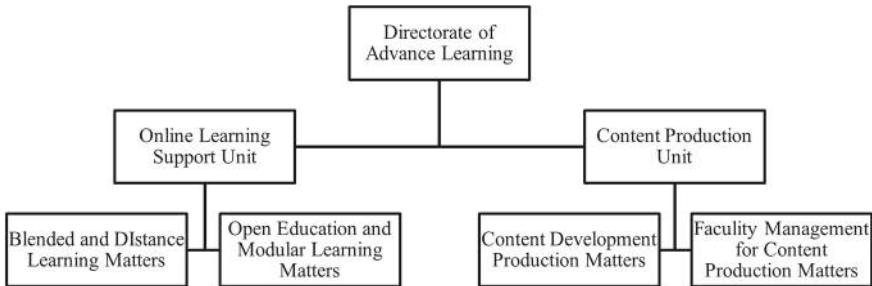


**Fig. 2** The use of e-learning in knowledge development according to the Nonaka and Takeuchi knowledge spiral

The close connection between moodle and KS is recognized in terms of incorporating explicit and tacit forms of knowledge, as both are essential for facilitating successful e-learning experiences. As depicted in Fig. 2, it is evident that when utilized and leveraged effectively, e-learning has the potential to greatly benefit organizations and their collaborators. This is achieved by granting access to both explicit knowledge held by the organization and valuable tacit knowledge that has been captured and made accessible as a valuable resource for the firm [19, 20].

### 3 Methodology

The fundamental concept behind the Knowledge Sharing System (KSS) in this research is to serve as a centralized repository for storing various data collections and information, ultimately forming a valuable knowledge base. This knowledge base is then utilized as an essential resource, particularly in the context of subjects derived from the semester learning plan (RPS). The implementation of the Learning Management System (LMS) as a knowledge repository involves several crucial steps, including defining the organizational structure responsible for its management and utilization, establishing the necessary infrastructure to support the development process, conducting case studies through grants, and its sustainability as a strategic process that provides benefits for learning. These efforts are aimed at creating a total of 1,336 subjects within the period from 2019 to 2020, through a grants program to stimulate ecosystem development, which later increased to 3,352 subjects in June 2023. The resulting collection of content is expected to consist of knowledge artifacts categorized according to the types of materials and activities, all stored within the Moodle platform.



**Fig. 3** Organization structure for KSS development

**Table 1** Operational details of KSS supporting units

| Online learning supporting unit                        | Content production unit                                |
|--------------------------------------------------------|--------------------------------------------------------|
| Provide support via the online learning platform       | Ensure accessibility and quality of learning materials |
| Oversee moodle infrastructure and add support features | Support online content creation                        |
| Address infrastructure and network issues              | Resolve issues with online learning materials          |

### 3.1 *Organization Structure*

The organizational structure for the development of the Knowledge Sharing System (KSS), utilizing Moodle as the platform, is designed in the shape of a directorate overseeing two primary units that are responsible for providing infrastructure services and content production services. The organizational structure for the development of KSS can be visualized in Fig. 3.

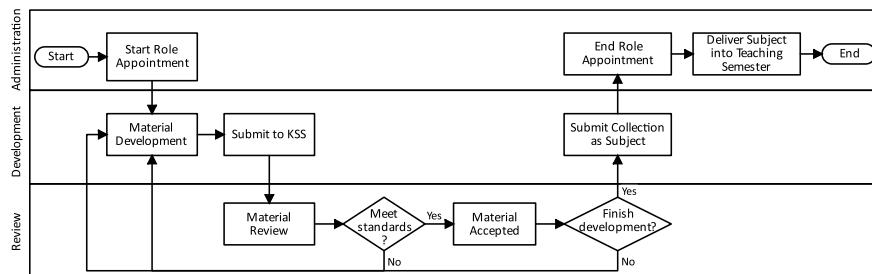
The supporting units within the directorate share a common goal of harnessing the resources available at the university to facilitate the development of the Knowledge Sharing System (KSS). The specific operational details related to this objective are presented in Table 1.

### 3.2 *Material Standard for KSS*

During the developmental stage, specific standards are established to determine the types of materials to be gathered into the Knowledge Sharing System (KSS). This approach is designed to align with the techniques and methods of delivering lecture materials that have been outlined in the Semester Learning Plans (RPS) from the academic department. The intention is to provide guidance and serve as a reference for teaching staff when developing content within the KSS. Table 2 provides an overview of the predetermined standards for the types of materials set by the organization.

**Table 2** Content standards for subject materials in KSS

| Materials         | Definition                                                                    |
|-------------------|-------------------------------------------------------------------------------|
| Learning guide    | Set of instructions for students to understand the learning objectives        |
| Interactive video | Learning videos from material with interactive content in the form of quizzes |
| Lecture notes     | Learning materials in the form of document that can be downloaded             |
| Forum             | Learning activity for discussion related to the topic                         |
| Quiz review       | Learning activity in the form of assessment                                   |
| External link     | Learning materials taken from other source beyond the KSS                     |
| Assignment        | Learning activity in the form of essay or document to be submitted            |

**Fig. 4** Flow Process administration process for material development in KSS

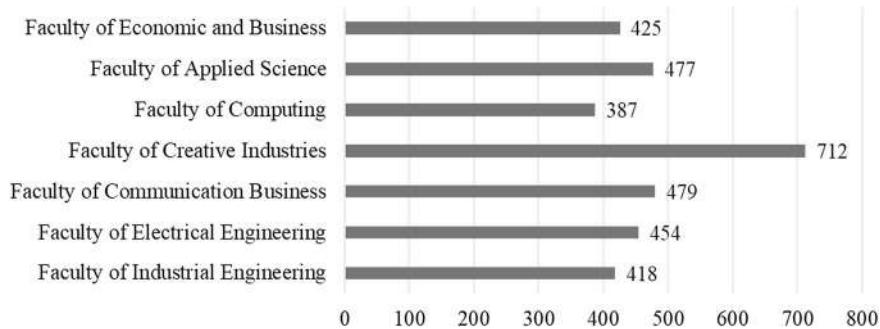
### 3.3 Development Process Flow

The flow for the development of KSS encompasses administrative phases that serve as guidelines. This involves defining the responsibilities of the content developer, reviewer, and final decision-maker to reach a consensus on the comprehensive collection of knowledge of the subject. Figure 4 will show the flow for the collection administration process.

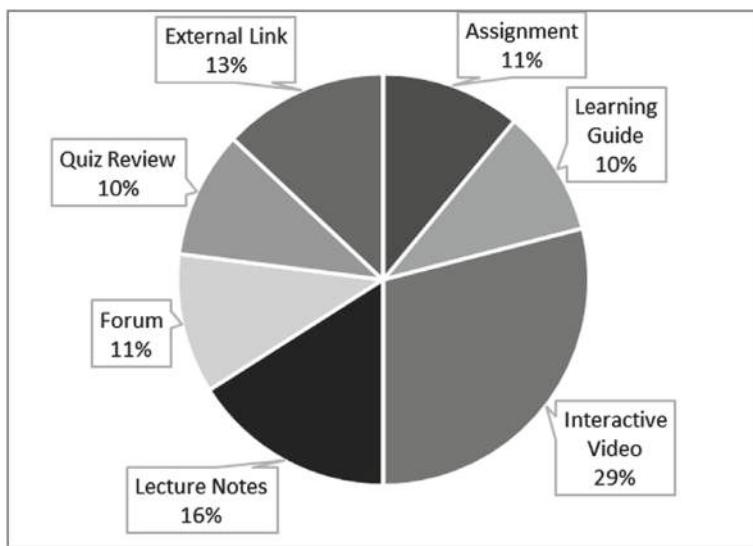
## 4 Results and Findings

As a result of the KSS development project at XYZ University, a total of 3,352 subjects have been populated with materials and content, serving as repositories for learning purposes. The involvement of users in this case primarily includes the teaching staff, who contributed to the compilation of materials to be stored in the KSS and disseminated at the university level. The distribution of the number of subjects supported in developing learning content for each faculty can be observed in Fig. 5 while the distribution of materials and contents can be seen in Fig. 6.

XYZ University encountered several challenges during the development of learning content, including lecturers' hectic schedules, difficulties in adhering to

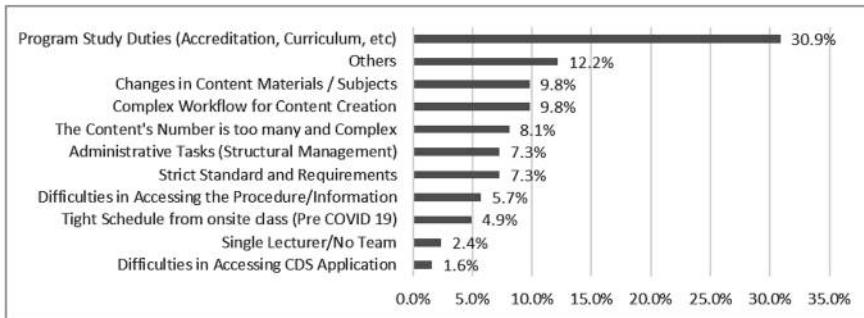


**Fig. 5** Number of subjects for each faculty that create e-learning content



**Fig. 6** Materials and content distribution in 3352 subjects

standards, technical issues, and problems within the content creation team. Based on the data presented in Fig. 7, we can observe the challenges encountered during the learning content creation process. The most significant issue reported by lecturers relates to their various responsibilities within the study program, including accreditation, curriculum development, research, administrative tasks, and managing academic activities, accounting for 30.9% of the reported challenges. On the other hand, the least significant problem, representing only 1.6% of the reported issues, is the difficulties in accessing the Course Development System (CDS), which can be interpreted that the application has small issue, and ready to be served as Knowledge Sharing System (KSS).

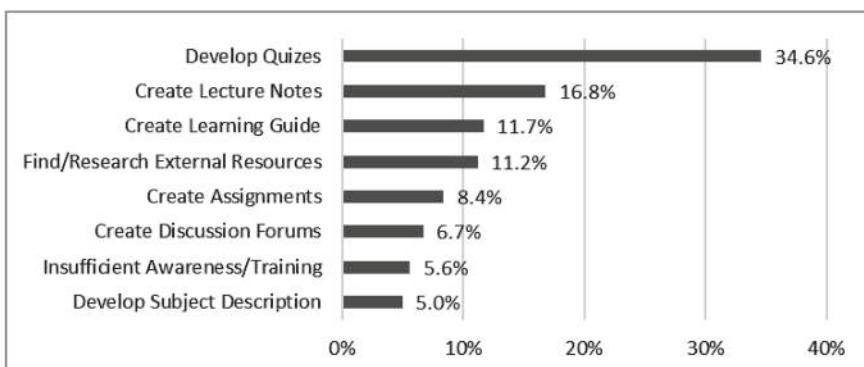


**Fig. 7** Issues in the content development process

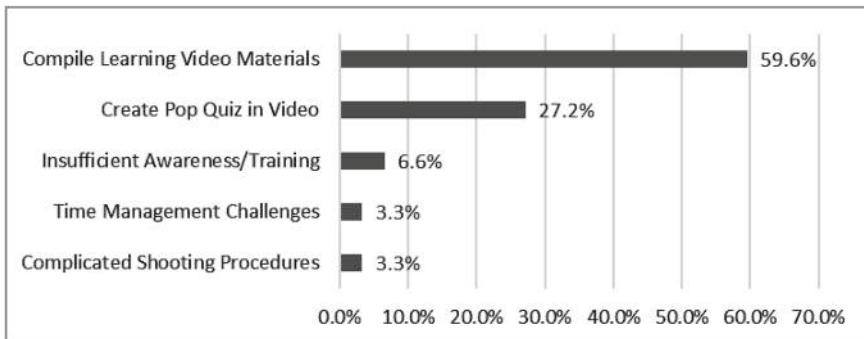
According to the lecturer's feedback (refer to Fig. 8), they encounter multiple challenges when generating non-video content. The most prominent obstacle they face is in the quizzes development, which is perceived to be complicated, with the following procedure from question bank creation, then map them into a quiz. On the other hand, the least significant issue encountered pertains to the development of subject descriptions. When it comes to producing video content (as depicted in Fig. 9), lecturers encounter distinct difficulties. Many of them struggle with video production, possibly due to factors such as discomfort in front of the camera, challenges in scriptwriting, or difficulties in converting material into video format.

Additional challenges arose from the production crew (refer to Table 3). Changes in production crew during COVID-19 pandemic). With the onset of the COVID-19 pandemic, the crew size was diminished by 50 percent. This reduction was implemented to mitigate the spread of the virus in compliance with government regulations and safety measures.

Throughout its evolution, the KSS development support unit embraced innovation by organizing training and certification programs for teaching staff. These initiatives



**Fig. 8** Non-video content issues



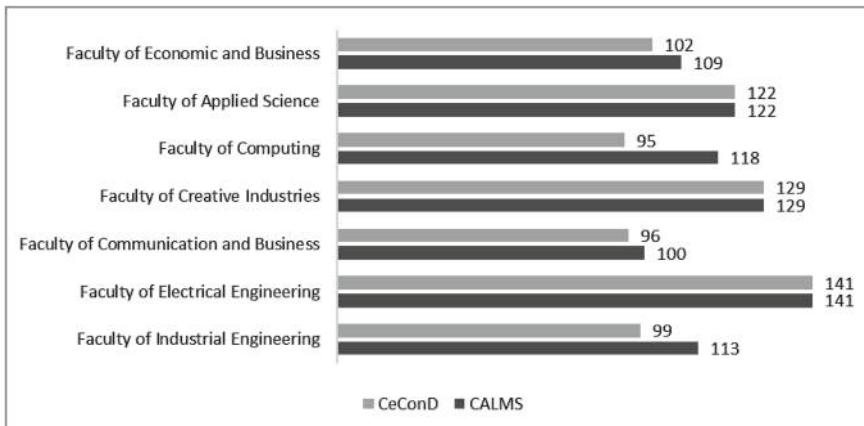
**Fig. 9** Video content development issues

**Table 3** Changes in production crew during COVID-19 pandemic

| Production crew       | Before COVID-19 | During COVID-19 |
|-----------------------|-----------------|-----------------|
| Administrative team   | 5 persons       | 3 persons       |
| Programmer            | 2 persons       | 1 person        |
| Assistant team        | 13 persons      | 3 persons       |
| Content creative team | 14 persons      | 6 persons       |
| Studio manager        | 14 persons      | 7 persons       |
| Camera person         | 14 persons      | 7 persons       |
| Editor                | 14 persons      | 7 persons       |
| Data management       | 4 persons       | 2 persons       |
| Make-up artists       | 7 persons       | 3 persons       |

yielded valuable artifacts in the form of quality assurance and competency standards, serving as crucial references for universities in managing KSS. Beyond serving as material repository, these endeavors instilled new practices and habits among users, driving future development. The training and certification process comprises two components: Certification in Administration of Learning Management System (CALMS) and Certification in Content Development (CeConD). CALMS aims to enhance lecturers' proficiency in operating Moodle and related systems for effective online learning implementation at universities. On the other hand, CeConD strives to enhance lecturers' competence in producing online learning videos and standardizing the content across universities.

Referring to Fig. 10, we can observe the cumulative count of lecturers from various faculties who have successfully completed the training and certification provided by the support units. This serves as an indication that the KSS development program is progressing effectively and able to continue as a strategic program.



**Fig. 10** Number of certified lecturers from supporting unit program

## 5 Conclusion

The implementation of the Knowledge Sharing System (KSS) at XYZ University encompasses a range of processes, including the establishment of organizational structures, roles, standards, and mechanisms for its utilization. This case study highlights how these efforts can be leveraged to enhance the university's business processes. The resulting artifacts, comprising a collection of materials and activities used in the learning process, can be replicated to enrich the knowledge base of XYZ University. Within this context, the KSS, powered by the Moodle platform, serves as an expansive repository with endless possibilities for ongoing development. The issues and problems which occurs in the process of KSS management are related to the infrastructure to support the development process, new habit in transforming the material to fit with the standard, and the changes in technique, method and features in KSS to support for the upcoming learning delivery process will become the challenge for the organization to have the continuous improvement strategy in maintaining KSS in the future. Therefore, the establishment of training and certification becomes crucial, not only preserving the utilization of KSS for material and subject development but also representing a new product developed by the university. This initiative can further capitalize the process as a culture and profitable business model, potentially to be shared with other institutions.

## References

1. Alier MF, Guerrero MJC, González MÁC, Penalvo FJG, Severance C (2010) Interoperability for LMS: the missing piece to become the common place for e-learning innovation. Int J Knowl Learns 6:130–141

2. Costello, E. Opening up to open source: looking at how moodle was adopted in higher education. <https://doi.org/10.1080/02680513.2013.856289> 28, 187–200
3. Aldowah H, Ghazal S, Umar IN, Sayekti R (2018) The implementation of E-learning system at UIN sumatera utara in response to technology challenge in education. *J Phys Conf Ser* 970:012026
4. Johannsen CG (2000) Total quality management in a knowledge management perspective. *J Doc* 56:42–54
5. Kim J, King J (2004) Managing knowledge work: Specialization and collaboration of engineering problem-solving. *J Knowl Manag* 8:53–63
6. Neta R, Pritchard D Arguing about knowledge (Routledge London, 2009)
7. Alavi M, Leidner DE (2001) Review: knowledge management and knowledge management systems: Conceptual foundations and research issues. *MIS Q* 25:107–136
8. Hansen MT, Nohria N, Tierney T What's your strategy for managing knowledge? in The knowledge management yearbook 2000–2001 55–69 (Routledge, 2013).
9. Stewart TA (1997) Intellectual capital: the new wealth of organizations 278
10. Nonaka I (1991) The knowledge-creating company [Electronic version]. *Harv Bus Rev* 69:96–104
11. Knowledge management in education: defining the landscape. <https://search.issuelab.org/resource/knowledge-management-in-education-defining-the-landscape.html>
12. Pinto M (2014) Knowledge management in higher education institutions: a framework to improve collaboration. Iberian Conference on Information Systems and Technologies, CISTI <https://doi.org/10.1109/CISTI.2014.6876876>
13. Reddy A, Devi K, Lakshmi VV (2020) Moodle—an effective learning management system for 21st century learners
14. Tiwana, A (2002) The knowledge management toolkit: orchestrating IT, Strategy, and knowledge platforms (2nd Edition). Prentice Hall 416
15. Lee CK, Al-Hawamdeh S (2012) Factors impacting knowledge sharing, 1: 49–56. <https://doi.org/10.1142/S0219649202000169>
16. Van Beveren J (2002) A model of knowledge acquisition that refocuses knowledge management. *J Knowl Manag* 6:18–22
17. Mahdi OR, Nassar IA, Almsafir MK (2019) Knowledge management processes and sustainable competitive advantage: an empirical examination in private universities. *J Bus Res* 94:320–334
18. O'Dell C, Grayson CJ (1998) If only we knew what we know: Identification and transfer of internal best practices. *Calif Manage Rev* 154–174
19. Wild R, Griggs K, Downing T (2002) A framework for E-learning as a tool for knowledge management. *Ind Manag Data Syst* 102:371–380
20. Tessier D, Dalkir K (2016) Implementing Moodle for e-learning for a successful knowledge management strategy. 8:414–429

# From Theory to Practice: Applications of Cooperative Game Theory in Economics



Anjeza Bekolli and Ina Pagria

**Abstract** This paper focuses on the applications of cooperative game theory in economics, examining various scenarios such as regulatory strategies in the sharing economy and profit allocation in supply chains. It discusses both theoretical approaches and practical implementations, emphasizing the potential benefits of cooperation in achieving efficiency, fairness, stability, and coordination in economic activities. It seeks to bridge the gap between theoretical frameworks and practical implementations, emphasizing the possible advantages of collaboration in economic decision-making processes. Additionally, it highlights the need for further research to address the challenges and limitations associated with the application of cooperative game theory in real-world economic scenarios. The paper concludes that cooperative game theory offers valuable insights and analytical tools for optimizing economic outcomes through cooperation. However, it also acknowledges the challenges and limitations inherent in its application, including complexity, assumptions about rational behavior, and distributional issues. By addressing these challenges and leveraging the strengths of cooperative game theory, policymakers and practitioners can better harness its potential benefits in various economic contexts.

**Keywords** Game theory · Strategy · Outcomes · Cooperation · Economics

## 1 Introduction

Game theory is a field within applied mathematics and economics that examines the strategic behavior of rational decision-makers. It offers a method for evaluating scenarios in which the result of one person's choice is influenced by the

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choices made by others, leading to interdependent relationships among the participants. Game theory seeks to understand how individuals, firms, governments, and other entities make decisions in strategic settings, taking into account their preferences, beliefs, and incentives. One of the founding figures of game theory, von Neumann, along with economist Oskar Morgenstern, published the groundbreaking book “Theory of Games and Economic Behavior” [20]. Von Neumann’s work laid the foundation for the mathematical formalization of game theory and its applications in economics and other fields. Game theory is utilized in multiple disciplines, such as economics, political science, biology, computer science, and philosophy, to examine strategic interactions and forecast results in competitive, cooperative, and mixed environments.

The term “strategy” is fundamental in game theory, it represents the key element of decision-making for agents in strategic interactions. On the other hand, this term is important in economics because it reflects the decision-making process of economic agents in various contexts. Some of the main purposes of this papers are: to provide an overview of game theory and its significance in analyzing strategic interactions in economics; to explore the concept of strategy and its application in both economics and game theory, emphasizing the differences and similarities; to examine the applications of cooperative game theory in various economic scenarios, including supply chain management, regulatory strategies in the sharing economy, and analysis of oligopolistic markets; to discuss the positive aspects of cooperative game theory, such as efficiency, fairness, stability, and coordination, along with the challenges and limitations associated with its application in economics.

## 1.1 *Strategy Concept*

In both economics and game theory, the term “strategy” refers to a plan or course of action chosen by a rational decision-maker to achieve their objectives. Both economics and game theory assume that decision-makers are rational actors who carefully weigh the costs and benefits of different actions and choose the one that maximizes their utility or achieves their objectives. Strategies in both economics and game theory take into account the anticipated behavior of other decision-makers. Players form beliefs about how others will respond to their actions and choose strategies that are optimal given these beliefs. This leads to strategic interactions where the actions of one player influence the actions of others [16]. However, there are differences in how the concept of strategy is used and applied in these two disciplines. In economics, strategies are typically analyzed in the context of individual decision-making, market interactions, and economic policy. Economic agents such as consumers, firms, and governments formulate strategies to maximize their utility, profits, or social welfare in various economic environments. In game theory, strategies are analyzed in the context of strategic interactions among multiple decision-makers (players) who have conflicting objectives.

Game theory models strategic interactions using formal mathematical frameworks to analyze how players choose strategies and predict the outcomes of their interactions. Game theory provides a more formal and mathematical treatment of strategies compared to economics. In game theory, strategies are often represented as mathematical functions or sets of actions that specify how players behave in different decision nodes of a game. This formalism allows for precise analysis of strategic interactions and the derivation of equilibrium concepts such as Nash equilibrium and subgame-perfect equilibrium. Two big branches of game theory are non-cooperative and cooperative (or coalitional) games. In this paper, we concentrate on cooperative games and especially their needs in the economy, how they are applied in several economic situations, and some positive and negative points of their application in economic situations.

## 1.2 *Cooperative Game Theory*

Cooperative game theory is a segment of game theory that examines scenarios in which players can create alliances or groups to accomplish specific objectives. In contrast to non-cooperative game theory, where players operate independently and competitively, cooperative game theory emphasizes collaboration among players and the equitable and efficient distribution of rewards. Cooperative game theory seeks to understand how rational individuals can cooperate to achieve outcomes that benefit all members of the group. It provides mathematical models and frameworks for analyzing situations where cooperation is possible and beneficial. These situations can arise in various real-life scenarios, including business negotiations, international diplomacy, resource allocation, and economic partnerships. One of the fundamental concepts in cooperative game theory is that of a coalition, which is a group of players who agree to work together to achieve common objectives. These coalitions can range from small groups to entire industries or nations. Within a coalition, members may cooperate by pooling their resources, sharing information, and coordinating their actions to maximize their collective welfare.

One of the key reasons why cooperative game theory is necessary in real-life situations, especially in economics, is its ability to provide insights into how individuals can overcome obstacles and achieve mutually beneficial outcomes through cooperation. In many economic scenarios, such as trade negotiations, joint ventures, and regulatory agreements, cooperation among stakeholders is essential for achieving optimal results. Cooperative game theory is closely related to economics because it provides analytical tools and frameworks for studying situations where individuals or organizations cooperate to achieve mutual benefits. In economics, cooperation among rational agents is essential for various activities such as trade, production, resource allocation, and regulation. Cooperative game theory also helps economists understand how resources can be allocated efficiently within a group or organization. By studying the distribution of costs and benefits among coalition

members, economists can identify mechanisms, such as cost-sharing agreements or revenue-sharing schemes, that incentivize cooperation and promote efficiency.

## 2 Some Applications in Economics

Due to the difficulty of generating results with a large number of agents, most applications in economics are of a theoretical nature. The reader can see the text of [15], which aims to provide an overview of cooperative and non-cooperative game theory and their applications. The application of game theory to regulating the sharing economy is discussed in [19]. It highlights the use of game theory to develop strategies for cooperation and non-cooperation between the state and sharing economy companies.

Game theory is utilized to analyze interactions, benefits, costs, and effects in the sharing economy. The study emphasizes the importance of regulatory strategies based on game theory to reconcile the interests of all participants and ensure sustainable development in the sharing economy. Another interesting topic, which is very useful, is the application of this model in several supply chains. The researcher [6] models the relationships between seller and buyer in both the non-cooperative and cooperative approaches. A review of more than 130 papers concerned with applications of game theory in supply chain management can see in [12]. There are numerous applications of the cooperative game theory model in the allocation of profit in supply chains under decentralized control composed of a single supplier and multiple distributors, like in the papers [2, 9, 10], etc.

In [17], there is an early neoclassical approach to economics, which focuses on the derivation of price relationships in perfectly competitive markets. The author argues that this approach is limited because it assumes a fixed institutional structure and overlooks the influence of institutions on economic results. The author proposes a game theoretical approach to economics that takes into account the strategic interactions between agents and the impact of institutions on determining economic results. The content concludes by arguing that the game theoretical approach is necessary to understand how prices and institutions are formed in large economies. In the paper [14], the limited impact of cooperative game theory on economics is discussed, despite its potential advantages. The author highlights the historical focus on cooperative game theory by influential figures such as J. von Neumann, O. Morgenstern, Nash, and Shapley. In industries characterized by a small number of firms (oligopolies), cooperation among competitors can lead to the formation of cartels or agreements to control prices, output levels, and market shares. Cooperative game theory provides insights into the stability and efficiency of cartels by analyzing the incentives for firms to cooperate and the potential gains from collusion. For example, in [18], it provides insights into cooperative game theory in oligopolistic markets through a game theoretic-mathematical programming analysis. It delves into the strategic interactions and cooperative phenomena among firms operating in such markets. The study likely discusses how firms can benefit from cooperation and

collaboration in oligopolistic settings to achieve mutual gains and strategic advantages. Another paper that provides insights into oligopoly and cooperative game theory by discussing various models, core solutions, and extensions in the context of industrial cooperation is done by [21]. It reviews different game models, including coalitional games, normal form games, and partition function games, emphasizing the core as a cooperative solution. A paper that explores cooperative Cournot games in oligopolistic markets where firms are boundedly rational is from [11]. It highlights the challenges of predicting coalition formations due to cognitive constraints. The paper contributes to understanding cooperative game theory in oligopoly settings with cognitive limitations. In [8] the perennial issue of site consolidation in land economics is addressed, focusing on the challenges of wholesale urban transformation due to the fragmented ownership of adjacent small land parcels. Additionally, the authors also share findings from an experiment on coalition and value distribution conducted in four European countries, offering insights into practical policy concerns, including self-initiated development, coalition stability, and the importance of urban planning agencies. Cooperative game theory operates within an axiomatic framework, which means it is grounded in a set of fundamental principles or axioms that define the properties of cooperative solutions that are also called allocations. These axioms serve as foundational assumptions about the behavior of rational agents and the principles of fairness and efficiency that underlie cooperative interactions. Reference [5] features an early survey paper on cooperative game theory that reviews the axiomatic characterizations of the Shapley value, the pre-kernel, the pre-nucleolus, and the core using a consistency property related to reduced games. The consistency property of a given solution can be crucial for advancing the theory of that solution and can help identify the ‘consistent’ solution to a practical problem. The reader can see paper from [1] for detail information about Shapley value and for other solutions like core, nucleolus in [13]. For a more general review about subset and one point solutions that cooperative game theory offer, and their relations the reader can see the paper [3].

### 3 Challenging of Applications

The application of cooperative game theory in economics offers both positive and negative aspects, each with its own implications and considerations:

Cooperative game theory provides analytical tools and frameworks for studying situations where cooperation among rational agents can lead to more efficient outcomes. It offers mechanisms for allocating rewards and benefits among participants in a fair and equitable manner. By considering principles of justice and fairness, cooperative solutions aim to ensure that all parties receive a share of the gains from cooperation proportional to their contributions or needs. Cooperative solutions such as the core [7] provide stable allocations of resources within coalitions, reducing the risk of defection or breakdown of cooperation over time. Cooperative game theory fosters stability and sustainability in cooperative arrangements by guaranteeing that

**Table 1** Positive and negative aspects

| Applications of cooperative game theory in economics |                                 |
|------------------------------------------------------|---------------------------------|
| Positive aspects                                     | Negative aspects                |
| Efficiency                                           | Complexity                      |
| Fairness                                             | Assumptions and simplifications |
| Stability                                            | Strategic behavior              |
| Coordination                                         | Distributional issues           |

no subset of players is motivated to break away from the coalition. Lastly, it helps facilitate coordination and collaboration among individuals or organizations, leading to better outcomes in various economic activities such as trade, production, and innovation. By analyzing the incentives and strategies of participants, cooperative solutions can help overcome coordination problems and achieve mutually beneficial goals (Table 1).

Overall, while cooperative game theory provides important insights into cooperative behavior and provides useful tools for analyzing and solving cooperative problems, it also has limitations and drawbacks that must be carefully considered. By acknowledging these negative points and addressing them appropriately, policymakers and practitioners can better harness the potential benefits of cooperative game theory while mitigating its shortcomings.

Regarding some of the disadvantages of the application of this model, it leads to what we call complexity [4]. Cooperative game theory often involves complex mathematical models and computational techniques for analyzing cooperative behavior and finding optimal solutions. The complexity of cooperative games can pose challenges for real-world application, requiring substantial expertise and computational resources to implement effectively. Moreover, cooperative game theory depends on specific assumptions and simplifications about the behavior of rational agents, the structure of coalitions, and the nature of cooperation. These assumptions may not consistently apply in real-world scenarios, leading to discrepancies between theoretical predictions and real-world outcomes. It also assumes that players act rationally and cooperatively to maximize their utility or achieve their objectives. However, in practice, players may exhibit strategic behavior such as opportunism, deception, or manipulation, which can undermine cooperation and lead to suboptimal outcomes.

To address the challenges of complexity and assumptions about rational behavior in cooperative game theory for real-world economic scenarios, several strategies can be employed:

-Incremental Model Complexity: Begin with simple models and gradually introduce complexity. This method helps manage computational challenges while ensuring the models remain realistic and applicable.

-Advanced Algorithms and AI: Utilize robust algorithms capable of processing extensive datasets and intricate interactions. Incorporating machine learning and artificial intelligence (AI) can aid in simulating and analyzing strategic interactions in cooperative games, enabling the management and interpretation of complex data.

-Scenario Analysis and Simulation: Apply scenario analysis and simulation techniques to understand how cooperative strategies function under varying conditions and assumptions. This approach enables economists to evaluate the robustness of cooperative solutions across different economic environments.

Cooperative solutions may face challenges in addressing distributional issues and ensuring that the benefits of cooperation are distributed fairly among participants. In some cases, cooperative arrangements may exacerbate inequalities or lead to inequitable outcomes, especially if bargaining power is unevenly distributed among participants.

## 4 Conclusions

Cooperative game theory provides a formal framework for analyzing strategic interactions among rational decision-makers who can form coalitions to achieve common goals. Applications of cooperative game theory in economics in various ways, from devising regulatory strategies for the sharing economy to the allocation of profit in supply chains. Cooperative solutions, provide stable allocations of resources within coalitions, promoting stability and sustainability in cooperative arrangements. Challenges associated with the application of cooperative game theory include complexity, assumptions about rational behavior, and addressing distributional issues and strategic behavior.

In conclusion, while cooperative game theory offers valuable insights and analytical tools for optimizing economic outcomes through cooperation, its application requires careful consideration of its limitations and drawbacks. By acknowledging these challenges and leveraging the strengths of cooperative game theory, policy-makers and practitioners can better harness its potential benefits in various economic contexts.

## References

1. Algaba E, Fragnelli V, Sánchez-Soriano J (2019) Handbook of the shapley value. In Chapman and Hall/CRC eBooks. <https://doi.org/10.1201/9781351241410>
2. Bekalli A, Guardiola L. A, Meca A (2023) Profit allocation in agricultural supply chains: exploring the nexus of cooperation and compensation. arXiv (Cornell University). <https://doi.org/10.48550/arxiv.2307.11065>
3. Bekalli A, Pagria I (2022) Relationships between subset and one-point solutions in cooperative game theory: a worker compensation application. Int J Acad Res Reflects 10(4)
4. Deng X, Papadimitriou CH (1994) On the complexity of cooperative solution concepts. Math Oper Res 19(2):257–266. <https://doi.org/10.1287/moor.19.2.257>
5. Driessens T (1991) A survey of consistency properties in cooperative game theory. SIAM Rev 33(1):43–59. <https://doi.org/10.1137/1033003>
6. Esmaeili M, Aryanezhad M, Zeephongsekul P (2009) A game theory approach in seller-buyer supply chain. Eur J Oper Res 195(2):442–448. <https://doi.org/10.1016/j.ejor.2008.02.026>

7. Gilles RP (2010) The core of a cooperative game. In Theory and decision library, pp 29–70. [https://doi.org/10.1007/978-3-642-05282-8\\_2](https://doi.org/10.1007/978-3-642-05282-8_2)
8. Gu Y, Lord A, Eika A, Dethier P, Samsura D, a. A, Nordahl B. I, Sommervoll D. E, Van Der Krabben E, Halleux J, (2021) Fair shares? advancing land economics through cooperative game theory. Land Use Policy 106:105400. <https://doi.org/10.1016/j.landusepol.2021.105400>
9. Guardiola LA, Meca A, Puerto J (2023) Allocating the surplus induced by cooperation in distribution chains with multiple suppliers and retailers. J Math Econ 108:102889. <https://doi.org/10.1016/j.jmateco.2023.102889>
10. Guardiola LA, Meca A, Timmer JB (2007) Cooperation and profit allocation in distribution chains. Decis Support Syst 44(1):17–27. <https://doi.org/10.1016/j.dss.2006.12.015>
11. Lekeas PV, Σταματόπουλος Γ (2014) Cooperative oligopoly games with boundedly rational firms. Ann Oper Res 223(1):255–272. <https://doi.org/10.1007/s10479-014-1580-z>
12. Leng M, Parlar M (2005) Game theoretic applications in supply chain management: a review. INFOR: Information Systems and Operational Research, 43(3): 187–220. <https://doi.org/10.1080/03155986.2005.11732725>
13. Luo C, Zhou X, Lev B (2022) Core, shapley value, nucleolus and nash bargaining solution: A Survey of recent developments and applications in operations management. Omega 110:102638. <https://doi.org/10.1016/j.omega.2022.102638>
14. Maskin E (2016) How can cooperative game theory be made more relevant to economics? an open problem. In Springer eBooks pp 347–350. [https://doi.org/10.1007/978-3-319-32162-2\\_9](https://doi.org/10.1007/978-3-319-32162-2_9)
15. McCain RA (2008) Cooperative games and cooperative organizations. J Socio-Econ 37(6):2155–2167. <https://doi.org/10.1016/j.socloc.2008.02.010>
16. Osborne MJ (2014) An introduction to game theory. In SAGE Publications, Inc. eBooks pp. 33–42. <https://doi.org/10.4135/9781452275567.n5>
17. Schotter A (1983) Why take a game theoretical approach to economies? institutions, economics and game theory. Econ Appliquée 36(4):673–695. <https://doi.org/10.3406/ecoap.1983.3995>
18. Sherali HD, Rajan R (1986) A game theoretic-mathematical programming analysis of cooperative phenomena in oligopolistic markets. Oper Res 34(5):683–697. <https://doi.org/10.1287/opre.34.5.683>
19. Veretennikova A, Selezneva DA (2023) Development of regulatory strategies in the sharing economy: the application of game theory. Econ 11(12):298. <https://doi.org/10.3390/economics11120298>
20. Von Neumann J, Morgenstern O (1945) Theory of games and economic behavior. J Philos 42(20):550. <https://doi.org/10.2307/2019327>
21. Zhao J (2018) TU oligopoly games and industrial cooperation. In Edward Elgar Publishing eBooks. doi 10(4337/9781785363283):00022

# Detecting Cyberbullying, Spam and Bot Behavior, Fake News in Social Media Accounts Using Machine Learning



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**Abstract** Due to the growing popularity of social media platforms in the present, there are various concerns, mostly cyberbullying, spam, bot accounts and the spread of incorrect information. To develop a risk score calculation system as a thorough method for deciphering and exposing unethical social media profiles, this research explores the most suitable algorithms to our best knowledge in detecting the mentioned concerns. Various multiple models such as Naïve Bayes, CNN, KNN, Stochastic Gradient Descent, Gradient Boosting Classifier, etc. were examined and the best results were taken into the development of the risk score system. For cyberbullying, Logistic Regression algorithm achieved an accuracy of 84.9% while the spam detecting MLP model gained 98.02% accuracy. The bot accounts identifying Random Forest algorithm obtained 91.06% accuracy and 84% accuracy was acquired for fake news detection using SVM.

**Keywords** Cyberbullying · Spam behavior · Bot accounts · Fake news · Machine learning

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## 1 Introduction

Social media, an integral part of modern life, facilitates diverse interactions and influences various sectors such as education, business, and philanthropy. Its exponential growth over the past fifteen years, with a current user base of 70% of adults in the United States, has drawn considerable attention [1]. Despite its benefits, social media also presents challenges, notably cyberbullying and the dissemination of fake news.

Cyberbullying, a prevalent issue particularly among adolescents, poses significant risks to victims' mental and physical well-being, with approximately 50% of American teenagers reported to have experienced it [2]. Addressing this concern is crucial for safeguarding teenagers' emotional health. Hence the US government took actions to tackle cyberbullying through awareness programs for children and parents [3]. For example, the Department of Defense Education Activity has an anti-bullying program. The FBI address online safety through the Safe Online Surfing (SOS) program [3]. This national program educates schoolchildren on cyber safety topics like passwords and social media, with quizzes to test their knowledge [3]. Originally a Miami field office initiative, SOS is now run by the FBI's Cyber Division [3]. The US Department of Homeland Security's CERT team also offers resources and direct users to stopbullying.gov and the National Crime Prevention Council for further help [3].

Spam behavior, characterized by repetitive content, excessive links, low-quality content, user reporting, and suspicious account behavior, is another challenge faced on social media platforms. Social media spam plagues platforms, with estimates suggesting 40% of accounts may be used to send deceptive messages targeting specific demographics via fake accounts and malicious links [4].

Social media bots, designed to mimic human behavior, pose a significant challenge due to their potential to spread misinformation rapidly and manipulate public opinion, as seen in incidents like the Associated Press Twitter hack [5]. This research aims to detect these bots using machine learning technology.

The rise of fake news on social media platforms poses significant societal concerns, including credibility erosion, biased influence, and real-world consequences like "Piz-zagate." Efforts to combat this issue focus on utilizing machine learning algorithms for detection.

Thus, it is imperative to develop effective detection mechanisms for these threats to ensure a safer and more trustworthy social media environment.

## 2 Research Statement

The motive of this research is to enhance social media's security and trustworthiness by implementing an effective tool to identify risks like bots, spam, harassment, and misinformation spreading. The primary focus will be on examining and providing an overall score for the public accounts.

### 3 Research Problem

Social media users are susceptible to a range of security threats arising from their followers. Notable among these threats are bots, spam, harassment, and misinformation, which have been identified as significant challenges in the realm of social media. Social networking platforms have introduced diverse mechanisms to shield users from malicious activities. However, the act of adding a new individual to one's friend list can expose users to a range of new vulnerabilities. Even if a user decides to unfollow or disengage from an account after suspecting malicious behavior, the repercussions may already have taken effect. Therefore, a crucial consideration emerges the ability to ascertain the risk associated with a public account before initiating interaction or adding it to one's network. While the development of effective detection methods is undoubtedly crucial, these research endeavors have not yet proposed a comprehensive approach that allows users to assess the potential risk associated with interacting with other users.

It was reported to BRIM anti-bullying software that out of reported cases of cyberbullying, 87% occurred on the biggest social media platform in the world, Facebook [6]. This means that, by far, most cyberbullying happens on Facebook. Unfortunately, of those victims of cyberbullying, only 37% ever reported the bullying to the social network it happened on [6]. According to Meta, the team reviewed reports of bullying and harassment in more than 50 languages acting out on more than 9 million pieces of content and proactively removing over 67% of bullying content in Q1 2022 [7]. Yet, there is cyberbullying happening all around the world.

Spamming on social media is another significant issue. The 2023 spam report by SEO & Content Marketing stated that Facebook and Instagram are the most spam-prone social networking sites while TikTok had an increase of spam compared to 2022 [8]. Among spam, spam comments were the highest raised concern while direct spam messages were followed second [8].

The proliferation of online services and the widespread use of social networking platforms such as Facebook, Twitter, and LinkedIn have led to an upsurge in problematic social bots [9]. Identifying these bots within online social networks (OSNs) presents significant challenges due to the dynamic nature of these platforms and the voluminous and ever-changing data they encompass. Current detection methods, primarily reliant on network structure analysis, are often sluggish and resource-intensive, even under static network conditions. For instance, employing the random-walk method entails considerable complexity, hindering swift execution [9]. Furthermore, existing methodologies exhibit limitations in accurately discerning bot presence, often resulting in false positives or failing to detect actual bot instances. To address this formidable challenge, this research endeavors to enhance the precision of bot detection methods, thereby improving the user experience and overall integrity of social networking platforms.

The spread of misinformation through social media has increased as the world has faced consecutive calamities. This fake news that is not authenticated affects the

users of social media who read it, as the majority of them will believe and take part in spreading the news further [10].

According to a survey conducted by pollster Ipsos across all 16 countries in September 2023, 68% of respondents said social media was where fake news was most widespread, ahead of messaging apps (38%), a belief “overwhelmingly prevalent in all countries, age groups, social backgrounds, and political preferences. In this paper, the spotlight is on the automatic identification of fake content in online news [11].

## 4 Literature Survey

In recent years, significant efforts have been directed towards the detection of cyberbullying, spam behavior, bot accounts and fake news. Diverse classifier architectures have been proposed to tackle these challenges. However, it remains a complex endeavor, plagued by issues of unwanted bias [6].

Various terms, including offensive or abusive language, online harassment, or aggression, hate speech, and harmful speech [2], have been used to describe these problematic forms of communication. In this context, we narrow our focus exclusively to the detection of cyberbullying in memes [2]. Meme originates from the Greek word “mimema” (imitated thing). Introduced by Richard Dawkins (British biologist) in his book “The Selfish Gene,” “meme” resembles “gene” to represent cultural information transmission [12]. There has been a notable scarcity of research concerning multimodal cyberbullying analysis, with only a limited number of studies incorporating both images and text. Yang et al. [13], for instance, observe a significant performance boost in hate speech detection when text is enriched with image embedding information. Chandra et al. [14] employed MFAS on a Twitter dataset, achieving a 68% accuracy rate. Meanwhile, Kirk et al. [15] implemented a CLIP (Linear Probe) approach on FBHM and Pinterest datasets, obtaining F1 scores of 56% and 57%, respectively. Lanyu Shang analyzed offensive memes using Analogy-aware Multi-modal Representation Learning, leveraging Faster R-CNN, ResNet50, Glove-based LSTM, and BERT, achieving a 69% accuracy [16]. Suryawanshi et al. [17] reviewed offensive content in images and texts using early fusion techniques, including Stacked LSTM/BiLSTM/CNN-Text+VGG16, yielding a 50% accuracy rate. Additionally, Dimitrov et al. [18] and Gupta et al. [19] employed VisualBERT pre-trained on MS COCO and RoBERTa, respectively, to analyze Face-book meme propaganda techniques, both achieving 48% accuracy.

To address spam behavior, there are various research conducted. Alhasun and Rassam proposed an architecture for Twitter spam identification [20]. For improved accuracy, this method intelligently blends text-based and metadata-based features. Text-based qualities were derived from tweets, whereas metadata-based elements were derived from user profiles. These characteristics were then fed into the deep learning model convolution neural networks (CNN) to classify accounts as spam or non-spam [20]. Alhassun and Rassam put their innovation to the test on an Arabic

Twitter dataset, comparing its performance to that of other spam detection systems. The suggested system outperformed others, with a maximum accuracy rate of 94.27% [20]. The authors emphasized the usefulness of this strategy for reducing spam not only on Twitter but also on other social media platforms.

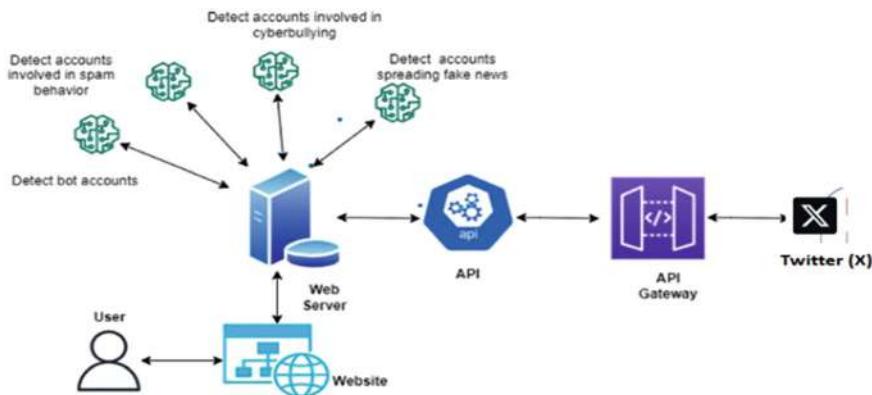
Said Salloum et al. offer a method for detecting possibly suspicious behavior on Twitter and Facebook using sentiment analysis [21]. Data is initially collected from the two aforementioned social media platforms and then subjected to a sentiment analysis algorithm for categorization into negative, positive, or neutral sentiments. Subsequent research is performed to uncover patterns that may indicate questionable activity. The study assesses the efficacy of their suggested technique on several datasets derived from Twitter and Facebook [21]. According to the data, the approach properly identified 5 suspicious activities with an accuracy rate of 85% for Twitter and 75% for Facebook [21]. In conclusion, the study underlines the potential of sentiment analysis as a promising option for detecting suspicious activity on social media. The study emphasizes the method's applicability to law enforcement agencies and social media corporations [21]. Sohrabi and Karimi present a novel strategy for detecting spam in the context of the Facebook social network in their paper [22]. The authors argue that due to the network's unique properties, traditional machine learning techniques used for spam identification may not produce good results on Facebook. They suggest a two-stage feature selection technique to overcome this concern. In the first stage, a genetic algorithm is used to curate a subset of attributes that have a high possibility of indicating spam content [22]. In the following stage, a support vector machine (SVM) classifier is used to build a model capable of detecting spam instances. This technique is evaluated using a dataset made up of Facebook posts [22].

For bot accounts detection, Arzum Karataş and Serap çahin discussed the “Bot or Not?” framework, an early social bot detection system for Twitter. By analyzing over 1000 features grouped into six classes and employing machine learning techniques, the framework achieves an overall accuracy of 86% for detecting social bots, thus highlighting the importance of feature-rich detection algorithms [9]. Awan et al. presented a Spark ML-based solution for fake profile recognition on social media platforms. With a classification accuracy of 94%, the proposed approach demonstrates the effectiveness of big data analytics in identifying fake profiles and preserving platform integrity [23]. Hayawi et al. explored various approaches to social media bot detection, emphasizing the utilization of deep learning models such as convolutional neural networks (CNN), recurrent neural networks (RNN), and gated recurrent units (GRU). Notably, Ping and Qin’s model achieves 100% accuracy by integrating tweet content and temporal features, underscoring the importance of feature fusion in bot detection [24]. Barhate et al. This research employed supervised ML techniques and a new feature called bot score to detect bots and analyze their influence on trending hashtags. Using 13 features for data preprocessing and Estimation of Distribution Algorithms (EDA), the RF classifier yielded an AUC result of 0.96 [25]. The study also revealed characteristics of bots such as a high friend-to-follower ratio and a low follower growth rate.

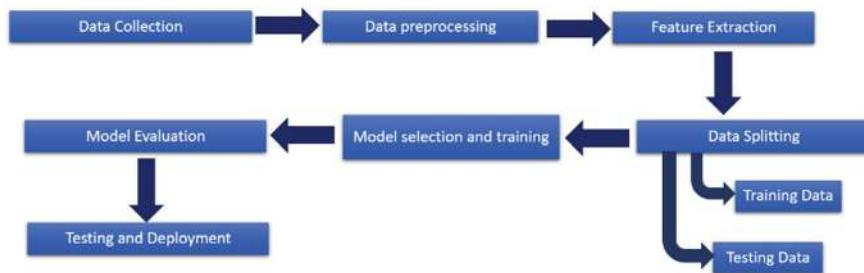
As fake news so common in social media, a lot of work has gone into creating detection frameworks a difficult but necessary endeavor. The challenge for natural language processing (NLP) researchers is to develop multilingual models that can be adjusted to different languages [26]. The problem was made worse by the late-2019 COVID-19 epidemic, which flooded media outlets with false information. Through social media, this erroneous information such as the assertion that COVID-19 is connected to 5G networks, or the provision of questionable preventive techniques spread quickly. Providing support for the so-called “infodemic.” Because of the vastness of this misinformation campaign, the authorities came up with a term for it [27]. It was difficult for reputable institutions to react quickly when bogus news started to circulate in many languages. Negative outcomes like mistrust and disobedience to public health efforts could result from failing to identify and eliminate multilingual COVID-19 misinformation [28]. Researchers are utilizing NLP methods such as BERT and machine learning to counteract misinformation. Preliminary research indicates that COVID-19 news can be effectively categorized. Furthermore, social media platforms such as Twitter have introduced novel approaches like X’s Community Notes feature, leveraging collective intelligence to confront misinformation. This collaborative tool empowers users to annotate and fact-check tweets in real time, furnishing crucial contextual details to effectively counter the dissemination of false information [29, 30]. Assessments of datasets and algorithms demonstrate how successful suggested models are. The focus on characteristics of standard languages highlights how useful they are for real-time applications. The significance of using NLP and machine learning to stop the spread of incorrect information is emphasized by this study [31]. For research on false news detection, a large dataset is available in the FakeNewsNet repository. To provide a more comprehensive picture, FakeNewsNet integrates multi-dimensional information, including spatial data, in contrast to other databases that mainly concentrate on linguistic elements. Researchers may examine the dissemination and effects of fake news in diverse settings because it covers a range of news categories, including political and entertainment sources. FakeNewsNet makes it possible for academics to create detection frameworks that are more effective by bridging the gap between social context, location information, and news content [32].

## 5 Methodology

COVID-19 The proposed approach leverages the use of an Apify API, which acts as an interface for interacting with Twitter. The process begins with the user inputting the account URL to detect the discussing social media malicious activities. Required data is gathered through the API. The collected data is then preprocessed to filter out irrelevant information and format it for further analysis. Next, machine learning algorithms are applied to detect patterns and anomalies indicative of defect bot accounts, cyberbullying, spam and fake news (Fig. 1).



**Fig. 1** Diagram illustrating the overall system



**Fig. 2** Flow diagram of the mechanism of training the machine learning models

Figure 2 portrays the basic mechanism followed to train the machine learning models to detect four social media threats discussed in this research.

### 5.1 Dataset

To develop models for cyberbullying detection, spam analysis, bot identification, and fake news recognition, data was collected from various sources. For cyberbullying detection 1600 (80%) of the data were trained and 600 (20%) were tested [33]. To identify spam behavior, a spam email classification dataset comprising 83,448 data points was utilized. Out of which 66,758 data points (80%) were allocated for training purposes, whereas 16,690 data points (20%) were reserved for testing the model [34]. Bot accounts were identified by analyzing data from 2,800 Twitter accounts and it was split in a 70:30 ratio (1,960 for training, 840 for testing) [35, 36]. Finally, for fake news detection, 18,796 (80%) news tweets were trained and tested on 4,684 (20%) from a dataset of 23,420 [37].

## 5.2 Model Architecture and Process

### 5.2.1 Cyberbullying Detection

Training the model to detect cyberbullying involves several crucial steps, beginning with text preprocessing. Initially, the text in memes is cleaned by converting them to lowercase, removing punctuation, numbers, and stop words. Next, it was further analyzed by performing part-of-speech tagging and lemmatization to understand the grammatical structure and base form. After cleaning, the data was split into training (80%) and testing (20%) sets. To represent the comments numerically, the Bag-of-Words approach was used, which captures the frequency of each word in the vocabulary. The model was trained using a linear Support Vector Classifier (SVC) model on the training data. This model learns to classify memes based on the features extracted during preprocessing. Linear SVC allows an easier understanding of how features like word usage contribute to cyberbullying classification. Moreover, it is computationally faster with kernel functions, making it ideal for large datasets of memes, which makes it a suitable model to detect cyberbullying. Finally, the model's performance was evaluated on the testing set using various metrics like accuracy, re-call, precision, and F1-score.

### 5.3 Spam Detection

To detect spam behavior methodology involved data preprocessing to prepare the text data, including techniques like text cleaning to improve feature representation. The text was converted to lowercase for case insensitivity. Punctuations, numbers, and stop words were removed to eliminate irrelevant information that wouldn't contribute to classification. These cleaning steps enhanced data quality and reduced noise within the text features. Next, the data was split into training and testing sets using a common 80/20 split. The training set (80% of the data) was used to train the machine learning models, while the testing set (20% of the data) was reserved for unbiased evaluation. Various machine learning models including Random Forest Classifier, Logistic Regression, Decision Tree Classifier, Neural Network (MLPClassifier), Stochastic Gradient Descent Classifier, and Gradient Boosting Classifier were trained on the training data and evaluated on the testing set using metrics like accuracy score and confusion matrix.

### 5.4 Bot Account Detection

Twitter data containing both bot and non-bot accounts was collected for training the bot detection model. Key features such as followers count, friends count, listed count,

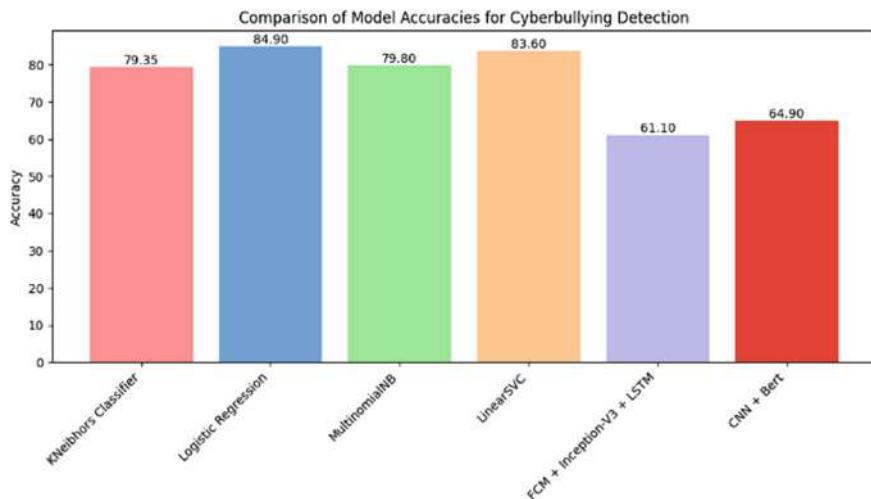
favorites count, statuses count, profile age and verification status were extracted from Twitter profiles. To ensure data consistency, date strings were standardized, and the age of the profiles was calculated in days to capture temporal aspects. Additionally, the “140k Real and Fake Faces” dataset from Kaggle was acquired to train a convolutional neural network (CNN) model using profile images. Image data preprocessing included resizing and normalization for uniform input dimensions and pixel values. The collected Twitter data and image dataset were split into training, validation, and test sets for model training and evaluation. Numerical features from Twitter profiles underwent preprocessing like normalization or scaling. Various machine learning and deep learning models such as KNN, SVM, Naive Bayes, Decision Tree, Random Forest, and XGBoost were trained and evaluated using standard metrics like accuracy, precision, recall, and F1 score. A CNN model based on the ResNet50 architecture was trained on preprocessed image data. The best-performing models, Random Forest and CNN, were integrated for final predictions, combining numerical features and profile images to determine bot likelihood. Model contributions and the impact of features on bot detection accuracy were analyzed for insights into model strengths and limitations.

### **5.5 *Fake News Detection***

In the quest to combat fake news, a comprehensive approach is essential, starting with meticulous data collection and preprocessing techniques. This includes the removal of HTML tags, tokenization, punctuation removal, and conversion to lowercase, among others. Feature engineering plays a pivotal role in converting textual data into numerical features, employing methods like TF-IDF vectorization and word embeddings. Models such as Naive Bayes, Random Forest, LSTM, NLP models, and SVM are trained on preprocessed data, with hyperparameter tuning conducted to optimize performance. Evaluation metrics like accuracy, precision, recall, and F1-score are employed to assess model performance, aiding in the selection of the most effective model. Further refinement through fine-tuning and optimization, including exploring advanced techniques like attention mechanisms in LSTM, is undertaken to enhance model efficacy. Finally, deployment and continuous monitoring ensure the model’s effectiveness over time, with periodic retraining conducted to adapt to evolving data landscapes.

## **6 Results**

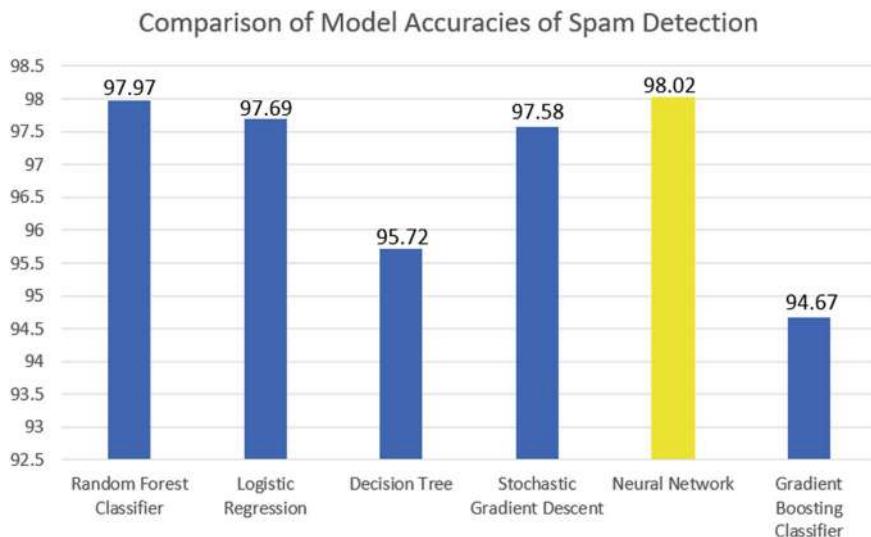
As shown in Figure 3, several models were trained, and the best model was chosen for cyberbullying detection. As per the results, Logistic regression gives the best accuracy out of all with 84.9%.



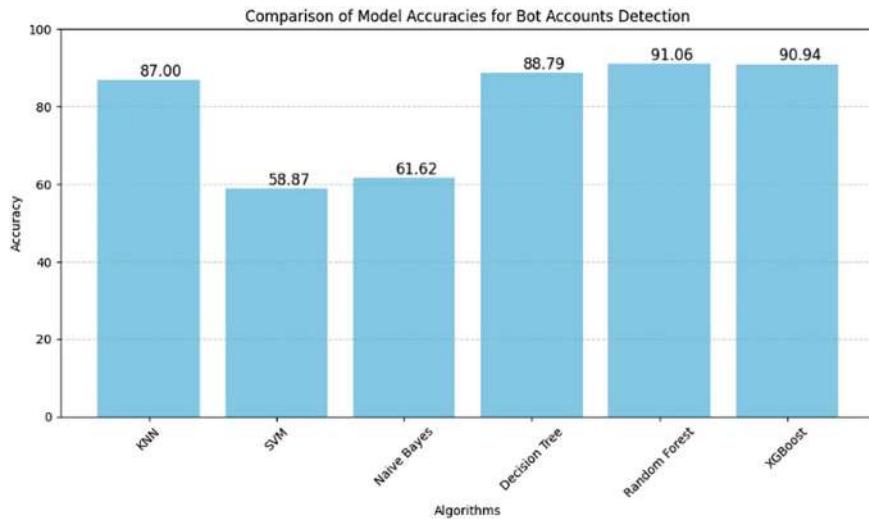
**Fig. 3** Graph representing the models trained and respective accuracies obtained for cyberbullying detection

Figure 4 illustrates how the Machine Learning models were trained and accuracies were obtained, the Neural Network (MLPClassifier) achieved the highest accuracy of 98.02%. Therefore, it was chosen to train the final spam behavior detection system.

In the analysis of bot detection models, Random Forest excels in bot detection, with an accuracy of 91%, achieving better accuracy than the other models tested.



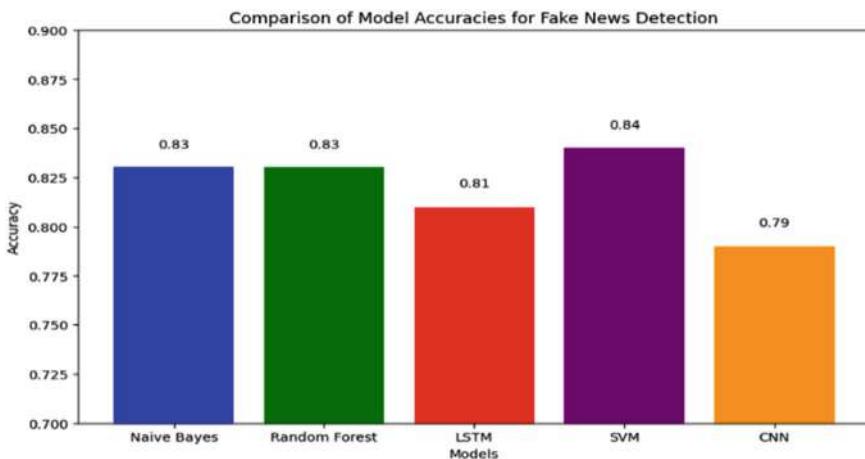
**Fig. 4** Graph representing the models trained and respective accuracies obtained for spam detection



**Fig. 5** Graph representing the models trained and respective accuracies obtained for bot accounts detection

ResNet-50 effectively distinguishes real and fake faces with high accuracy and minimal loss. Integrating bot detection with image classification enhances predictive capabilities for comprehensive social media analysis (Fig. 5).

The bar chart provides a visual representation of the accuracies achieved by different models for fake news detection. SVM demonstrates the highest accuracy at 0.84, with Naive Bayes and Random Forest closely trailing at 0.83. LSTM follows at 0.81, while CNN lags slightly behind at 0.79. Based on these results, the SVM model was selected for its superior performance in accurately identifying fake news (Fig. 6).



**Fig. 6** Graph representing the models trained and respective accuracies obtained for fake news detection

## 7 Conclusion

The four models, each trained to detect different security issues on social media platforms, were combined to form a comprehensive system capable of assessing the trustworthiness probability of social media accounts overall. Currently as the future of the research, combining this system output value with the risk score which is calculated by multiplying the Risk Impact Rating by Risk Probability will be determined to further assess social media accounts. The risk score can be implemented to display the individual threat as well as the overall threat by combining the four threat categories assessed in this research.

## References

- Perrin A (2015) Social media usage: 2005–2015. Pew Research Center. <https://www.pewresearch.org/internet/2015/10/08/social-networking-usage-2005-2015/>. Accessed 15 Oct 2023
- Islam MM, Uddin MA, Islam L, Aktar A, Sharmin S, Acharjee UK (2020) Cyberbullying detection on social networks using machine learning approaches, In IEEE, Gold Coast, Australia
- Kaough E Combatting cyberbullyinorg: government, NGO and the private sector, information and knowledge services. Policy and stratigic planning division, ministry of public security
- The history of digital spam–communications of the ACM. Aug. 01, 2019. <https://cacm.acm.org/research/the-history-of-digital-spam/>
- What is a social media bot? Social media bot definition. cloudflare. <https://www.cloudflare.com/en-gb/learning/bots/what-is-a-social-media-bot/>
- Cyber bullying on facebook and what to do about it, BRIM anti-bullying software. <https://antibullyingsoftware.com/facebook-bullying/>. Accessed 30 July 2023

7. Bullying and harassment. meta. <https://about.meta.com/actions/safety/topics/bullying-harassment>. Accessed 30 July 2023
8. Crestodina A (2023) The 2023 spam report: the state of unwanted marketing (plus, tips from 7 legit marketers) by SEO Content Marketing. Orbit Media Studios. <https://www.orbitmedia.com/blog/spam-statistics/> Accessed 19 Nov 2023
9. Karataş A, çahin S (2017) A review on social bot detection techniques and research directions. Ankara, Turkey
10. Khan M, Jain A, Chouhan R, Sheikh SH (2020) Fake news identification on social media. Int J Eng Res 9(1). <https://doi.org/10.17577/ijertv9is010183>
11. Survey on the impact of online disinformation and hate speech. 2023. [https://www.unesco.org/sites/default/files/medias/fichiers/2023/11/unesco\\_ipso\\_survey.pdf](https://www.unesco.org/sites/default/files/medias/fichiers/2023/11/unesco_ipso_survey.pdf)
12. What Is a Meme? Buffer: all-you-need social media toolkit for small businesses. <https://buffer.com/social-media-terms/meme>
13. Das A, Wahi JS, Li S Detecting hate speech in multi-modal Memes. India
14. Chandra M et al (2021) Subverting the Jewtocracy': online antisemitism detection using multi-modal deep learning. In 13th ACM Web Science Conference 2021. <https://doi.org/10.1145/3447535.3462502>
15. Kirk H et al (2021) Memes in the wild: assessing the generalizability of the hateful memes challenge dataset. ACLWeb. <https://aclanthology.org/2021.woah-1.4/>
16. Shang L, Zhang Y, Zha Y, Chen Y, Youn C, Wang D (2021) AOMD: An analogy-aware approach to offensive meme detection on social media. arXiv.org. <https://arxiv.org/abs/2106.11229> Accessed 01 May 2024
17. Suryawanshi S, Chakravarthi BR, Arcan M, Buitelaar P (2020) Multimodal meme dataset (MultiOFF) for identifying offensive content in image and text. ACLWeb. <https://aclanthology.org/2020.trac-1.6/>
18. Dimitrov D et al (2021) Detecting propaganda techniques in memes. <https://aclanthology.org/2021.acl-long.516.pdf>
19. Gupta K, Gautam D (2021) Volta at SemEval-2021 Task 6: towards detecting persuasive texts and images using textual and multimodal ensemble. Accessed 01 Mar 2024. <https://aclanthology.org/2021.semeval-1.149.pdf>
20. Alhassun AS, Rassam MA (2022) A combined text-based and metadata-based deep-learning framework for the detection of spam accounts on the social media platform twitter. 10(439). <https://doi.org/10.3390/%20pr10030439>
21. Salloum SA, Almansoori A, Alshamsi M, Shaalan K, Mansoori Sal (2020) Suspicious activity detection of twitter and facebook using sentimental analysis. TEM J 9(4). <https://doi.org/10.18421/TEM94%E2%80%9001>
22. Sohrabi MK, Karimi F (2017) A feature selection approach to detect spam in the facebook social network. Arab J Sci Eng 43(2):949–958. <https://doi.org/10.1007/s13369-017-2855-x>
23. Awan MJ, Khan MA, Ansari ZK, Yasin A, Shehzad HMF (2022) Fake profile recognition using big data analytics in social media platforms
24. Hayawi K, Saha S, Masud MM, Mathew SS, Kaosar M (2023) Social media bot detection with deep learning methods: a systematic review. Neural Comput Appl
25. Barhate S, Mangla R, Panjwani D, Gatkal S (2020) Twitter bot detection and their influence in hashtag manipulation
26. Ahmed AAA, Aljarbouh A, Donepudi PK, Choi MS (2021) Detecting fake news using machine learning, arXiv. <https://arxiv.org/pdf/2102.04458>
27. Akhtar P, Ghouri AM, Khan HUR, Haq MAU, Awan U, Zahoor N, Khan Z, Ashraf A (2021) Detecting fake news and disinformation using artificial intelligence and machine learning. ResearchGate. [https://www.researchgate.net/publication/364986503\\_Detecting\\_fake\\_news\\_and\\_disinformation\\_using\\_artificial\\_intelligence\\_and\\_machine\\_learning\\_to\\_avoid\\_supply\\_chain\\_disruptions](https://www.researchgate.net/publication/364986503_Detecting_fake_news_and_disinformation_using_artificial_intelligence_and_machine_learning_to_avoid_supply_chain_disruptions)
28. Ahmad I, Yousaf M, Yousaf S, Ahmad MO (2020) Fake news detection using machine learning ensemble methods. Complexity 2020 (8885861). <https://downloads.hindawi.com/journals/complexity/2020/8885861.pdf>

29. Pio L Twitter launches integrity update in community notes to tackle the viral spread of fake images. Rockcontent. <https://rockcontent.com/blog/twitter-update-community-notes/>
30. Ono M Study finds X's community notes provides accurate responses to vaccine misinformation. UC San Diego. <https://today.ucsd.edu/story/study-finds-xs-formerly-twitters-community-notes-provide-accurate-credible-answers-to-vaccine-misinformation>
31. Cueva E, Ee G, Iyer A, Pereira AS, Roseman AS, Martinez D (2019) Detecting fake news on twitter using machine learning models. In proceedings of the IEEE international conference on machine learning and applications (ICMLA), pp 875–880. <https://www.semanticscholar.org/paper/Detecting-Fake-News-on-Twitter-Using-Machine-Models-Cueva-Ee/c31e838c900111772e84e683f7142593a1aa1935>
32. Ali I, Ayub MNB, Shivakumara P, Noor NFBM (2022) Fake news detection techniques on social media: a survey. Wirel Commun Mob Comput 2022 (6072084). <https://www.hindawi.com/journals/wcmc/2022/6072084/>. Disclaimer/Publishers Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content
33. Suspicious communication on social platforms. [www.kaggle.com. https://www.kaggle.com/datasets/syedabbasraza/suspicious-communication-on-social-platforms](http://www.kaggle.com/datasets/syedabbasraza/suspicious-communication-on-social-platforms)
34. Spam email classification dataset. [www.kaggle.com. https://www.kaggle.com/datasets/purushvini/email-spam-classification-dataset](http://www.kaggle.com/datasets/purushvini/email-spam-classification-dataset)
35. Bot-Detection/test\_data\_4\_students.csv at master AayushTyagi1/Bot-Detection. GitHub. [https://github.com/AayushTyagi1/Bot-Detection/blob/master/test\\_data\\_4\\_students.csv](https://github.com/AayushTyagi1/Bot-Detection/blob/master/test_data_4_students.csv)
36. Twitter-bot detection dataset. [www.kaggle.com. https://www.kaggle.com/datasets/goyaladi/twitter-bot-detection-dataset](http://www.kaggle.com/datasets/goyaladi/twitter-bot-detection-dataset)
37. FakeNewsNet\_Dataset—Google Drive. drive.google.com. [https://drive.google.com/drive/folders/1cj6QyPLJvBfDZQ\\_jdXdEAss14tnDSoGK](https://drive.google.com/drive/folders/1cj6QyPLJvBfDZQ_jdXdEAss14tnDSoGK)

# Evaluating the Influence of Regional Economic Factors on Local Budget Revenues Using Econometric Models



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**Abstract** Regional economic potential has a substantial impact on the financial health of local governments. Gaining insight into the impact of these factors on municipal revenues is crucial for formulating efficient fiscal strategies and promoting long-term sustainable development. This study investigates the influence of important economic sectors on local budgets by employing sophisticated econometric models and analyzing panel data from 13 areas of Uzbekistan spanning from 2014 to 2023. The study employed econometric techniques like Pooled Ordinary Least Squares (POLS), Fixed Effects Estimator (FEE), and Random Effects Estimator (REE). The study examines the correlation between municipal budget revenues and the contributions made by the agricultural, industrial, and service sectors. The findings indicate that the service sector has a substantial impact on municipal revenues, as even a 1% growth in this sector results in a notable rise in tax revenues. In contrast, agriculture has a detrimental impact on income, and the industrial sector has a moderately beneficial impact. The REE model, which was validated using the Hausman test,

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was determined to be the most suitable. These findings emphasize the significance of comprehending regional economic dynamics in order to optimize local budgets and formulate focused fiscal strategies for sustainable development.

**Keywords** Regional economic factors · Local budget revenues · Fixed effects estimator · Random effects estimator · Uzbekistan

## 1 Introduction

The economic potential of regions plays a crucial role in setting the income base of local budgets, fostering sustainable development, and facilitating the effective provision of public services [1]. Local governments' fiscal well-being is impacted by a range of factors, such as economic capacity, industrial operations, and levels of investment. Local governments require consistent budget revenues in order to efficiently control economic activity, mitigate fiscal risks, and establish a secure financial environment for economic development [2]. The majority of regions in the country exhibit robust financial stability, which local governments can leverage to enhance their financial stability and facilitate budgetary expansion.

There is growing interest in comprehending the impact of regional economic potential on the financial capability of local governments. The various sectors of the economy, namely agriculture, industry, and services, provide distinct contributions to the income base. These contributions are determined by investment levels, industrial activity, and the general economic vibrancy. Econometric models offer a solid foundation for assessing these interactions, providing a comprehensive comprehension of the influence of regional economic issues on local government revenues.

The objective of this study is to evaluate the influence of key sectors of the regional economy on local budget revenues in Uzbekistan by employing sophisticated econometric models. The study aims to comprehend the relationship between economic activity and local financial health by examining panel data from 13 locations spanning from 2014 to 2023. The study offers a thorough examination using POLS, FEE, and REE models.

The results are anticipated to provide empirical data to the body of knowledge on regional economic determinants and the financial resources of local governments. Furthermore, the outcomes will offer pragmatic insights for policymakers aiming to enhance the financial capability and economic steadiness of regional administrations. Analyze the industries that have a substantial impact on local revenues to formulate focused policies that promote sustainable economic growth and financial stability.

The subsequent parts provide a comprehensive explanation of the methodology employed in the econometric analysis, provide the findings of the study, examine the ramifications, and conclude by offering recommendations for policymakers.

## 2 Literature Review

Regional economic factors play a significant role in influencing the budget revenues of local governments. Research results show that factors such as regional GDP, the volume of agriculture and industry have a positive impact on the formation of local budget revenues [3, 4]. However, the number of small businesses revealed a negative effect, although not statistically significant. In addition, the implementation of regional autonomy emphasizes the importance of local revenue sources to finance regional development in order to reduce dependence on the central government [5, 6]. Research has also shown that regional revenues, balancing funds, and capital expenditures can influence local government financial performance, with regional revenues having a negative effect in some cases [7, 8]. Coordination of funding through components such as regional revenues and expenditures in the APBD structure is critical for transparent and effective budget management at the local government level [9].

The economic potential of the region significantly affects the revenues of its local budget. Research has shown that factors such as regional GDP, the volume of agriculture and industry, have a positive effect on the formation of local budget revenues, while the number of small businesses, although it has a negative effect on income generation, is not statistically significant [10, 11]. The economic potential of a region includes various elements, such as environmental, financial, resource, human potential, quality of life, investment and innovation potential, each of which plays a decisive role in the economic development and income generation of the region [12–14]. In addition, the impact of digitalization on the economic potential of the region was highlighted, emphasizing the importance of using new knowledge, information and innovation to accelerate regional development and income generation [15, 16]. Developing a budget policy based on understanding and using the economic potential of the region can lead to sustainable growth in local budget revenues and overall social development [17, 18].

A number of studies have examined the contribution of specific sectors to local budget revenues. The agricultural sector, often characterized by extensive tax incentives and subsidies, can result in lower tax revenues despite high productivity [19, 20]. Conversely, industrial activities, especially those associated with the production of high-value products, have been found to have a positive impact on local government revenues by contributing to the corporate and property tax bases [21, 22].

The service sector has been identified as an important factor in local financial health. Regions with thriving service sectors, including tourism, retail and financial services, have seen significant growth in local incomes [23, 24]. These results suggest that policies that promote service sector growth can improve financial stability and income growth.

### 3 Methodology

This study uses a comprehensive econometric approach to assess the impact of regional economic factors on local budget revenues in Uzbekistan. The methodology is based on the collection and analysis of panel data, the use of econometric models and rigorous statistical testing to ensure the reliability of the results.

Data for this study was obtained from the Uzbekistan Statistics Agency and the State Customs Committee and covers the period from 2014 to 2023. The dataset includes quarterly observations from 13 regions, resulting in a total of 352 observations.

Key variables include:

Y-Dependent variable: local budget revenues (tax\_ben),

X1-Independent variable: value of the agricultural sector (agrcul\_sect),

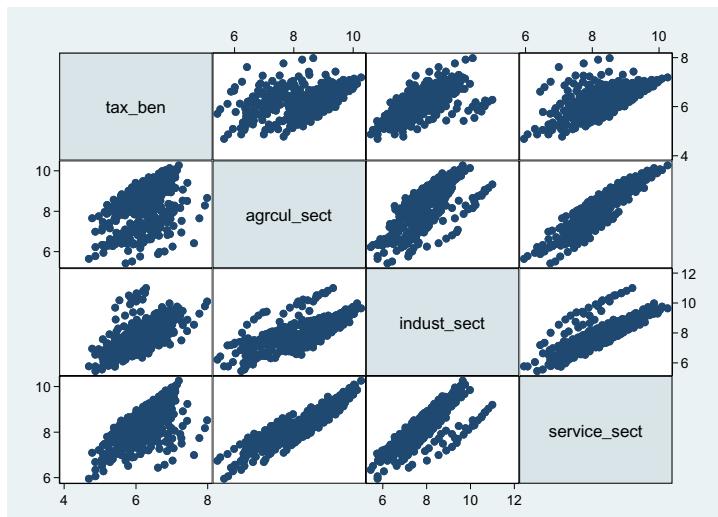
X2-Independent variable: industrial sector value (indust\_sect),

X3-Independent variable: service sector value (service\_sect).

Analysis: POLS, FEE and REE. These models were chosen because of their ability to handle panel data and account for both cross-sectional and time series variation.

### 4 Result and Discussion

At the initial stage of the study, an analytical graphical matrix of dependent and independent variables was developed (see Fig. 1).



**Fig. 1** Graphical matrix of the relationship between dependent and independent variables

According to Fig. 1 there is a strong correlation between all variables, as well as a noticeable density state. The density condition specifies the concentration of data points in certain areas of the data set. High density means that many data points are clustered in a small area, indicating that similar variable values appear frequently.

A strong correlation associated with dense clustering of data points demonstrates a stable and reliable relationship between the dependent and independent variables. This density condition confirms that this relationship is consistently observed across the entire data set, resulting in more accurate predictions. This data set is very valuable for statistical analysis because it provides confidence in the predictive power of the identified relationships.

The correlation between tax revenues and gross value added in the agricultural sector is negative. This indicates that increases in agricultural productivity are associated with decreases in tax revenues, possibly due to extensive tax incentives and subsidies in the agricultural sector that reduce its fiscal contribution.

The next step was to develop the parameters of econometric models, including the POLS, FEE and REE models (see Tables 2, 3, 4 and 5).

In addition, Shapiro–Wilk and Durbin–Watson tests were performed to evaluate the pooled OLS estimator (POLS) model.

In addition, the Hausman test was performed to evaluate the fit of the FEE and REE models, and the variance inflation factor (VIF) was calculated to test for multicollinearity.

According to Table 1, econometric models based on panel data were analyzed for each indicator and test.

The study used the POLSE model to test the hypotheses. The null hypothesis ( $H_0$ ) states that the dependent variable ( $y$ ) is equal to zero, while the alternative hypothesis ( $H_1$ ) states that ( $y$ ) is different from zero. The test results show that both the F-statistic

**Table 1** Indicators of the econometric model based on panel data analysis

| Indicators                | 1st model       | 2nd model      | 3rd model       |
|---------------------------|-----------------|----------------|-----------------|
|                           | POLSE model     | FEE model      | REE model       |
| <b>Tax_ben</b>            |                 |                |                 |
| Agrcul_sect               | −0. 45 (0.04)   | −0. 48 (0.07)  | −0. 44 (0.06)   |
| Industry_sect             | 0.23 (0.03)     | −0.10 (0.10)   | 0.12 (0.04)     |
| Service_sect              | 0.74 (0.07)     | 1. 11 (0.17)   | 0.80 (0.11)     |
| F-test                    | 134.32 (0.0000) | 67.28 (0.0000) |                 |
| R <sup>2</sup>            | 0.51            | 0.42           | 0.72            |
| Chi-square                |                 |                | 233.76 (0.0000) |
| Adjustment R <sup>2</sup> | 0.51            |                |                 |
| Durbin watson             | 0.30            |                |                 |
| Shapiro- wilk             | 0.43            |                |                 |
| Vif                       | 5.82            |                |                 |
| Houseman                  |                 |                | 0.78            |

and the t-statistic are below the 0.05 level of significance, which results in the null hypothesis being rejected in favor of the alternative hypothesis. Moreover, according to the pooled OLS estimator model, the R-squared (coefficient of determination) is 0.51, which is a high value.

The results of hypothesis testing using the pooled OLS model highlight its statistical significance and practical importance for understanding the relationship between dependent and independent variables.

The POLSE model developed during the study is as follows:

$$Tax\_ben = -0.45 \text{ Agrcul\_sect} + 0.23 \text{ Indust\_sect} + 0.74 \text{ Service\_sect} + 1.88 \quad (1)$$

According to this model:

An increase in gross value added of the agricultural sector by 1% leads to a decrease in tax revenues by 0.45%.

An increase in gross value added of the industrial sector by 1% leads to an increase in tax revenue by 0.23%.

An increase in gross value added of the service sector by 1% leads to an increase in tax revenues by 0.74%.

This step reveals the results of several statistical analyzes conducted to examine the Gauss-Markov assumptions within a pooled OLS econometric equation.

Durbin-Watson and Shapiro-Wilk tests were performed, showing that the null hypothesis ( $H_0: y = 0$ ) and alternative hypothesis ( $H_1: y \neq 0$ ) were statistically significant at a significance level greater than 0.05. Thus, in this study, the alternative hypothesis was not confirmed. The test results are presented in Table 2.

To assess multicollinearity in the OLS pooled estimator econometric equation, the variance inflation factor (VIF) was calculated, resulting in a value of 5.82. This value falls within the confidence interval [1, 10], which indicates the absence of multicollinearity in the model.

According to the REE model, the Chi-square statistic of 233.76 indicates a satisfactory fit between the observed and expected values. This demonstrates that the model fits the data effectively and confirms the independent variables' positive and robust predictions for the dependent variable.

The model's R-square value of 0.72 means that 72% of the variance in the dependent variable is explained by the model. This highlights the relevance of the model in data collection and highlights the useful predictive influence of the independent variables on the dependent variable.

The REE model developed for the study is as follows:

$$Tax\_ben = -0.44 \text{ Agrcul\_sect} + 0.12 \text{ Industry} + 0.80 \text{ Services sector} + 1.88 \quad (2)$$

According to this model:

An increase in gross value added of the agricultural sector by 1% leads to a decrease in tax revenues by 0.44%.

An increase in gross value added of the industrial sector by 1% leads to an increase in tax revenue by 0.12%.

An increase in gross value added of the service sector by 1% leads to an increase in tax revenue by 0.80%.

These results highlight the significant role of the service sector in increasing local tax revenues, and also indicate a negative impact of the agricultural sector and a moderate positive impact of the industrial sector.

Hausman test value obtained from the REE econometric model is 0.78. These results show that the null hypothesis ( $H_0: y = 0$ ) and alternative hypothesis ( $H_1: y \neq 0$ ) are statistically significant at a significance level greater than 0.05. In this study, accepting the null hypothesis assumes that the random effects estimator model is superior to the fixed effects estimator model. In addition, the observed p-value  $> 0.05$  meets the criteria of the Hausman test, which confirms the correct application of the test to the data set and ensures the reliability of the results obtained.

The FEE model developed in the study is as follows:

$$Tax\_ben = -0.48 \text{ Agrcul\_sect} - 0.10 \text{ Industry\_sect} + 1.15 \text{ Service\_sect} + 1.78 \quad (3)$$

According to this model:

An increase in gross value added of the agricultural sector by 1% leads to a decrease in tax revenues by 0.48%.

An increase in gross value added of the industrial sector by 1% leads to a decrease in tax revenue by 0.10%.

An increase in gross value added of the service sector by 1% leads to an increase in tax revenue by 1.15%.

These results highlight the significant impact of the service sector on local tax revenues and also indicate the negative impact of both the agricultural and industrial sectors in this particular model.

## 5 Conclusion

The service sector has the most significant positive impact on local budget revenues. The expansion of this sector is closely linked to increased tax revenue, highlighting the importance of promoting service-oriented economic activity to improve financial health.

The industrial sector also has a positive effect on local budget revenues, although to a lesser extent than the service sector. Policies that support industrial development and investment can help create a stronger revenue base for local governments.

The agricultural sector, on the contrary, shows a negative relationship with local budget revenues. This finding suggests that extensive tax breaks and subsidies in this sector could undermine its fiscal contribution. A review of agricultural tax policies and incentives is needed to ensure a more effective contribution to local revenues.

The results of this study have several important implications for policymakers:

Given the significant positive impact of the services sector on local incomes, targeted policies that promote growth in tourism, retail trade and financial services should be a priority. Investments in infrastructure and regulatory frameworks that support service-oriented businesses can yield significant financial benefits.

Policies that encourage industrial growth and attract investment in manufacturing and high value-added industries can improve local fiscal health. This includes providing incentives for industrial innovation and development while ensuring a fair tax contribution from the sector.

The negative impact of the agricultural sector on local revenues requires a re-evaluation of current tax incentives and subsidies. Implementing a more balanced fiscal policy in agriculture can help ensure that the sector makes an adequate contribution to local budget revenues.

This study lays the foundation for future research in several areas:

Extending the analysis over a longer period of time can provide greater insight into long-term trends and the impact of economic policies on local revenues.

Comparing Uzbekistan's results with those of other countries can help identify best practices and common challenges in managing the financial impacts of regional economic activity.

Further research into sectoral policies and their impact on local revenues could provide the basis for more targeted and effective budget strategies.

Understanding the dynamics between regional economic factors and local government revenues is critical to developing effective fiscal policies and promoting sustainable economic development. This study provides robust empirical evidence on these relationships, highlighting the critical role of the service sector and the need for policy reforms in agriculture and industry. Using these insights, policymakers can develop strategies that will improve the fiscal capacity and economic stability of local governments in Uzbekistan.

## References

1. Jin H, Qian Y, Weingast BR (2005) Regional decentralization and fiscal incentives: Federalism, Chinese style. *J Public Econ* 89(9–10):1719–1742
2. Kassouri Y (2022) Fiscal decentralization and public budgets for energy RD&D: A race to the bottom? *Energy Policy* 161:112761
3. Zhang J, Qi Y, Song Y, Li Y, Lin R, Su X, Zhu D (2023) The relationship between industrial transfer parks and county economic growth: Evidence from Guangdong Province China. *Habitat Int* 139:102894
4. Shoh-Jakhon K. Theoretical and methodological aspects of intensive economic growth in ensuring sustainable economic development. *Social and Economic Studies within the Framework of Emerging Global Developments* 3, 283
5. Gong X, Wong WK, Peng Y, Khamdamov SJ, Albasher G, Hoa VT, Nhan NTT (2023) Exploring an interdisciplinary approach to sustainable economic development in resource-rich regions: An investigation of resource productivity, technological innovation, and ecosystem resilience. *Resour Policy* 87:104294

6. Makhmudov S, Khamdamov S-J, Karlibaeva R, Mamadiyarov Z, Haydarov O, Khujamurodov A, Imomov K (2023) The impact of digital technologies on the labor market of Uzbekistan. In: Proceedings of the 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp. 260–267. Association for Computing Machinery, New York, NY, USA
7. Alam P, Sharholy M, Khan AH, Ahmad K, Alomayri T, Radwan N, Aziz A (2022) Energy generation and revenue potential from municipal solid waste using system dynamic approach. *Chemosphere* 299:134351
8. Urunov R, Makhmudov S, Mamadiyorov Z, Khamdamov S-J, Kurbanov ZN, Dadabaev U (2023) Digitalization and its econometric analysis on transforming sustainable regional development into improved population living standards. In: Proceedings of the 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp. 438–442. Association for Computing Machinery, New York, NY, USA
9. Iliopoulos P, De Witte K (2024) The expenditure composition and trade-offs in local government budgets. *Socioecon Plann Sci* 93:101900
10. Giusti F, de Lima Green MP, de Freitas Lins F, de Castro FF, de Miranda FSDM (2023) Transparency in the planning for the use of mining royalties in Brazilian municipalities. *Extr Ind Soc* 16:101352
11. Lee D, Min S (2023) Participatory budgeting and the pattern of local government spending: Evidence from South Korea. *Eur J Polit Econ* 76:102235
12. Tran TK, Lin CY, Tu YT, Duong NT, Thi TDP, Shoh-Jakhon K (2023) Nexus between natural resource depletion and rent and COP26 commitments: Empirical evidence from Vietnam. *Resour Policy* 85:104024
13. Abdelwahed L (2020) More oil, more or less taxes? New evidence on the impact of resource revenue on domestic tax revenue. *Resour Policy* 68:101747
14. Xiong J, Huang L, Yang Z, Wang X (2024) The impact of local government debt on entrepreneurship: Evidence from a quasi-natural experiment of local debt governance reform. *Int Rev Econ Financ* 93:501–519
15. Mamatkulov B, Khamdamov S-J, Togayniyazov S, Tukhtabaev J, Quldoshev Q, Qarshiev D (2023) Predicting future living standards in Uzbekistan: Utilizing econometric analysis. In: Proceedings of the 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp. 425–431. Association for Computing Machinery, New York, NY, USA
16. Alves PJHF, Araujo JM (2024) The effects of intergovernmental transfers on the local fiscal incentives of Brazilian municipalities. *J GovMent Econ* 13:100104
17. Kurbonov K, Makhmudov S, Mamadiyorov Z, Khamdamov S-J, Karlibaeva R, Samadov A, Djailov F (2023) The impact of digital technologies on economic growth in the example of Central Asian and European countries. In: Proceedings of the 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp. 403–409. Association for Computing Machinery, New York, NY, USA
18. Khamdamov SJ, Usmanov AS, Abdulazizova O, Isaev F, Kholbaev N, Makhmudov S, Kholbaeva S (2022) Econometric modeling of central bank refinancing rate in Uzbekistan. In: Proceedings of the 6th International Conference on Future Networks & Distributed Systems, pp 253–257
19. Yusupov S, Boymuratov S, Bobamatova D, Shukhratova M, Marupov I, Akramova DT, Muradova DA (2022) Diagnostic aspects of zygomatico-orbital complex fractures with the use of modern digital technologies. In: Proceedings of the 6th International Conference on Future Networks & Distributed Systems (ICFNDS '22), pp 399–403
20. Yu B, Zhou X (2024) Land finance and urban sprawl: Evidence from prefecture-level cities in China. *Habitat Int* 148:103074
21. Muftaydinova SK, Chuprynni VD, Fayzullin LZ, Buralkina NA, Muminova ZA, Asaturova AV, Abdullayev SI (2022) Expression of the tyrosine kinase receptor (EPHA1) in the eutopic and ectopic endometrium of patients with deep infiltrative endometriosis use of modern digital technologies. In: Proceedings of the 6th International Conference on Future Networks & Distributed Systems (ICFNDS '22), pp 416–421

22. Zhang Z, Hua Z, He Z, Wei X, Sun H (2021) The impact of local government attention on green total factor productivity: An empirical study based on System GMM dynamic panel model. *Journal of Cleaner Production* 142275
23. Khamdamov SJ (2021) Calculating share of factors of intensive economic growth in Uzbekistan. In: Proceedings of the 5th International Conference on Future Networks & Distributed Systems, pp 393–397
24. Mamadiyarov Z, Hakimov H, Askarov S (2024) Development of retail banking services in the context of digital transformation. *Financ Credit Act Probl Theory Pract* 1(54):51–67

# An Econometric Analysis of the Factors Impacting the Foreign Trade Operations of Entrepreneurial Firms



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**Abstract** The engagement of entrepreneurial organizations in foreign trade plays a crucial role in the global economy, enhancing economic integration and stability among nations. The primary objective of this research is to scrutinize the determinants influencing these operations and their repercussions on economic advancement, evolution, and affluence. Employing an econometric methodology, specifically the autoregressive distributed lag (ARDL) model, was imperative to evaluate the influence of various macroeconomic parameters on the foreign trade endeavors of entrepreneurial entities. Empirical data spanning from 2016 to 2023 was amassed

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from diverse sources such as the State Committee on Statistics, the Central Bank, and the Customs Committee of Uzbekistan. The outcomes divulge that customs value, import volume, total benefits, and exchange rate wield a substantial impact on customs duties. Notably, a mere 1% escalation in customs value, import volume, and exchange rate yields a proportional rise in customs duties by 0.88%, 0.45%, and 0.93%, respectively. Conversely, a 1% upsurge in total benefits triggers a decline in customs duties by 0.42%. These findings underscore the intricate interplay between macroeconomic indicators and the performance of foreign trade. The positive relationship between customs value, import volume, exchange rate, and customs duties underscores the significance of these factors in shaping trade strategies. This analysis furnishes crucial insights into the determinants of the foreign trade operations of entrepreneurial entities. Policymakers can leverage these insights to enhance trade frameworks, fostering economic growth and stability. Subsequent research endeavors could enrich these discoveries by incorporating supplementary variables and exploring alternative econometric frameworks.

**Keywords** Foreign trade · ARDL model · Customs duties · Import volume · Exchange rate · Trade policy

## 1 Introduction

The global economy is becoming increasingly interconnected, and international trade plays a key role in the economic growth and stability of countries. Foreign trade activities, including the cross-border exchange of goods, services, and capital, are an integral part of this relationship [1, 2]. This activity not only facilitates the flow of resources but also increases the competitive advantages of countries in the world market.

Business entities, especially small and medium-sized enterprises (SMEs), are at the forefront of foreign trade activities. These businesses make significant contributions to economic development by creating jobs, promoting innovation, and improving the efficiency of resource allocation [3, 4]. However, their participation in foreign trade is influenced by many factors, including macroeconomic conditions, trade policies, and international economic relations [5, 6].

In the context of Uzbekistan, the role of business entities in foreign trade has gained significant importance as the country seeks to integrate more deeply into the global economy [7]. Understanding the factors influencing their foreign trade activities is critical to developing effective trade policies and creating an enabling environment for economic growth.

The purpose of this study is to conduct an econometric analysis of factors influencing the foreign trade activities of business entities in Uzbekistan. Using an autoregressive distributed lag model, the study aims to identify and quantify the impact of key macroeconomic indicators on customs duties, a critical component of trade

activity. The results of this study are expected to provide policymakers and business leaders with valuable information to improve trade performance and economic contribution of business organizations.

The rest of the article is structured as follows: the Methods section describes the econometric approach and data sources; the “Results” section presents the results of the analysis; the Discussion section interprets the results in the context of existing literature; and the Conclusion section summarizes key findings and makes recommendations for future research and policy development.

## 2 Literature Review

Foreign trade activities of business entities have been widely studied in the context of various economic and econometric models. These studies highlight the critical role that external economic factors and macroeconomic indicators play in shaping the trading activities of SMEs.

The main macroeconomic factors influencing foreign trade include exchange rates, gross fixed capital formation, gross domestic income, foreign direct investment (FDI), and the innovative activities of domestic businesses. These factors play a significant role in shaping the dynamics of international trade, affecting the value of trade, exports, imports, and trade balances. Studies of countries such as Indonesia, Switzerland, Ghana, Malawi, Slovakia, and Greece have highlighted the importance of these factors in increasing foreign trade volumes, forecasting trade flows, and assessing the impact of FDI on trade balances [8–11].

Previous studies highlight the significant impact of macroeconomic variables such as exchange rates, inflation rates, and gross domestic product (GDP) on foreign trade activities. For example, one study used a statistical model based on data from 105 countries over 20 years to examine how interest rates and credit availability influence the creation of new businesses and increased foreign trade. The results show that foreign direct investment (FDI) is complementary to foreign trade, indicating a positive relationship between the two factors [12–14].

Similarly, another study used the ARDL model to analyze the impact of government expenditure, GDP, foreign direct investment, and exchange rates on Iran’s foreign trade from 1990 to 2019. The results showed that there are both short-term and long-term relationships between these macroeconomic variables and foreign trade, with GDP growth significantly increasing trade volumes [15–17].

Trade liberalization in developing countries has various economic consequences. Research shows that trade liberalization can lead to increased import growth, which is positively influenced by joining organizations such as the World Trade Organization and rising domestic income [18–21]. However, the impact on government revenues and expenditures is mixed: low-income countries often lose trade tax revenue without being able to recoup it through other means [22–24].

The interaction between FDI and foreign trade has been the focus of several econometric analyses. One study on the influence of macroeconomic factors on foreign

direct investment decisions emphasized the importance of an enabling business environment and effective trade regulations in attracting foreign investment. The study found that countries with strong trade agreements and regulatory frameworks are more likely to attract FDI, which in turn improves their trade efficiency [25, 26].

### 3 Methodology

#### 3.1 Data Collection

Data for this study was collected from several sources, including:

State Committee of Statistics of Uzbekistan.

Central Bank of Uzbekistan.

Customs Committee of Uzbekistan.

The dataset covers the period from 2016 to 2023 and includes quarterly observations. The variables considered in this study include customs duties (dependent variable), customs value, volume of imports, total benefits, and exchange rate (independent variables).

#### 3.2 Variables

The dependent variable is customs duties used as Custom\_d.

Independent variables:

Import duty—import\_d;

Exchange rate—exch\_rate;

Inflation rate—infl\_rate.

#### 3.3 Hypotheses

##### 3.3.1 Null hypothesis (H0)

Import duty, exchange rate, and inflation rate do not significantly affect customs duties. In other words, changes in import duty, exchange rate, and inflation do not have a statistically significant impact on the amount of customs duties.

### 3.3.2 Alternative Hypothesis (H1)

Import duty, exchange rate, and inflation rate significantly influence customs duties, and changes in these variables have a statistically significant effect on the amount of customs duties. According to the alternative hypothesis (H1):

Changes in import duty rates are associated with changes in the amount of customs duties. An increase in import duty may lead to an increase in customs duties.

Changes in currency exchange rates affect customs duties. If the national currency depreciates, the prices of imported goods may rise, leading to higher customs duties.

Inflation rate changes in the inflation rate affect customs duties. High inflation may lead to a reduction in customs duties due to a reduction in import volumes or adjustments in valuations.

### 3.4 Econometric Model

An econometric model was developed for the study using the ARDL model. The ARDL model is shown below:

$$\begin{aligned} \varepsilon \text{ Custom\_d} = & \alpha_0 + \alpha_1 \sum_{(p=1)}^n \varepsilon \text{ Custom\_d}_{i,t-p} + \alpha_2 \sum_{(p=1)}^n \varepsilon \text{ Import\_d}_{t-p} \\ & + \alpha_3 \sum_{(p=1)}^n \varepsilon \text{ Exch\_rate}_{i,t-p} \\ & + \alpha_4 \sum_{(p=1)}^n \varepsilon \text{ Infl\_rate}_{i,tp} + \delta_1 \text{Custom\_d}_{i,t-1} \delta_2 \text{Import\_d}_{i,t-1} \\ & + \delta_3 \text{Exch\_rate}_{i,t-1} + \delta_4 \text{Infl\_rate}_{i,t-1} + \varepsilon_{i,t} \end{aligned} \quad (1)$$

where

$\varepsilon \text{ Custom\_d}$ —change in customs duties,

$\text{Custom\_d}_{t-1}$ —customs duties from the previous year,

$\text{Import\_d}$ —import duty,

$\text{Exch\_rate}$ —exchange rate,

$\text{Infl\_rate}$ —inflation rate,

$\varepsilon$ —growth operator,

$\alpha_0$ —intercept term,

$\alpha_1, \alpha_2, \alpha_3$ , and  $\alpha_4$ —short-run elasticity coefficients,

$\delta_1, \delta_2, \delta_3$  and  $\delta_4$ —long-run dynamic multipliers,

N—number of lags,

p—lag length,

$\varepsilon_{i,t}$ —error term.

### 3.5 Model Evaluation

Unit root test: The stationarity of the data series is first tested using the Augmented Dickey–Fuller (ADF) test. This ensures that the variables are properly integrated into the ARDL model.

Bounds test for cointegration. The bounds testing approach is used to determine whether a long-term relationship exists between dependent and independent variables. This step involves comparing the F-statistic to the critical value bounds.

Short-term and long-term dynamics. The ARDL model is estimated to capture both short-term and long-term dynamics. The error correction model (ECM) is based on the ARDL model and is designed to estimate the rate of adjustment to the long-term equilibrium after a short-term shock.

Diagnostic tests: Various diagnostic tests, including the Durbin–Watson test for autocorrelation, the Breusch–Godfrey LM test for serial correlation, the Breusch–Pagan test for heteroscedasticity, and the CUSUM test for parameter stability, are conducted to ensure the reliability of the model.

### 3.6 Software and Tools

Statistical analysis and econometric modeling are performed using Stata software. Stata's comprehensive set of econometric tools facilitates ARDL model estimation and diagnostic testing, providing accurate and reliable results.

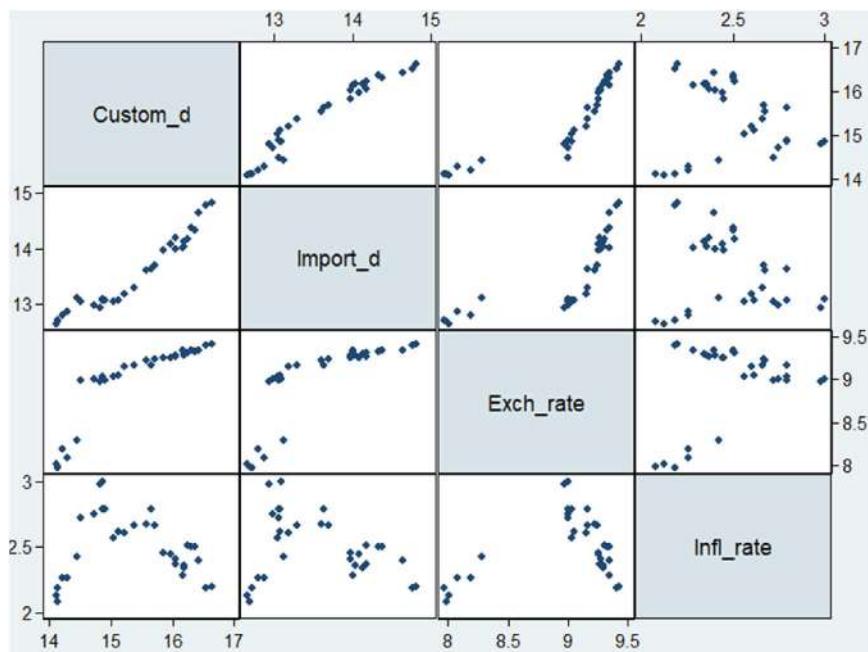
### 3.7 Conclusion

The methodology outlined above provides a rigorous basis for studying the factors influencing the foreign trade activities of business entities in Uzbekistan. Using the ARDL model, this study aims to provide a detailed understanding of the macroeconomic determinants of customs duties, thereby informing policy decisions aimed at improving trade efficiency and economic growth.

## 4 Result and Discussion

An analytical graph matrix and a scatterplot of the dependent and independent variables were developed (see Figs. 1).

Figures 1 illustrate the strong correlation between the results and the characteristic factors, indicating specific density conditions in the data set. Cluster analysis based on the density of visual data points showed significant correlations. From an analytical



**Fig. 1** Graph matrix of dependent and independent variables

perspective, these graphs show a clear clustering pattern where data points converge along certain axes. This clustering indicates significant relationships between the variables being analyzed and suggests that data points tend to correspond to specific configurations rather than being randomly distributed.

Additionally, in the next step, the econometric equation of the ARDL model was developed using Stata software, as shown in the following table (see Table 1).

The R-squared value represents the proportion of variance in the dependent variable that is explained by the model. Here, the R-square is 0.89 (89%), indicating that the ARDL model explains approximately 89% of the variation in the dependent variable. A high R-squared value suggests that the model fits the observed data well. Additionally, the ARDL (1,1,1,2) test was conducted, the results of which showed that the F-statistic and t-statistic are statistically significant at the 0.05 level, which leads to the rejection of the null hypothesis. Therefore, the alternative hypothesis (H1) was accepted.

According to the results of the ARDL (1,1,1,2) model, in long-term relations within the national economy, an increase in import duties by 1% leads to an increase in customs duties by 0.37%. A 1% increase in the exchange rate results in an increase in customs duties of 1.37%. In addition, a 1% increase in the inflation rate leads to a decrease in customs duties by 0.99%.

For the study, we tested the important conditions of the Gauss–Markov theorem using the ARDL model and achieved the following results:

**Table 1** ARDL (1,1,1,2) Model Regression Equation Results

| D.Custom_d    | Coef   | Std.Err | t      | P > t | [95%Conf | Interval] sig |
|---------------|--------|---------|--------|-------|----------|---------------|
| <b>ADJ</b>    |        |         |        |       |          |               |
| Custom_d (L1) | -0.440 | 0.079   | -5.550 | 0.000 | -0.605   | -0.275 ***    |
| <b>LR</b>     |        |         |        |       |          |               |
| Import_d      | 0.372  | 0.132   | 2.830  | 0.010 | 0.098    | 0.647 ***     |
| Exch_rate     | 1.373  | 0.203   | 6.760  | 0.000 | 0.951    | 1.796 ***     |
| Infl_rate     | -0.994 | 0.248   | -4.010 | 0.001 | -1.509   | -0.478 ***    |
| <b>SR</b>     |        |         |        |       |          |               |
| Import_d      |        |         |        |       |          |               |
| D1            | 0.479  | 0.085   | 5.640  | 0.000 | 0.302    | 0.655 ***     |
| Exch_rate     |        |         |        |       |          |               |
| D1            | -0.440 | 0.108   | -4.050 | 0.001 | -0.665   | -0.214 ***    |
| Infl_rate     |        |         |        |       |          |               |
| D1            | 0.268  | 0.099   | 2.710  | 0.013 | 0.063    | 0.474 ***     |
| LD            | 0.260  | 0.086   | 3.010  | 0.007 | 0.080    | 0.439***      |
| _cons         | 0.240  | 0.349   | 0.690  | 0.500 | -0.487   | 0.966         |

Root MSE = 0.0517.

Number of obs = 32.

Log likelihood = 51.642945.

R-squared = 0.8958.

Adj R-squared = 0.8561.

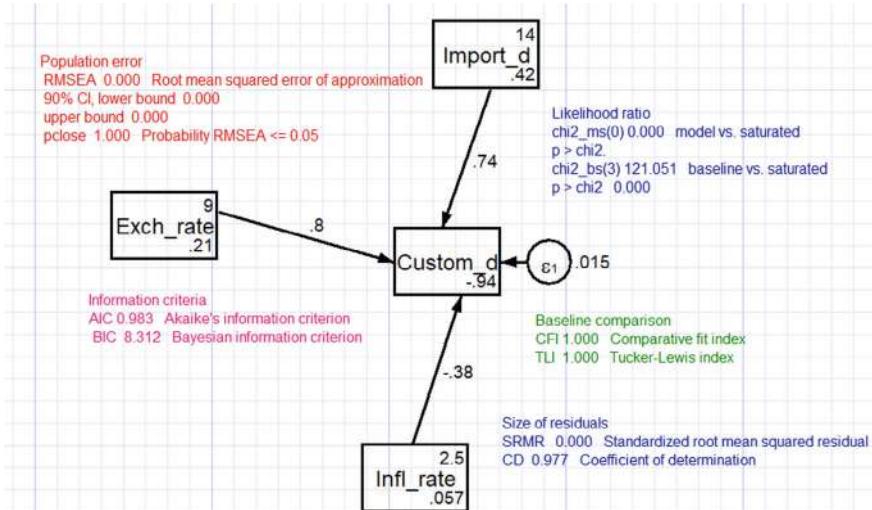
\*\*\*P < 0.01, \*\*P < 0.05, \*P < 0.1

- The Durbin–Watson test result for the ARDL (1,1,1,2) model showed a value of 2.31. Additionally, the Shapiro–Wilk test yielded a value of 0.76 and the Breusch–Godfrey LM test yielded a value of 0.26.
- During the study, the primary hypothesis H0:  $y = 0$  and its alternative H1:  $y \neq 0$  were statistically tested at a significance level of  $p > 0.05$ .
- After performing the Durbin–Watson, Shapiro–Wilk W, and Breusch–Godfrey LM tests, the alternative hypothesis was rejected and the p-value was found to be above the 0.05 threshold. Thus, the econometric model adequately satisfies the main criteria of the Gauss–Markov theorem.

Based on the study, it can be concluded that the Gauss–Markov assumption is correct, confirming that there is no correlation between the error terms and the independent variables. The econometric model successfully satisfies the basic conditions of the Gauss–Markov theorem.

The SEM (structural equation modeling) regression model developed for the study is as follows:

$$Custom\_d = 0.74 Import\_d + 0.80 Exch\_rate - 0.38 Infl\_rate - 0.94 \quad (2)$$



**Fig. 2** Schematic representation of the SEM regression model between dependent and independent variables

The results of the multiple regression equation and the SEM regression model recorded similar performance. In addition, the SEM regression model diagram and test results are shown below (see Fig. 2).

As shown in Fig. 2, the SEM regression model yielded positive results. This model demonstrates good fit for accurately estimating relationships among variables.

Evaluating the performance of a SEM regression model typically involves the use of various statistics and estimators, including the chi-square test, comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR).

The SEM regression model showed good fit based on these measures, demonstrating its effectiveness in explaining the observed relationships and offering meaningful insight into the study's hypotheses.

## 5 Conclusion

The purpose of this study was to analyze the impact of import duty, exchange rate and inflation rate on customs duties in the national economy using ARDL (1,1,1,2) regression model and SEM regression model. The results provide significant insight into the relationships between these key economic variables and customs revenues.

The analysis showed that an increase in import duty by 1% leads to an increase in customs duties by 0.37%. This indicates that an increase in import duties directly leads to an increase in customs revenues. Import duties are a critical component of

customs duties, and any adjustments to these rates have a proportionate impact on overall customs revenues.

The study found a strong positive relationship between exchange rate and customs duties. A 1% increase in the exchange rate results in an increase in customs duties of 1.37%. This suggests that the depreciation of the national currency will significantly increase the cost of imported goods, thereby increasing customs duties.

Conversely, a 1% increase in the inflation rate results in a 0.99% decrease in customs duties. This finding indicates that high inflation is associated with lower customs revenues, likely due to lower import volumes and the impact of inflation on cost and tariff structures.

Future research could expand on these findings by including additional variables and exploring different econometric models to more fully capture the complexities of foreign trade dynamics. Comparative studies across different regions or countries can provide a broader understanding and increase the generalizability of results.

This study presents a comprehensive econometric analysis of the factors influencing customs duties in the national economy. The results highlight the importance of import duty, exchange rate, and inflation rate as key determinants of customs revenue. Using this knowledge, policymakers can formulate effective trade and economic policies to increase customs revenues and stimulate economic growth. The robust methodology and significant results make a valuable contribution to understanding the complex relationships between economic variables and customs duties.

## References

1. Hu C, Parsley D, Tan Y (2021) Exchange rate induced export quality upgrading: A firm-level perspective. *Econ Model* 98:336–348
2. Giuliano F, Luttini E (2020) Import prices and invoice currency: Evidence from Chile. *J Int Money Financ* 106:102183
3. Pavlova KS, Smolina ES (2021) Digitalization of tax and customs control of foreign trade operations. In *Economic systems in the new era: Stable systems in an unstable world* (pp 684–691). Springer International Publishing
4. Muigu E, Mincu MB (2020) Factors affecting collection of customs trade statistics at the port of Mombasa
5. Hendy R, Zaki C (2021) Trade facilitation and firms exports: Evidence from customs data. *Int Rev Econ Financ* 75:197–209
6. Akdoğan K, Bağır YK, Torun H (2023) Heterogeneous effect of exchange rates on firms' exports: Role of labor intensity. *CentL Bank Rev* 23(3):100130
7. Salimov B, Kholikova R, Khamdamov S-J, Turaev A, Tukhtabaev J, Nosirova N, Akhmedova D (2023) Strategies for integrating digitalization in leveraging regional economic and scientific expertise for the innovative growth of small and medium enterprises. In *Proceedings of the 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23)* (pp 483–490). Association for Computing Machinery, New York, NY, USA
8. Basuki AT, Amatullah L (2023) Analysis of Macro Economic influence on Indonesian trade. *Eur J Dev Stud* 3(3):67–75
9. Mehrotra R, Carbonnier G (2021) Abnormal pricing in international commodity trade: Empirical evidence from Switzerland. *Resour Policy* 74:102352

10. Ahene-Codjoe AA, Alu AA, Mehrotra R (2022) Abnormal pricing in international commodity trading: Evidence from Ghana. *Int Econ* 172:331–348
11. Montfaucon AF (2022) Invoicing currency and symmetric pass-through of exchange rates and tariffs: evidence from Malawian imports from the EU. *Int Econ* 169:191–207
12. Krammer SM (2009) Drivers of national innovation in transition: Evidence from a panel of Eastern European countries. *Res Policy* 38(5):845–860
13. Bruckner M, Giljum S, Lutz C, Wiebe KS (2012) Materials embodied in international trade—Global material extraction and consumption between 1995 and 2005. *Glob Environ Chang* 22(3):568–576
14. Mehar MA, Al-Faryan MAS (2022) Effects of monetary policy on business startups and trade activities: Global empirical evidences. *Theor Econ Lett* 12(6):1825–1844
15. Jassim OAL, Al-Kawaz SM (2022) Measure and analyze the impact of some macroeconomic variables on Iran's foreign trade for the period (1990–2019). *Tikrit J Adm Econ Sci* 18(58, 1):174–191
16. Hurley DT, Papanikolaou N (2021) Autoregressive distributed lag (ARDL) analysis of US-China commodity trade dynamics. *Q Rev Econ Finance* 81:454–467
17. Kong Q, Peng D, Ni Y, Jiang X, Wang Z (2021) Trade openness and economic growth quality of China: Empirical analysis using ARDL model. *Financ Res Lett* 38:101488
18. Makhmudov S, Khamdamov S-J, Karlibaeva R, Mamadiyarov Z, Haydarov O, Khujamurodov A, Imomov K (2023) The impact of digital technologies on the labor market of Uzbekistan. In: Proceedings of the 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23) (pp 260–267). Association for Computing Machinery, New York, NY, USA
19. Kurbonov K, Makhmudov S, Mamadiyorov Z, Khamdamov S-J, Karlibaeva R, Samadov A, Djalilov F (2023) The impact of digital technologies on economic growth in the example of Central Asian and European countries. In: Proceedings of the 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23) (pp 403–409). Association for Computing Machinery, New York, NY, USA
20. Wang Y, Yu M (2021) Imports and RMB exchange rate pass-through: The role of quality sorting. *J Econ Behav Organ* 187:470–487
21. Essandoh OK, Islam M, Kakinaka M (2020) Linking international trade and foreign direct investment to CO<sub>2</sub> emissions: any differences between developed and developing countries? *Sci Total Environ* 712:136437
22. Urnov R, Makhmudov S, Mamadiyorov Z, Khamdamov S-J, Kurbanov ZN, Dadabaev U (2023) Digitalization and its econometric analysis on transforming sustainable regional development into improved population living standards. In: Proceedings of the 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23) (pp 438–442). Association for Computing Machinery, New York, NY, USA
23. Tran TK, Lin CY, Tu YT, Duong NT, Thi TDP, Shoh-Jakhon K (2023) Nexus between natural resource depletion and rent and COP26 commitments: Empirical evidence from Vietnam. *Resour Policy* 85:104024
24. Gong X, Wong WK, Peng Y, Khamdamov SJ, Albasher G, Hoa VT, Nhan NTT (2023) Exploring an interdisciplinary approach to sustainable economic development in resource-rich regions: An investigation of resource productivity, technological innovation, and ecosystem resilience. *Resour Policy* 87:104294
25. He B, Jie W, He H, Alsuhib M, Arnone G, Makhmudov S (2024) From resources to resilience: How green innovation, fintech and natural resources shape sustainability in OECD countries. *Resour Policy* 91:104856
26. Liu X, Wang C, Wei Y (2001) Causal links between foreign direct investment and trade in China. *China Econ Rev* 12(2–3):190–202

# Evaluating Financial Management Efficiency in Higher Education Institutions: An Econometric Analysis Using the ARDL Model



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**Abstract** Financial management is critical to higher education institutions (HEIs), influencing their financial sustainability and academic success. This study evaluates the financial management performance of universities, focusing on the relationship between asset turnover and profitability using the autoregressive distributed lag (ARDL) model. Analyzing financial data of Tashkent State University of Economics for 15 years (2008–2022), we assessed total asset turnover, non-financial asset turnover, and financial asset turnover, measuring profitability by return on assets (ROA). The results show that higher asset turnover is positively correlated with profitability: a 1% increase in asset turnover leads to a 0.22% increase in ROA, a 1% increase in non-financial asset turnover results in a 0.41% increase in ROA, and a 1% increase in financial asset turnover results in a 0.67% increase in ROA. Co-integration tests confirm a stable long-run relationship between these variables. This study highlights the importance of effective asset management to improve financial performance of institutions and calls for the use of advanced econometric models such as ARDL to understand financial dynamics in educational institutions.

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**Keywords** Financial management · Higher education institutions · ARDL model · Asset turnover · Profitability · Tashkent state economic university

## 1 Introduction

Financial management is a fundamental component of institutions, significantly impacting their ability to maintain academic excellence, support research initiatives, and ensure the sustainable integration of students and faculty. Effective financial management allows institutions to navigate the complexities of resource allocation, budgeting, and financial planning that are necessary to achieve long-term success and stability.

In recent years, institutions of higher learning have faced increasing financial challenges due to a variety of factors, including declining government funding, rising operating costs, and the need for technological advancements. These challenges require a robust financial management system that includes strategic planning, transparency, accountability, and the integration of innovative technologies. Such a system is vital for improving financial efficiency, ensuring financial stability, and achieving institutional goals.

This study is devoted to the effectiveness of financial management of universities with a special emphasis on TSUE. By examining the relationship between asset turnover and profitability, this study aims to provide insight into the factors that contribute to the financial sustainability of HEIs. This study aims to contribute to the broader understanding of financial management in higher education institutions and offer practical recommendations for improving financial performance and sustainability. The results of this study are expected to provide information to policymakers, university administrators, and financial managers in their efforts to optimize financial practices and achieve institutional goals.

## 2 Literature Review

Financial management in higher education is a critical area of research, reflecting the growing complexity and importance of effective resource allocation and financial sustainability in academia [1]. This literature review examines various studies on financial management practices, asset utilization, and their impact on the financial performance of universities, which forms the basis for this study [2].

The effectiveness of financial management in higher education institutions, as measured by the ARDL model, is influenced by several key factors. These include the implementation of university financial policies to increase financial autonomy and competitiveness and reduce risks [3, 4]. Additionally, the use of data-driven thinking and early warning systems for financial risks plays a critical role in decision-making processes, leading to effective financial management [5, 6]. The concept of financial

resource management efficiency is important for the development of higher education institutions, emphasizing the importance of analytical approaches and analysis of real data [7, 8]. Moreover, the use of modern tools such as the Financial Health Index helps to measure financial performance, set strategic goals, and ensure sustainable development in higher education institutions [9, 10]. By integrating these factors, institutions can improve financial strength, transparency, and decision-making processes, which will ultimately contribute to their overall success and development.

The importance of sound financial management systems in higher education institutions has been highlighted in numerous studies [11, 12]. Research into the institutional foundations of higher education financing highlights the critical role of affordability and financial assistance in addressing current challenges in the sector [13, 14]. Effective economic processes significantly impact student access and success, highlighting the need for strategic financial management to address these challenges [15, 16].

The relationship between asset turnover and financial performance has been widely studied in the context of both public and private sectors [17]. Research shows that resource disparities between public and private institutions, including faculty salaries and staff turnover rates, profoundly impact academic performance and financial stability [18, 19]. These results highlight the importance of efficient use of assets to maintain the competitiveness and financial stability of universities.

A comprehensive study of university financial dynamics using econometric models to analyze variables such as tuition, state funding, endowments, and tax incentives found that changes in tax incentives and endowment levels over time have a significant impact on university endowments and their financial health [20, 21].

The use of econometric models, especially the ARDL model, has become widespread in the analysis of financial data in universities. Research on student persistence and outcomes that includes financial dynamics demonstrates how enrollment patterns, student characteristics, and institutional financial decisions influence overall academic performance [22]. Econometric models are used to identify temporal relationships between these variables, providing a comprehensive understanding of financial dynamics in higher education [23, 24].

The ARDL model has a significant impact on the accuracy of financial management performance assessment in higher education institutions by providing a reliable basis for analysis. Although the ARDL model is not explicitly mentioned in the presented context, various studies highlight the importance of using advanced algorithms and data-driven approaches to improve financial decision-making and performance measurement in higher education institutions [25–28]. By implementing sophisticated models such as ARDL, institutions can improve their financial forecasts, risk assessments, and decision-making processes, ultimately leading to more accurate assessments of financial management performance [29]. Integrating the ARDL model can offer a comprehensive understanding of financial dynamics in educational institutions, allowing institutions to make informed decisions and effectively optimize their financial performance.

Strategic financial management practices are essential for improving the financial performance of universities. Equilibrium models of the higher education market

focus on student selection, financial aid, educational costs, and outcomes. These models highlight the critical role of financial aid and pricing strategies in maintaining colleges' hierarchical structure based on quality and financial resources [30, 31].

These differences highlight the importance of institutional, competitive, and organizational factors influencing the adoption and implementation of practices in higher education institutions.

### 3 Methodology

This section outlines the methodological approach used to assess the effectiveness of financial management of universities, in particular TSUE. The study uses econometric analysis using the ARDL model to examine the relationship between asset turnover and profitability.

Data for this study were collected from TSEU financial statements over a 15-year period, from 2008 to 2022. Variables of interest include:

$Y$ -ROA (dependent variable): it is used as an indicator of profitability;

$X_1$ -Total Asset Turnover (independent variable): the ratio of total income to total assets.

$X_2$ -Turnover of non-financial assets (independent variable): the ratio of total revenue to non-financial assets.

$X_3$ -Financial asset turnover (independent variable): the ratio of total income to financial assets.

These variables were selected to provide a comprehensive view of how various aspects of asset management impact overall financial performance.

This study tests the following hypotheses:

- Null Hypothesis (H0): There is no significant relationship between asset turnover ratios (total, non-financial, and financial) and return on assets.
- Alternative Hypothesis (H1): There is a significant relationship between asset turnover ratios (total, non-financial, and financial) and return on assets.

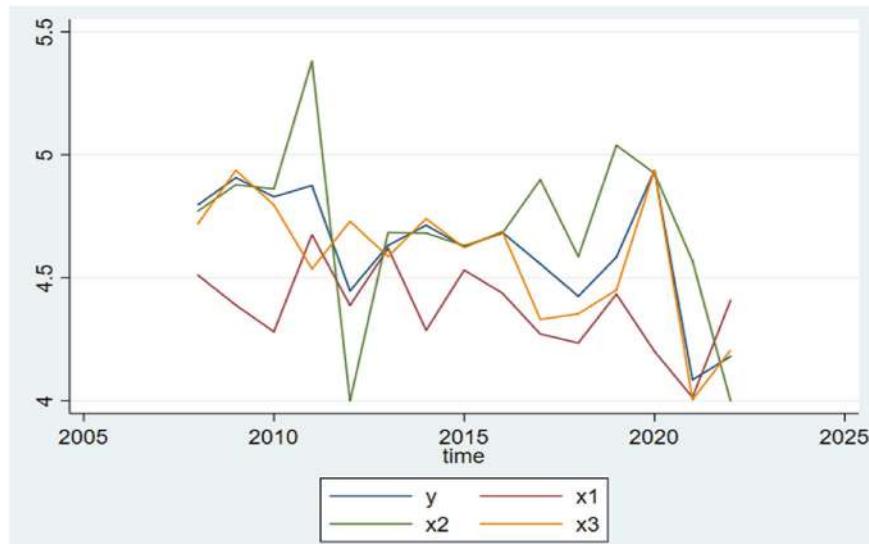
### 4 Results and Discussions

According to the study, the analytical graph of the indicators of the dependent and independent variables over time has the following form (see Fig. 1).

As shown in Fig. 1, the data showed consistent seasonal dynamics over the observed period. Under such conditions, it becomes increasingly important to predict changes in factors over time that may have potential consequences.

In the next stage of the study, the correlation matrix between each of the dependent and independent variables was examined using Stata software (see Table 1).

The correlation matrix presented in Table 1 shows the absence of multicollinearity between the dependent variable and the independent variables.

**Fig. 1** Graph of dependent and independent variables over time**Table 1** Spearman correlation matrix of dependent and independent variables

| Variables      | Y                | x <sub>1</sub>   | x <sub>2</sub>   | x <sub>3</sub> |
|----------------|------------------|------------------|------------------|----------------|
| Y              | 1.000            |                  |                  |                |
| x <sub>1</sub> | 0.394<br>(0.054) | 1.000            |                  |                |
| x <sub>2</sub> | 0.671<br>(0.006) | 0.210<br>(0.095) | 1.000            |                |
| x <sub>3</sub> | 0.710<br>(0.000) | 0.278<br>(0.316) | 0.241<br>(0.386) | 1.000          |

At the next stage of the study, a unit root test was performed to determine the stationarity of the dependent and independent variables (see Table 2).

**Table 2** Unit root test results for dependent and independent variables

| Variables      | Test statistics | 1% critical value | 5% critical value | 10% critical value | p-value for Z(t) |
|----------------|-----------------|-------------------|-------------------|--------------------|------------------|
| Y              | - 5.271         | - 3.750           | - 3.000           | - 2.630            | 0.0000           |
| x <sub>1</sub> | - 5.573         | - 3.750           | - 3.000           | - 2.630            | 0.0000           |
| x <sub>2</sub> | - 5.739         | - 3.750           | - 3.000           | - 2.630            | 0.0000           |
| x <sub>3</sub> | - 6.139         | - 3.750           | - 3.000           | - 2.630            | 0.0000           |

According to the data in Table 2, the unit root test yielded a statistical value of  $-5.271$  for the dependent variable and values of  $-5.573$ ,  $-5.739$ , and  $-6.139$  for the independent variables. The results of the unit root test indicate that both the outcome and the independent variables have reached stationarity, as evidenced by the low MacKinnon values and  $Z(t) = 0.0000$ . In addition, after the initial integration of the dependent and independent variables, the unit root test values confirmed their stationarity.

Next step, the econometric equation of the ARDL model was developed using Stata software, as presented in the following table (see Table 3).

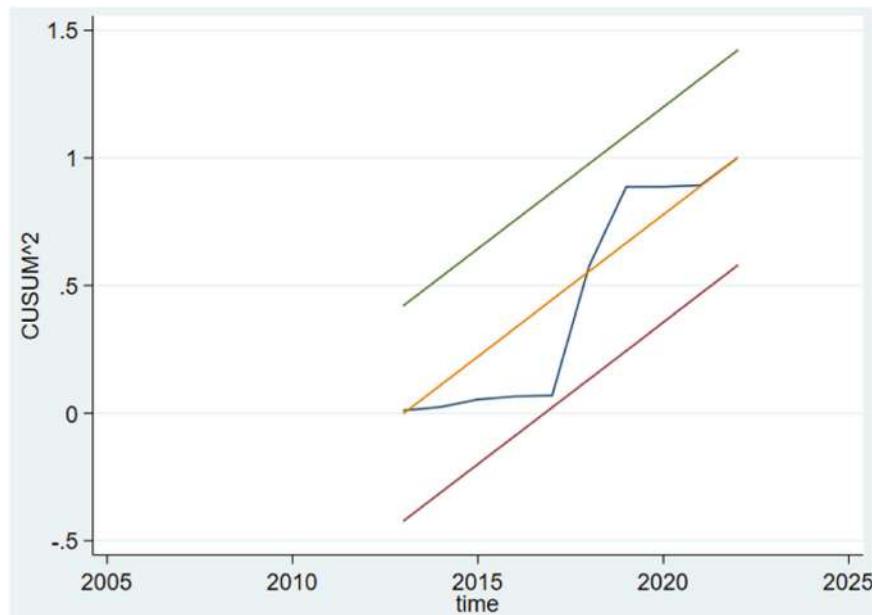
The ARDL (1,2,1,2) model as shown in Table 3 indicates a significant correlation between the variables and shows a positive effect with an R-square value of 0.99. The performed ARDL (1,2,1,2) test yielded statistically significant F-statistics and t-statistics at the 0.05 significance level. This resulted in the rejection of the null hypothesis ( $H_0$ ) and the acceptance of the alternative hypothesis ( $H_1$ ).

The cointegration status of the model was tested using the connectivity test for the ARDL (1,2,1,2) model. The F-statistic value of 29.944 exceeded the critical bounds for all intervals, confirming the presence of cointegration in this context and providing a positive result for the connectivity test.

As a result, in the financial management system of the Tashkent State Economic University, an increase in total asset turnover by 1% leads to an increase in the return

**Table 3** Regression equation results for the ARDL (1,2,1,2) model

|                                                                                                               |         |                |                                                                      |       |                     |         |
|---------------------------------------------------------------------------------------------------------------|---------|----------------|----------------------------------------------------------------------|-------|---------------------|---------|
| ARDL(1,2,1,2) regression<br>Number of observations = 115<br>R-squared = 0.9994<br>Adjusted R-squared = 0.9977 |         |                | Sample: 2010–2022<br>Log likelihood = 45.914477<br>Root MSE = 0.0147 |       |                     |         |
| Di                                                                                                            | Coef    | Standard error | T                                                                    | P > t | [95% Conf Interval] |         |
| ADJ th                                                                                                        |         |                |                                                                      |       |                     |         |
| L1                                                                                                            | − 1.909 | 0.217          | − 8.810                                                              | 0.003 | − 2.599             | − 1.220 |
| x <sub>1</sub>                                                                                                | 0.224   | 0.044          | 5.080                                                                | 0.015 | 0.084               | 0.364   |
| x <sub>2</sub>                                                                                                | 0.412   | 0.015          | 27.250                                                               | 0.000 | 0.364               | 0.460   |
| x <sub>3</sub>                                                                                                | 0.677   | 0.034          | 19.730                                                               | 0.000 | 0.568               | 0.786   |
| SR                                                                                                            |         |                |                                                                      |       |                     |         |
| x <sub>1</sub>                                                                                                |         |                |                                                                      |       |                     |         |
| D1                                                                                                            | − 0.389 | 0.096          | − 4.070                                                              | 0.027 | − 0.693             | − 0.085 |
| LD                                                                                                            | − 0.244 | 0.055          | − 4.440                                                              | 0.021 | − 0.418             | − 0.069 |
| x <sub>2</sub>                                                                                                |         |                |                                                                      |       |                     |         |
| D1                                                                                                            | − 0.370 | 0.096          | − 3.870                                                              | 0.031 | − 0.675             | − 0.066 |
| x <sub>3</sub>                                                                                                |         |                |                                                                      |       |                     |         |
| D1                                                                                                            | − 0.654 | 0.140          | − 4.680                                                              | 0.018 | − 1.100             | − 0.209 |
| LD                                                                                                            | − 0.169 | 0.028          | − 5.920                                                              | 0.010 | − 0.259             | − 0.078 |
| _cons                                                                                                         | − 2.701 | 0.457          | − 5.920                                                              | 0.010 | − 4.154             | − 1.248 |



**Fig. 2** CUSUM diagnostic test graph

on assets of the university by 0.22%. A 1% increase in non-financial asset turnover leads to a 0.41% increase in return on assets, and a 1% increase in financial asset turnover leads to a 0.67% increase in return on assets.

At the next stage of the study, the CUSUM diagnostic test was performed for the ARDL (1,2,1,2) model (see Fig. 2).

The CUSUM diagnostic test used in the ARDL (1,2,1,2) model includes the following hypotheses:

Null hypothesis (H0): There are no structural breaks or instability. This hypothesis assumes that there is no change or shift in the coefficients of the ARDL model over time, indicating that the model parameters remain stable throughout the sample period.

Alternative hypothesis (H1): There are structural changes or instability. H1 indicates that there are one or more structural breaks or shifts in the coefficients of the ARDL model (1,2,1,2). This means that, at certain points in the sample period, there are fundamental changes in the relationships between the variables in the model.

We have tested the important conditions of the Gauss–Markov theorem for the ARDL model and obtained the following results.

The Durbin–Watson test for the ARDL (1,2,1,2) model yielded a value of 1.48. Additionally, the Shapiro–Wilk W test yielded a value of 0.27 and the Breusch–Godfrey LM test yielded a value of 0.17.

During the study, the main hypothesis  $H_0: y = 0$  and its alternative  $H_1: y \neq 0$  were tested at a significance level of  $p > 0.05$ . After performing the Durbin–Watson,

Shapiro–Wilk W, and Breusch–Godfrey LM tests, the alternative hypothesis was rejected based on the  $p > 0.05$  criterion. Thus, we can conclude that the Gauss–Markov assumption is valid in our study, confirming that the error terms are not correlated with the independent variables. The econometric model used in the study effectively satisfies the fundamental conditions of the Gauss–Markov theorem.

## 5 Conclusion

Based on the analysis of the study and conclusions about the financial management system of higher education institutions and its impact, the following recommendations and proposals have been developed:

A 1% increase in total asset turnover in a university's financial management system is associated with a 0.22% increase in ROA. This means that if a university improves the efficiency of its use of both financial and non-financial assets, it will have a positive impact on its overall return on assets. Effective use of financial or non-financial resources ensures high returns on assets.

Particular attention is paid to non-financial assets: a 1% increase in their turnover leads to a higher ROA, namely an increase of 0.41%. This indicates that optimizing the use of non-financial assets has a greater impact on improving the overall return on assets of the university. Effective management of operating assets is critical to improving asset profitability.

At the same time, if we focus on financial assets, then an increase in their turnover by 1% leads to a significant increase in ROA, namely by 0.67%. It is emphasized that improving the turnover of financial assets has a greater impact on increasing the total return on assets of the university compared to the total turnover of assets. Effective management of financial resources significantly contributes to increasing the return on assets.

Based on these econometric results, it can be concluded that effective management of financial and non-financial assets is critical to influence the profitability of Tashkent State University of Economics. Accordingly, a university can improve its overall profitability by strategically improving asset turnover and optimizing the use of both financial and non-financial resources.

## References

1. Watt HM, Richardson PW (2020) Motivation of higher education faculty: (How) it matters! *Int J Educ Res* 100:101533
2. McCowan T, Omingo M, Schendel R, Adu-Yeboah C, Tabulawa R (2022) Enablers of pedagogical change within universities: Evidence from Kenya, Ghana, and Botswana. *Int J Educ Dev* 90:102558
3. Makhmudov S, Khamdamov S-J, Karlibaeva R, Mamadiyarov Z, Haydarov O, Khujamurodov A, Imomov K (2023) The impact of digital technologies on the labor market of Uzbekistan.

- In: 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp. 260–267. Association for Computing Machinery, New York, NY, USA
- 4. Kurbonov K, Makhmudov S, Mamadiyorov Z, Khamdamov S-J, Karlibaeva R, Samadov A, Djahilov F (2023) The impact of digital technologies on economic growth in the example of Central Asian and European countries. In: 7th International Conference on Future Networks and Distributed Systems (ICFNDS' 23), pp 403–409. Association for Computing Machinery, New York, NY, USA
  - 5. He B, Jie W, He H, Alsubih M, Arnone G, Makhmudov S (2024) From resources to resilience: How green innovation, fintech, and natural resources shape sustainability in OECD countries. *Resour Policy* 91:104856
  - 6. Gaševic D, Dawson S, Rogers T, Gasevic D (2016) Learning analytics should not promote one size fits all: The effects of instructional conditions in predicting academic success. *Internet High Educ* 28:68–84
  - 7. Turayeva G, Berdiyev G, Eshpulatov D, Alimova D, Odilbekov A, Davletova D, Burxanov A (2022) Opportunities to use financial services—“1 C PROGRAM”. In: 6th International Conference on Future Networks and Distributed Systems, pp 556–561
  - 8. Khamdamov SJ (2021) Calculating Share of Factors of Intensive Economic Growth in Uzbekistan. In: 5th International Conference on Future Networks and Distributed Systems, pp pp 393–397
  - 9. Tran TK, Lin CY, Tu YT, Duong NT, Thi TDP, Shoh-Jakhon K (2023) Nexus between natural resource depletion and rent and COP26 commitments: Empirical evidence from Vietnam. *Resour Policy* 85:104024
  - 10. Khamdamov SJ, Usmanov AS, Abdulazizova O, Isaev F, Kholbaev N, Makhmudov S, Kholbaeva S (2022) Econometric modeling of central bank refinancing rate in Uzbekistan. In: 6th International Conference on Future Networks and Distributed Systems, pp 253–257
  - 11. Mamadiyorov Z, Sultanova N, Makhmudov S, Khamdamov S-J, Mirpulatova L, Jumayev A (2023) The impact of digitalization on microfinance services in Uzbekistan. In: 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp 453–463. Association for Computing Machinery, New York, NY, USA
  - 12. Zacher H, Rudolph CW, Todorovic T, Ammann D (2019) Academic career development: A review and research agenda. *J Vocat Behav* 110:357–373
  - 13. Salimov B, Kholikova R, Khamdamov S-J, Turaev A, Tukhtabaev J, Nosirova N, Akhmedova D (2023) Strategies for integrating digitalization in leveraging regional economic and scientific expertise for the innovative growth of small and medium enterprises. In: 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp 483–490. Association for Computing Machinery, New York, NY, USA
  - 14. Urunov R, Makhmudov S, Mamadiyorov Z, Khamdamov S-J, Kurbanov ZN, Dadabaev U (2023) Digitalization and its econometric analysis on transforming sustainable regional development into improved population living standards. In: 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp 438–442. Association for Computing Machinery, New York, NY, USA
  - 15. Perkmann M, Tartari V, McKelvey M, Autio E, Broström A, D'este P, Sobrero M (2013) Academic engagement and commercialisation: A review of the literature on university–industry relations. *Res Policy* 42(2):423–442
  - 16. Apostolou B, Dorminey JW, Hassell JM, Watson SF (2013) Accounting education literature review (2010–2012). *J Account Educ* 31(2):107–161
  - 17. Xu Q, Lu Y, Lin H, Li B (2021) Does corporate environmental responsibility (CER) affect corporate financial performance? Evidence from the global public construction firms. *J Clean Prod* 315:128131
  - 18. Mamadiyarov Z, Hakimov H, Askarov S (2024) Development of retail banking services in the context of digital transformation. *Financ Credit Act Probl Theory Pract* 1(54):51–67. <https://doi.org/10.55643/fcaptp.1.54.2024.4288>
  - 19. Kellard NM, Kontonikas A, Lamla MJ, Maiani S, Wood G (2022) Risk, financial stability and FDI. *J Int Money Financ* 120:102232

20. Mamatkulov B, Khamdamov S-J, Togayniyazov S, Tukhtabaev J, Quldoshev Q, Qarshiev D (2023) Predicting future living standards in Uzbekistan: Utilizing econometric analysis. In: 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp 425–431. Association for Computing Machinery, New York, NY, USA
21. Shoh-Jakhon K. Theoretical and Methodological Aspects of Intensive Economic Growth in Ensuring Sustainable Economic Development. In: Social and Economic Studies within the Framework of Emerging Global Developments, vol. 3, pp 283
22. Kasimov A, Tukhtabaev J, Bondarskaya O, Bondarskaya T, Ochilov A, Mamatov M, Nomozova K, Khamdamov S-J, Makhmudov S, Gaynullaev R, Usmanov C (2023) Organizational and economic modeling of the system of interregional industrial cooperation as a control object. In: 7th International Conference on Future Networks and Distributed Systems (ICFNDS '23), pp 333–343. Association for Computing Machinery, New York, NY, USA
23. Fayzieva M, Makhmudov S, Gaipov J, Isakov J (2023) Econometric Analysis of the Impact of Digital Infrastructure on Investment Practices in Uzbekistan. In: 7th International Conference on Future Networks and Distributed Systems, pp 12–18
24. Gong X, Wong WK, Peng Y, Khamdamov SJ, Albasher G, Hoa VT, Nhan NTT (2023) Exploring an interdisciplinary approach to sustainable economic development in resource-rich regions: An investigation of resource productivity, technological innovation, and ecosystem resilience. *Resour Policy* 87:104294
25. Gaipov J, Fayzieva M, Makhmudov S, Urinov B, Xodjayeva J (2023) The Influencing Factors of High-Technology Industries in the Global Market. In: 7th International Conference on Future Networks and Distributed Systems, pp 58–64
26. Umarovich JG, Bakhtiyorovich RK (2021) Modeling the decision-making process of lenders based on blockchain technology. In: 2021 International Conference on Information Science and Communications Technologies (ICISCT), pp 1–5. IEEE
27. Compagnucci L, Spigarelli F (2020) The Third Mission of the university: A systematic literature review on potentials and constraints. *Technol Forecast Soc Chang* 161:120284
28. Juraev G, Rakhimberdiev K (2022) Mathematical modeling of credit scoring system based on the Monge-Kantorovich problem. In: 2022 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), pp 1–7. IEEE
29. Abdurakhmanov K, Nurimbetov R, Zikriyoev A, Khojamkulov D (2022) Comparison between Correlation and Latent Model Analysis on Estimating Causality of Occupational Health and Safety in Human Capital Development for Raising Economic Efficiency (Evidence from Building Material Manufacturing Companies of Uzbekistan). *AIP Conference Proceedings* 2432
30. Zikriyoev A, Khomidov S, Nurimbetov R, Khasanov T, Abdullayeva Z (2019) Improving the school quality through winning education turbulence in Uzbekistan (Evidence from the Ministry of Secondary Education Uzbekistan, Gijduvan Region 65 Schools). *Int J Innov Technol Explor Eng* 9(1):3225–3231
31. Asrar-ul-Haq M, Kuchinke KP, Iqbal A (2017) The relationship between corporate social responsibility, job satisfaction, and organizational commitment: Case of Pakistani higher education. *J Clean Prod* 142:2352–2363

# Design of a Semi-automatic Dough Mixer for the Prevention of Occupational Diseases in Marzipan Artisans



Ana Álvarez-Sánchez and Alexis Suárez del Villar-Labastida

**Abstract** Older people, due to the natural aging process, are particularly vulnerable to occupational tasks, as they experience a gradual loss of physical capacities, which increases the incidence of occupational diseases in this population. Despite these challenges, their experience and skills acquired over the years make them a valuable resource for society. This study focuses on designing a semi-automatic dough sheeter for the dough making process used by the artisans of Calderón in Ecuador, who currently carry out this work manually, this practice being an integral part of the local culture. The research began with a detailed analysis of modern manual molders, collecting data on shear force, bending moment, and tensile stress, which are fundamental to the design. Subsequently, a simulation of the design was carried out using SolidWorks software. The result was the creation of a prototype kneading machine equipped with AISI 1050 steel rollers, processed by HR. This device was able to significantly reduce repetitive hand movements, reducing the effort during the kneading process by 25,000 TMU, which translates into improved health and work performance for the artisans. The implementation of this technology reduced the risk of occupational diseases such as bursitis, which is caused by inflammation of the bursae in the joints, and carpal tunnel syndrome, which affects the functionality of the hands. In addition to the physical benefits, this project also addresses the psychological aspect, as many older craftsmen and women feel demotivated due to their diminished ability to perform tasks they used to do in their youth. The research aims to provide a better quality of life for these workers, protecting both their physical health and emotional well-being. In short, the semi-automatic laminator not only improves the working conditions of the Calderon artisans but also preserves and promotes an important cultural tradition, ensuring that these valuable knowledge and skills can continue to be practiced in a safe and sustainable manner.

**Keywords** Artisans · Crafts · Elderly · Illnesses · Laminator

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## 1 Introduction

Work is a universal right that everyone has, in terms of free choice, fair conditions and without discrimination. However, in Ecuador, there are barriers that hinder access to employment, including age discrimination, especially for older adults [1]. This situation forces many to look for alternatives in emerging or traditional jobs, such as handicrafts and crafts, which offer an adequate source of income regardless of geographical location within the Ecuadorian territory. In 2023, 843,745 economic activities were registered in Ecuador, and approximately 90% of these are micro-enterprises, many of which are dedicated to the manufacture of handicrafts [2]. The urban parish of San José de Calderón in the Metropolitan District of Quito is an outstanding example, with a large economic activity based on agriculture, construction, handicrafts, transport, and warehousing, which account for 63% of the activities in the area [3].

In line with the guidelines of the World Labour Organization and the regulations of public regulatory institutions, occupational safety and health policies have been intensified [4]. However, the application of these regulations in the artisanal sector faces difficulties, resulting in a high incidence of health problems related to these work activities [5]. This work focuses on facilitating the development and performance of these tasks through the implementation of machinery and technology that contribute to an adequate productive development, minimizing the ergonomic and musculoskeletal risks inherent to these activities [6].

The proposal is based on reducing the load and effort of artisans who suffer from occupational diseases due to repetitive movements, by designing a semi-automatic kneading machine [7]. This machine will guarantee the quality of the kneading and the final product, optimize working times, and offer practicality of use, especially for craftsmen over 50 years of age [8]. The implementation of this technology will not only alleviate the physical effort required in the kneading process but also preserve the health of the artisans, who often develop problems such as bursitis and carpal tunnel syndrome due to the repetitive movements involved in their manual activity [9].

The semi-automatic sheeter will allow the quality and consistency of the handmade products to be maintained, which is crucial to ensure market acceptance and success [10]. Partial automation of the kneading process will significantly reduce the physical burden on workers, allowing them to concentrate on other creative and technical aspects of their work. The reduction of repetitive physical strain is expected to reduce not only the incidence of occupational diseases but also to increase productivity and job satisfaction among artisans [11].

The study began with a detailed analysis of modern hand molders, collecting data on shear force, bending moment, and tensile stress, which are fundamental to the design of the molder [12]. Subsequently, a simulation of the design was carried out using SolidWorks software, which allowed the structure and functionality of the

equipment to be optimized before proceeding to the manufacture of the prototype [13]. The final machine was equipped with AISI 1050 steel rollers, processed by HR, ensuring durability and resistance in continuous use [14].

With the implementation of the semi-automatic kneading machine, it is expected that artisans will be able to reduce repetitive movements by 25,000 TMU (movement time units), representing a significant improvement in terms of ergonomics and occupational health [15]. In addition to the physical benefits, the introduced technology has the potential to improve the quality of life of older artisans, who often feel demotivated due to their decreased ability to perform intensive physical tasks [16]. This project aims not only to protect the physical health of the workers but also their emotional well-being by providing them with tools that facilitate their work and enable them to remain productive and creative in their craft.

The importance of this project lies in its ability to preserve a valuable cultural tradition while adapting to modern occupational health and safety needs. The artisans of Calderón, who have kept the tradition of marzipan manufacturing alive for generations, will be able to continue their work more safely and efficiently thanks to technological innovation. This balance between tradition and modernity is crucial for the sustainable development of the artisan community, ensuring that traditional techniques and knowledge are kept alive and passed on to future generations. The implementation of the semi-automatic laminator could serve as a model for other craft communities in Ecuador and in the region, promoting the adoption of technologies that improve working conditions without sacrificing the quality and authenticity of craft products. The dissemination of this innovation could contribute to the creation of public policies that support artisans in the incorporation of appropriate technologies, thus strengthening the artisanal sector as a whole.

Collaboration between researchers, artisans, and local authorities has been fundamental for the development of this project. The active participation of artisans in the design and testing of the prototype has ensured that the machinery is suitable for their needs and working conditions. This participatory approach has also fostered a sense of ownership and commitment among the artisans, who see the semi-automatic laminator as a tool that respects and enhances their craftsmanship. The semi-automatic laminator designed in this project represents an innovative and necessary solution for the Calderón artisans, allowing them to work more safely and efficiently. By reducing the risks of occupational diseases and improving the ergonomics of the kneading process, this technology not only preserves the health and well-being of the workers but also contributes to the long-term sustainability and viability of the marzipan craft tradition. The successful implementation of this technology could inspire other artisan communities to adopt similar solutions, promoting balanced economic and cultural development in Ecuador and beyond.

The relevance of this project extends beyond the local level, providing an example of how technological innovation can be integrated into traditional practices to improve the quality of life of workers without compromising the authenticity of their products. This initiative demonstrates that it is possible to balance modernization with cultural preservation, ensuring that traditional crafts can continue to thrive in a safe and healthy working environment. With the right support, this and other

technologies can help revitalize the craft sector, providing artisans with the tools they need to compete in a globalized market while maintaining their unique methods and traditions.

## 2 Materials and Methods

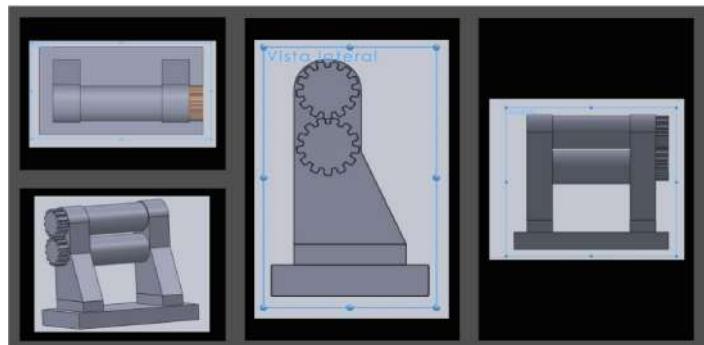
The method used in this research began with a detailed analysis of the ergonomic and health needs of the Calderón artisans, specifically in the manual kneading process. A comprehensive review of existing studies on applied forces, repetitive movements, and associated health problems such as bursitis and carpal tunnel syndrome was carried out. A semi-automatic kneading machine was then designed using SolidWorks software, which allowed the design to be simulated and optimized prior to manufacture. The design was evaluated in terms of sheer force, bending moment, and tensile stress, ensuring that the mechanical components met the necessary requirements to withstand the loads and continued use. Once the design and simulation phase were completed, a prototype was built and tested under real conditions to verify its effectiveness and make final adjustments.

The materials selected for the construction of the semi-automatic dough mixer were crucial to ensure its durability and performance. AISI 1050 steel was used for the rollers and other main components because of its mechanical properties, which include high tensile strength and good ability to withstand the compressive forces involved in the kneading process. This type of steel also meets the specifications of international standards, ensuring that the machinery is not only robust but also safe and reliable for prolonged use. The processing of the steel components was carried out using appropriate heat treatments to improve their hardness and wear resistance. In addition, factors such as ease of maintenance and accessibility of materials on the local market were considered to ensure the long-term sustainability of the project.

### 2.1 Principles of Operation

The semi-automatic dough mixer operates using two rollers that apply pre-squeezing pressure to flatten the dough to the desired consistency (see Fig. 1). This equipment has been designed to operate with a power of 1 HP (0.746 kW) and is mounted on a solid and robust structure. The system uses a 110 V single-phase motor to provide the necessary power, driving the rollers via a belt drive. The motor and frame specifications comply with the most common and accepted standards for this type of machinery, ensuring efficient performance suitable for the demands of artisan work.

The problems associated with manual hand kneading work fall under the category of repetitive movements, as indicated in the literature, and constitute the main reason for this research. These activities mainly affect the joints of the hands, wrists, and



**Fig.1** Design and views of the prototype semi-automatic dough mixer

shoulders, a situation that is aggravated by the fact that a large part of the population studied is made up of adults aged 50 and over. This reality is not alien to the national and Latin American situation, highlighting the urgent need to improve working conditions for older workers.

Livelihoods and decent work for older people have become latent needs that must be prioritized from both a socio-economic and health perspective. This research proposal aims to improve the working conditions of artisans, focusing on reducing the negative impact on hands and wrists to prevent acute and, in the long term, chronic injuries.

## 2.2 *Design and Functionality of the Semi-automatic Mixer*

The mixer has been specifically designed to improve manual kneading work, using a strong AISI 1050 steel alloy. The design incorporates two external gears that facilitate the movement of the working motor. These gears are connected via two brackets extending from the opposite end of the rollers. The dimensions of the machine are: 75 cm long, 45 cm wide, and 50 cm high. The base of the mixer is fixed by means of four mounting bolts, two on each side. This solution aims to reduce occupational musculoskeletal diseases resulting from inappropriate postures and repetitive movements.

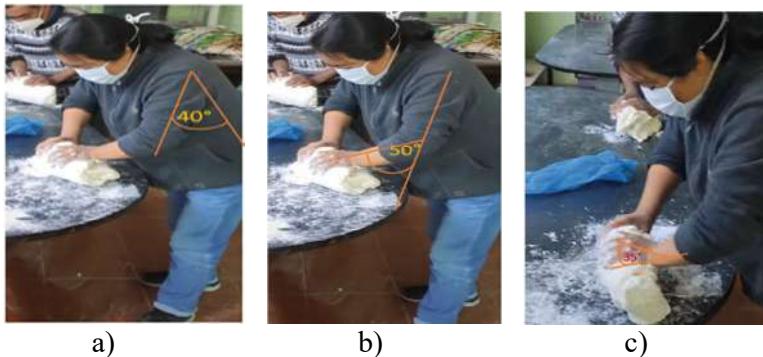
Figure 2 illustrates the pressure areas identified in the upper joints, indicating the potential risks of injury. Pressure sites in the upper joints, such as the shoulders, elbows, and wrists, are critical because of their susceptibility to overuse injuries or sudden movements. The shoulders, the head of the humerus, and the glenoid socket of the scapula are vulnerable areas. In the elbows, the humeral condyle and the olecranial fosae of the ulna may be subject to pressure. In the wrists, the distal radioulnar and carpal joints are points of stress. Undue or repetitive pressure on these areas can lead to tendonitis, bursitis, or even more serious injuries such as ligament

rupture or joint dislocation. It is therefore essential to maintain proper posture, avoid sudden movements, and perform stretching and strengthening exercises to prevent injury to these joints.

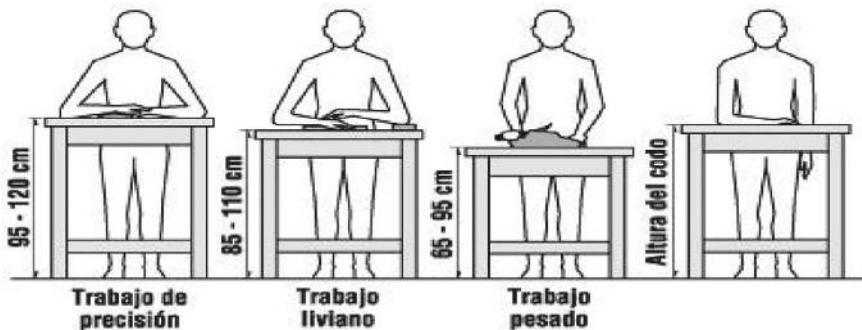
The following aspects have been considered in the design of the laminating machine:

The optimum height of the working plane has been set between 0.95 m and 1.20 m from ground level, which provides ergonomic conditions suitable for precision work and helps to prevent bad posture (see Fig. 3).

According to the information gathered, the desired thickness of the laminated dough varies between 2 and 15 mm, depending on the specific task. Therefore, the machine has been designed to provide a kneading process that allows for a dough that is easy to handle and operate.



**Fig. 2** Pressure points in the upper joints at risk of injury. **a** Shoulder, **b** Elbow, and **c** Wrist



**Fig. 3** Adequate height of the worktables according to their intensity

**Table 1** Risk categorization of posture

| No | Back | Arms | Legs | Load |
|----|------|------|------|------|
| 1  | 2    | 1    | 3    | 1    |
| 2  | 2    | 1    | 3    | 1    |
| 3  | 4    | 1    | 3    | 1    |
| 4  | 2    | 1    | 3    | 1    |
| 5  | 2    | 1    | 3    | 1    |

### 3 Experiments and Results

The experimentation is based on the application of the OWAS Method (Ovako Working Analysis System), designed to evaluate the physical loads derived from the postures adopted during the performance of work tasks. In particular, the position used in the manual dough kneading process was analyzed. The results obtained, reflected in Table 1, indicate a risk level categorized as 2. This level implies that the postures required for the back, arms, legs, and load parameters have a potential risk of causing damage to the artisans' musculoskeletal system. It is important to note that most of the artisans involved in the study are over 50 years of age, which further increases the vulnerability to this risk.

#### 3.1 Risk Rating Checklist OWAS Method

Another fundamental result of the research was obtained by using the OCRA method (The Occupational Repetitive Actions), which is a method designed to assess the risk associated with repetitive work. This method allowed us to analyze in more detail the risk generated by the repetitive movements involved in the kneading process. The results of this analysis, detailed in Table 2, revealed very high levels of risk, above 25 points and considered unacceptable according to the rating scale used (Tables 3 and 4).

### 4 Conclusions

The research has shown that the design of the dough sheeter meets the required ergonomic standards in terms of working plane height and dough kneading capacity. However, significant risks associated with repetitive work, especially in the kneading process, have been identified, suggesting the need to implement additional measures to mitigate these risks and protect the health of the artisans.

The results obtained through the OWAS and OCRA methods highlight the importance of considering ergonomics in the design of industrial equipment. Although

**Table 2** Risk category scale

| Risk category | Posture effect                                                                               | Required action                                     |
|---------------|----------------------------------------------------------------------------------------------|-----------------------------------------------------|
| 1             | Normal and natural posture without harmful effects on the musculoskeletal system             | It requires no action                               |
| 2             | Positions with the possibility of causing damage to the musculoskeletal system               | Corrective actions are required in a near future    |
| 3             | Posture with harmful effects on the musculoskeletal system                                   | Corrective actions are required as soon as possible |
| 4             | The load caused by this posture has extremely damaging effects on the musculoskeletal system | Corrective actions are required immediately         |

**Table 3** OCRA checklists

| Risk factors in repetitive work | Right | Left  |
|---------------------------------|-------|-------|
| Insufficient recovery time      | 4     | 4     |
| Movements frequency             | 4.5   | 4.5   |
| Force application               | 16    | 16    |
| Shoulder                        | 1     | 1     |
| Elbow                           | 8     | 8     |
| Wrist                           | 2     | 2     |
| Hand fingers                    | 4     | 4     |
| Stereotype                      | 1.5   | 1.5   |
| Forced Postures                 | 9.5   | 9.5   |
| Complementary risk factor       | 1     | 1     |
| Duration factor                 | 0.85  | 0.85  |
| Risk index                      | 29.75 | 29.75 |

the sheeter meets certain ergonomic criteria, such as the height of the work surface, there are still areas for improvement in terms of reducing the risk of musculoskeletal injuries associated with repetitive movements in the kneading process.

These findings underline the need for further research and improvement in the design of industrial equipment to ensure the health and safety of workers. Adjustments to the design of the dough sheeter are recommended, as well as the implementation of ergonomics training and awareness programs for operators, in order to reduce the identified risks and improve the quality of working life in the industrial sector.

**Table 4** Risk category scale

| Risk scale | Risk level                   | Checklist |
|------------|------------------------------|-----------|
| 1          | Admissible                   | Hasta 7.5 |
| 2          | Very mild or uncertain       | 7.6–11    |
| 3          | Not acceptable. Mild level   | 11.1–14   |
| 4          | Not acceptable. Medium level | 14.1–22.5 |
| 5          | Not acceptable. High level   | ≤22.5     |

## References

1. Aktur Y (2023) Acute muscle loss and early effects of COVID-19 on skeletal muscle in adult patients: A retrospective cohort study. Radiologia 65: S50–S58. <https://doi.org/10.1016/j.rxa.2022.12.008>
2. Calisti y R, Ballatori G (2016) Fatal silicosis in a funeral arts' craftsman. Medicina del Lavoro 107(00257818):478–484
3. Gounongbé y CF, Azandjèmè CS (2023) Epidemiological profile of occupational risks associated with artisanal burning of plastic materials in Parakou. Sante Publique 35(13):205–210. <https://doi.org/10.3917/spub.232.0205>
4. Kilinc-Tuncer G (2023) Effect of skeletal muscle area and prognostic nutritional index in peri-ampullary tumors. Cirugia y Cirujanos (English Edition) 91:73–78. <https://doi.org/10.24875/CIRU.21000563>
5. Weiß y SMS, Von Gall F (2017) Hypothenar hammer syndrome and thenar hammer syndrome as an occupational disease (BK 2114). Zentralblatt für Arbeitsmedizin, Arbeitsschutz und Ergonomie 67(27):230–233. <https://doi.org/10.1007/s40664-017-0192-2>
6. Abusleme T (2022) Histopathology, TBARS concentration and total protein level of skeletal muscle in newborn rats exposed to hyperoxia and the protective effect of taurine. Acta Microscopica 31(07984545):1–12
7. Maryantari y ES, Keman S (2020) Analysis of health risk and respiratory complaints on footwear craftsman exposed to toluene vapour. J Public Health Res 9:125–129. <https://doi.org/10.4081/jphr.2020.1818>
8. Espinosa y MA, Barzola DdP (2017) Revista Espacios [En línea]. <https://www.revistaespacios.com/a18v39n23/a18v39n23p32.pdf>
9. Mora APS (2017) Repositorio Digital Universidad Central del Ecuador [En línea]. <http://www.dspace.uce.edu.ec/bitstream/25000/10806/1/T-UCE-0009-709.pdf>
10. Nemery B (2018) Assessing exposure to metals using biomonitoring: Achievements and challenges experienced through surveys in low- and middle-income countries. Toxicol Lett 298: 13–18. <https://doi.org/10.1016/j.toxlet.2018.06.004>
11. Omrane y A, Kacem I (2017) Prevalence and determinants of musculoskeletal disorders of the upper limbs among Tunisian artisans. East Mediterran Health J 23:774–780. <https://doi.org/10.26719/2017.23.11.774>

12. Sannita y DA, Yuliani S (2018) Mapping of work hazards environment and illness risk of employment on brass craftsman based on geographic information system (GIS),» E3S Web of Conferences 73: 16–21. <https://doi.org/10.1051/e3sconf/20187306012>
13. Santamaría GFT (2018) Repositorio Universidad Tecnológica Indoamérica [En línea]. <http://repositorio.uti.edu.ec//handle/123456789/755>.
14. Setyaningsih y Y, Husodo A (2018) Factores del entorno laboral y su influencia en los niveles de cromo en la orina en trabajadores informales de galvanoplastia. E3S Web de Conferencias 06007:31<https://doi.org/10.1051/e3sconf/20183106007>
15. Sriagustini y I, Supriyani T (2021) The risk assessment on bamboo weaving craftsmen in Rajapolah district Tasikmalaya regency. Indones J Occup Saf Health 10(10): 64–78. <https://doi.org/10.20473/ijosh.v10i1.2021.64-78>
16. Álvarez-Sánchez A, Suárez del Villar-Labastida y A, Villamarín N (2022) Tools for Occupational Diseases Control in the Artisan Figures of Marzipan. Lect Notes Netw Syst 319(1034–1040). [https://doi.org/10.1007/978-3-030-85540-6\\_132](https://doi.org/10.1007/978-3-030-85540-6_132)

# An Effective Approach to Ensure Brand Safety in Online Advertising Using Image Multiclass Classification and Deep Learning



Nhan T. Cao, Quan M. Vo, and An H. Ton-That

**Abstract** Contextual advertising is a digital advertising method of displaying advertisements on the Internet according to the host website's context. This leads to the need for businesses to ensure brand safety on the Internet, which is a strategy that enables a brand to avoid display of advertisement on illegal or inappropriate pages. This work proposes an effective approach to ensure brand safety online using multiclass classification to detect unsafe images for brands. We created a dataset with seven unsafe classes (adult, gore, gambling chip, gun, knife, alcohol, and cigarette) and a safe class. Moreover, some pruning techniques are investigated to observe the performance of our method. The performance is tested on certain key factors such as accuracy, model size, and inference speed. Experimental results demonstrate that our proposed approach obtains good performance and has potential to apply to real systems.

**Keywords** Brand safety · Online advertising · Multiclass classification · Deep learning · Pruning techniques

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## 1 Introduction

In the era of widespread mobile commerce applications exploding globally, online advertising plays a very important role for businesses. For an online advertising campaign to be successful, many critical requirements need to be met such as budget, time, target customers, expected revenue, smart information technology functions. One of the most important issues is that businesses are very interested in preserving the brand image and minimizing negative impacts caused by risks on the internet environment.

Contextual advertising is a form of digital advertising in which advertisements are displayed on a website depending on the host website's context. There are four stakeholders: publisher (the host website on which advertisements can be displayed on), advertiser (the brand representative to display advertisements), advertising network (the platform used to manage publishers and advertisers), and users (the people who can access websites and can and view click on advertisements).

When a user accesses a website via an advertising network, a bid request is sent to advertisers. Then, advertisers check suitability and make the decision of doing or rejecting the bidding. The main factors used in decision-making are the contextual relevance of the website and brand, the safety of the brand's image when placed on the website, and the advertising budget. This work aims to propose an effective method to avoid unsafe websites in the examination phase to ensure brand safety.

As shown in the white paper on brand safety [1] of the Internet Advertising Bureau, brand safety solutions protect brands safely during online advertising, avoiding placing ads on websites with inappropriate or illegal content. Moreover, based on the observation that almost of websites contain many images, identifying unsafe images is a suitable approach to solve this problem.

This work presents an effective approach to ensure brand safety in online advertising. The first step is to build a dataset with categories often used in brand safety issues. The next step is proposing image multiclass classification models to detect unsafe images. The approach combines pre-trained deep learning model and network pruning technique to reduce training costs and increase inference speed. The work also shows suggestions for choosing the appropriate model when building practical applications.

## 2 Related Work

There has been a lot of research on identifying malicious images. Depending on the goal of the research, different models are proposed to detect unsafe images. Most of the studies are single categories such as adult category [2–4], gore or horror category [5–7], weapon category [8], gun category [9, 10]. There is little research for many unsafe categories for brand safety, our initial research [11] proposed a method that can detect five unsafe classes including adult, gore, gun, knife, and gambling chip.

Deep learning dominates research on classifying malicious images because of its superior advantages compared to traditional methods. Convolution neural networks are used in many works [5–10]. Some studies used convolution neural networks combined with some other features to improve accuracy [2–4]. Others used pre-trained deep learning models and fine-tuned models to solve specific problems [8, 11].

To solve the problem of brand safety, the method proposed in [11] has advantages including identifying five unsafe classes and combining pruning techniques to enhance performance. However, there are still issues that can be further studied as follows: detecting more unsafe classes, evaluating performance of original models and its pruned models as well as feasibility for practical application.

### 3 Proposed Method

#### 3.1 VGG Network, Deep Residual Learning

Deep convolutional neural networks (CNNs) have demonstrated excellent results in image classification. However, there are still some challenges such as difficulties in network design, or the existence of degradation issue. VGG network and deep residual learning are two approaches to solving the challenges mentioned.

As shown in [12], CNNs obtain very good results; however, it does not offer a framework to support researchers in order to design new networks. A suggestion for designing network architecture from each block was proposed by the Visual Geometry Group of Oxford University, and the result of this research is the VGG network [13]. A basic block of CNN includes (1) convolutional layer, (2) non-linear function, and (3) pooling layer. The original VGG network has five blocks, the first two blocks include one convolution layer each and the following blocks each include two convolution layers. Because the network has a total of three fully connected layers and eight convolution layers, it is often called VGG11. VGG network thus is easy to implement.

One other problem of deep learning methods is degradation issue. The residual learning framework [14] (called ResNet) can address this problem. Based on the observation that new layers are not guaranteed better outcomes, we let these layers fit a residual mapping in place of fitting new stacked layers underlying mapping directly. Deep residual networks achieve better accuracy in comparison to previous networks because the depth is significantly increased.

Both VGG11 and RestNet are effective pre-trained models and can be fine-tuned to successfully solve many different classification topics. Our work is also used to solve the problem of brand safety.

### 3.2 Network Pruning Techniques

Pruning is used for reducing model complexity by removing less useful filters in a CNN. Different criteria in picking what should be pruned create a variety of pruning methods.

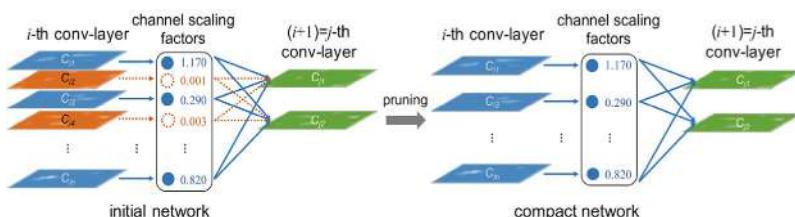
The main phases of pruning procedure include (1) training a large over-parameterized model, (2) pruning redundant architectures or weights, and (3) fine-tuning. The research in [15] showed that pruned architectures are more significant than weights. Some of the network pruning techniques widely used are L1-norm-based filter pruning, regression-based feature reconstruction, network slimming, and ThiNET. Figure 1 shows one example of the network slimming pruning process [16].

L1-norm-based filter pruning [17] aims to prune less useful filters of each layer using the sum of its absolute weights. The sensitivity level is observed by pruning them independently and evaluating the resulting pruned network's accuracy based on the validation set. For sensitive layers, either a smaller amount of these layers will be pruned or pruning will be skipped entirely. The method achieved about a 30% reduction in FLOP for VGGNet and ResNets without significant loss in the original accuracy.

Regression-based feature reconstruction [18] introduces an iterative algorithm with the purpose of pruning each layer using two phases. The first phase is using the LASSO regression-based approach to select redundant channels and prune them. The second phase is reconstructing the outputs with linear least squares. The method obtained very good results both in accuracy and speed.

Network slimming [16] applies sparsity-induced regularization on the scaling factors in batch normalization layers. Insignificant channels are identified automatically during the training phase, after which will be pruned. The authors stated that the method can reduce computational cost of existing networks with no accuracy loss, model size, computing operations, and run-time memory.

ThiNet [19] focuses on the filter level pruning. It means that the entire filter will be removed in the case it is less important. This work prunes filters based on a statistical value calculated from its next layer. The experimental results of the paper show better results than existing methods, especially the compact size of the ThiNet model.



**Fig. 1** Network slimming pruning [16]

### 3.3 *Proposed Method*

Our proposed method aims to meet criteria of brand safety including support many unsafe categories, reduce training costs, achieve high accuracy, increase inference speed, and have potential for practical implementation.

Currently, we have not found a shared image dataset for brand safety research, so we built our own dataset to conduct experiments. Seven unsafe classes are adult, gore, gambling chip, gun, knife, alcohol, and cigarette. This dataset includes the most common safety categories so that it can be applied in almost of branches.

Pre-trained models have been used in many applications because of computational cost reduction and good accuracy obtained. Take advantage of pre-trained models on large datasets and fine-tune on datasets. Instead of training the model from scratch, it is possible to take advantage of information learned from large models. To reduce training costs, we used popular pre-trained models and then fine-tuned them on our brand safety dataset. The pre-trained models are VGG11, ResNet34, and ResNet50.

As shown in the network pruning techniques session, pruning techniques are investigated. Observe accuracy, model size, and inference speed together to analyze and find a suitable model for practical application. Pruning techniques carried out include (1) network slimming used to prune VGG11; (2) L1-norm-based filter pruning used to prune ResNet34; and (3) regression-based feature reconstruction, ThiNet30, and ThiNet50 used to prune ResNet50.

## 4 Experiments and Results

### 4.1 *Dataset*

To test our proposed method, a dataset was created with eight classes including seven unsafe classes and one safe class. The dataset is built based on three main steps: Category selection, Data crawling, and Data cleaning:

- Category selection: Based on the White Paper on Brand Safety of Internet Advertising Bureau [1] and improvement of previous research [11], we select seven unsafe classes (adult, gore, gambling chip, knife, gun, alcohol, and cigarette) and one safe class.
- Data crawling: Data is collected from the Internet. Adult and gore images are crawled from porn and gore websites, gambling chip/knife/gun/alcohol/cigarette images are crawled from their sales websites. Safe images include a variety of topics like pets, animation, celebrities, and banners.
- Data cleaning: Images obtained after data crawling step still have not good quality images such as logo images, error images, or noise images. So, for each category, we manually checked and removed incorrect images.

**Table 1** Created dataset statistics

| Category      | Amount of images |
|---------------|------------------|
| Adult         | 14,994           |
| Gore          | 3,523            |
| Gambling chip | 3,819            |
| Knife         | 4,909            |
| Gun           | 6,681            |
| Alcohol       | 4,844            |
| Cigarette     | 4,370            |
| Safe          | 22,575           |
| <b>Sum</b>    | <b>65,715</b>    |

We obtain a dataset of 65,715 images with statistics shown in Table 1. The dataset has eight classes in total, of which there are seven unsafe classes and one safe class.

## 4.2 Experiment Models and Carry Out Environment

As shown in the proposed method, VGG11, ResNet34, and ResNet50 are carried out and fine-tuned for brand safety. Then, pruning techniques are applied to reduce the training cost and model size. They are using network slimming to prune VGG11 [16], using L1-norm-based filter pruning [17] to prune ResNet34, using regression-based feature reconstruction [18], ThiNet30, and ThiNet50 [19] to prune ResNet50. These pruned models are named Slim-VGG11, L1-ResNet34, Regression-ResNet50, ThiNet30-ResNet50, and ThiNet30-ResNet50, respectively.

All experiments are set up as following:

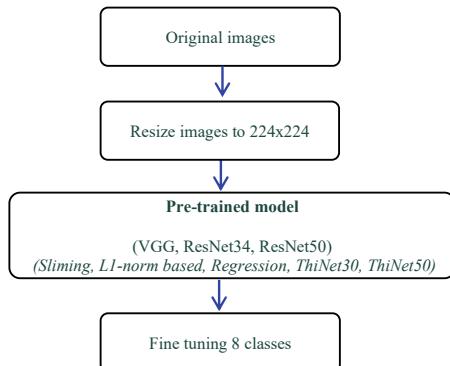
- Fivefold cross-validation
- Pytorch 1.2, CUDA 9.0 framework, and GTX 1070Ti GPU are used to implement
- RMSprop is used for optimization
- Cross-entropy is applied as a loss function to optimize multiclass classification models.

Figure 2 illustrates the experimental process.

## 4.3 Experimental Results

### 4.3.1 Accuracy

The F1-score is used to measure accuracy because the dataset is imbalanced. Table 2 demonstrates accuracy for each class and average accuracy of each model. The

**Fig. 2** Experimental process**Table 2** Experimental accuracy

| Model                             | Adult        | Gambling chip | Gore         | Gun          | Knife        | Alcohol      | Cigarette    | Safe         | Average      |
|-----------------------------------|--------------|---------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| VGG11                             | 89.74        | 87.42         | 70.12        | 93.62        | 85.77        | 82.19        | 70.96        | 85.79        | <b>83.20</b> |
| <i><b>Slim-VGG11</b></i>          | <b>94.49</b> | <b>90.33</b>  | <b>79.99</b> | <b>95.49</b> | <b>90.74</b> | <b>86.08</b> | <b>79.11</b> | <b>90.03</b> | <b>88.28</b> |
| ResNet34                          | 95.35        | 91.69         | 81.37        | 96.44        | 93.38        | 87.44        | 81.83        | 91.64        | <b>89.89</b> |
| <i><b>L1-ResNet34</b></i>         | <b>95.06</b> | <b>91.12</b>  | <b>81.14</b> | <b>96.67</b> | <b>92.39</b> | <b>86.83</b> | <b>80.45</b> | <b>91.26</b> | <b>89.36</b> |
| ResNet50                          | 95.70        | 93.01         | 83.85        | 97.37        | 93.88        | 88.75        | 84.13        | 92.38        | <b>91.13</b> |
| <i><b>Regression-ResNet50</b></i> | <b>95.87</b> | <b>92.62</b>  | <b>83.23</b> | <b>96.59</b> | <b>92.95</b> | <b>88.33</b> | <b>82.72</b> | <b>91.92</b> | <b>90.52</b> |
| <i><b>ThiNet30-ResNet50</b></i>   | <b>94.39</b> | <b>90.25</b>  | <b>80.19</b> | <b>95.81</b> | <b>91.67</b> | <b>86.61</b> | <b>79.67</b> | <b>90.38</b> | <b>88.62</b> |
| <i><b>ThiNet50-ResNet50</b></i>   | <b>95.00</b> | <b>91.41</b>  | <b>80.16</b> | <b>96.62</b> | <b>92.89</b> | <b>87.36</b> | <b>80.75</b> | <b>91.07</b> | <b>89.41</b> |

accuracy of all models achieves from 83.2% to 91.13%. Observation on each class, the group of adult, gambling chip, knife, gun, and safe shows higher accuracy in a comparison of the group of gore, alcohol, and cigarette.

In comparison with the original models, Slim-VGG11 has an increased accuracy of 5.08%, contradictory to L1-ResNet34, Regression-ResNet50, ThiNet30-ResNet50, and ThiNet50-ResNet50 which have decreased its accuracy by in the range of 0.53%–2.51%.

To better understand wrong predicted images, some examples are observed and explained further. Some safe images are predicted as alcohol (as shown in Fig. 3) because the safe image class includes meal images with a glass of water or a bottle of water. Some other safe images are predicted as cigarette (as shown in Fig. 4) because the image has a posture like holding a cigarette. Some cigarette images are predicted to be safe (as shown in Fig. 5) because the cigarette object in the image is so small and makes it very difficult to recognize correctly. And some images have both alcohol and cigarette, so it cannot be recognized correctly as shown in Fig. 6.

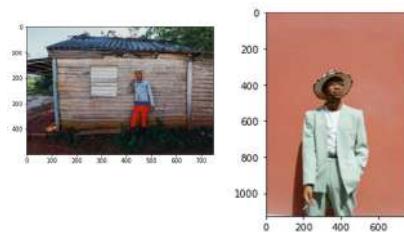


**Fig. 3** Some safe images are predicted as alcohol

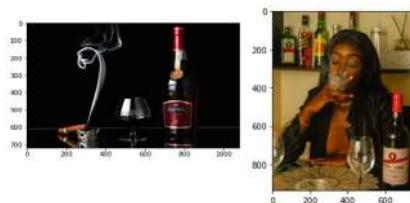
**Fig. 4** Some safe images are predicted as cigarette



**Fig. 5** Cigarette images are predicted as safe



**Fig. 6** Cigarette images are predicted as alcohol



#### 4.3.2 Inference Speed

In this work, the inference speed is calculated by an average inference speed of 100 runs and is measured in frames per second. The inference speed of batch sizes of 1, 32, 64, 128, and 256 is illustrated in Table 3.

The inference speed of pruned models obtains higher performance in almost all cases (only Regression-ResNet50 is lower). For example, observe the batch size 64, Regression-ResNet50, ThiNet30-ResNet50, and ThiNet50-ResNet50 speed up the original model (ResNet50) by 1.04, 1.44, and 1.36, respectively. The L1-ResNet34's

**Table 3** Inference speed

| Model                             | 1          | 32         | 64         | 128        | 256        |
|-----------------------------------|------------|------------|------------|------------|------------|
| VGG11                             | 179        | 461        | 464        | 467        | 486        |
| <b><i>Slim-VGG11</i></b>          | <b>256</b> | <b>466</b> | <b>482</b> | <b>484</b> | <b>464</b> |
| ResNet34                          | 247        | 724        | 740        | 761        | 765        |
| <b><i>L1-ResNet34</i></b>         | <b>258</b> | <b>878</b> | <b>885</b> | <b>961</b> | <b>968</b> |
| ResNet50                          | 172        | 375        | 389        | 388        | 397        |
| <b><i>Regression-ResNet50</i></b> | <b>121</b> | <b>390</b> | <b>406</b> | <b>409</b> | <b>417</b> |
| <b><i>ThiNet30-ResNet50</i></b>   | <b>210</b> | <b>557</b> | <b>562</b> | <b>562</b> | <b>561</b> |
| <b><i>ThiNet50-ResNet50</i></b>   | <b>190</b> | <b>518</b> | <b>530</b> | <b>528</b> | <b>535</b> |

speed has increased compared to ResNet34 by 1.2 times, and only Slim-VGG has small improvement.

#### 4.3.3 Model Size

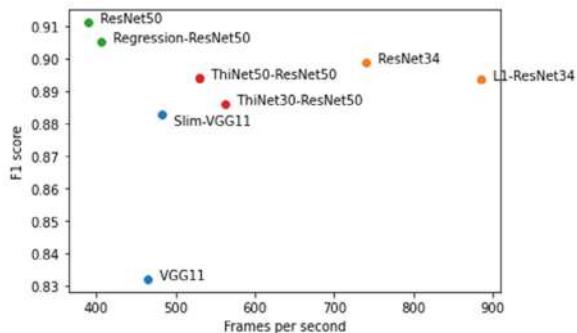
As shown in Table 4, ThiNet30-ResNet50 and ThiNet50-ResNet50 have the smallest model sizes, which are very meaningful in considering applications deployed in real systems. In terms of compression ability in comparison of the pruned models and the original model, Slim-VGG11 gives the best result, reducing the model size by up to 72.18%; however, the VGG11 model has a quite large model size compared to other models. Meanwhile, L1-ResNet34, Regression-ResNet50, ThiNet30-ResNet50, and ThiNet50-ResNet50 reduce the model size by 10.11%, 22.02%, 62.39%, and 48.62%, respectively.

Compared with the 6-class dataset [11], the model size remains unchanged when adding two new classes. This indicates the feasibility of adding unsafe labels.

**Table 4** Model size

| Model                              | Size (Mb) applied for 8-class dataset | Size (Mb) applied for 6-class dataset [11] |
|------------------------------------|---------------------------------------|--------------------------------------------|
| VGG11                              | 532                                   | 532                                        |
| <b><i>Slim-VGG11</i></b>           | <b>148</b>                            | <b>148</b>                                 |
| ResNet34                           | 89                                    | 89                                         |
| <b><i>L1-ResNet34</i></b>          | <b>80</b>                             | <b>80</b>                                  |
| ResNet50                           | 109                                   | 109                                        |
| <b><i>Regression -ResNet50</i></b> | <b>85</b>                             | <b>85</b>                                  |
| <b><i>ThiNet30-ResNet50</i></b>    | <b>41</b>                             | —                                          |
| <b><i>ThiNet50-ResNet50</i></b>    | <b>56</b>                             | —                                          |

**Fig. 7** Comparison of inference speed and accuracy (batch size 64)



To evaluate the applicability to practical systems, Fig. 7 demonstrates the comparison of inference speed and accuracy for each pair of the original and pruned models. Based on the priority criteria (accuracy or inference speed) when building the application, the appropriate model can be selected.

## 5 Conclusions

The research presented an effective approach to ensure brand safety in online advertising using image multiclass classification and deep learning. First, we created a dataset with eight classes (seven unsafe classes and one safe class) to test our proposed model focusing on some key performance indicators: accuracy, inference speed, and model size. After that, pre-trained models and pruned modes are investigated and are adjusted to solve the brand safety issues using multiclass classification on images. This approach greatly reduces model training costs while still achieving the given key performance indicators. Experimental results showed that the proposed method achieved good performance and has potential for application to real systems. Moreover, experimental results also provided suggestions for choosing an appropriate model in building a real system, flexibly meeting the priority needs.

Based on the obtained results, this work can be improved in the following issues:

- Research on adding new unsafe classes while remaining high performance.
- Research on improving accuracy, especially for images that contain the meaning of some classes or malicious areas in images is too small.

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## References

1. Brand Safety (2018) White Paper on Brand Safety in Today's Digital Context, Internet Advertising Bureau (iAB) Lab
2. Wang X, Cheng F, Wang S, Sun H, Liu G, Zhou C (2018) Adult image classification by a local-context aware network. In: 25th IEEE International Conference on Image Processing (ICIP), pp 2989–2993
3. Ou X, Ling H, Yu H, Li P, Zou F, Liu S (2017) Adult image and video recognition by a deep multicontext network and fine-to-coarse strategy. In: ACM Transactions on Intelligent Systems and Technology, 8
4. Mazinani MR, Hoseini SM, Dadashtabar Ahmadi K (2021) Time-sensitive adaptive model for adult image classification. Comput Inform 39(6):1282–1310
5. Sivaraman K, Somappa G (2017) MovieScope: Movie trailer classification using Deep Neural Networks. University of Virginia
6. Simões GS, Wehrmann J, Barros RC, Ruiz DD (2016) Movie genre classification with Convolutional Neural Networks. In: 2016 International Joint Conference on Neural Networks (IJCNN), pp 259–266
7. Chen S-L, Yang C, Zhu C, Yin X-C (2016) Bloody image classification with global and local features. In: Chinese Conference on Pattern Recognition, pp 379–391
8. Kaya V, Servet T, Ahmet B (2021) Detection and classification of different weapon types using deep learning. Appl Sci 11(16):7535
9. Karakaya İ, Öztürk O, Bal M, Esin YE (2020) Deep learning based gun classification in X-ray images. In: 2020 28th Signal Processing and Communications Applications Conference (SIU), Gaziantep, Turkey, pp. 1–4
10. Manikandan VP, Rahamathunnisa U (2022) A neural network aided attuned scheme for gun detection in video surveillance images. Image Vis Comput 120
11. Vo QM, Cao NT, Ton-That AH (2020) Unsafe image classification using convolutional neural network for brand safety. In: 2020 IEEE Asia-Pacific Conference on Computer Science and Data Engineering, 2020, pp 1–4
12. Krizhevsky A, Sutskever I, Hinton GE (2012) Imagenet classification with deep convolutional neural networks. Adv Neural Inf Process Syst 25:1097–1105
13. Simonyan K, Zisserman A (2015) Very deep convolutional networks for large-scale image recognition. In: The 3rd International Conference on Learning Representations
14. He K, Zhang X, Ren S, Sun J (2016) Deep residual learning for image recognition. In: 2016 IEEE Conference on Computer Vision and Pattern Recognition, pp 770–778
15. Liu Z, Sun M, Zhou T, Huang G, Darrell T (2019) Rethinking the value of network pruning. In: International Conference on Learning Representations
16. Liu Z, Li J, Shen Z, Huang G, Yan S, Zhang C (2017) Learning efficient convolutional networks through network slimming. In: 2017 IEEE International Conference on Computer Vision (ICCV), pp 2755–2763
17. Li H, Kadav A, Durdanovic I, Samet H, Graf HP (2017) Pruning filters for efficient convnets. In: 5th International Conference on Learning Representations
18. He Y, Zhang X, Sun J (2017) Channel pruning for accelerating very deep neural networks. In: 2017 IEEE International Conference on Computer Vision (ICCV), 2017, pp 1398–1406
19. Luo J-H, Wu J, Lin W (2017) ThiNet: A filter level pruning method for deep neural network compression. In: 2017 IEEE International Conference on Computer Vision (ICCV), Venice, Italy, pp 5068–5076

# Enhancing Health Data Utilization with Business Analytics in Academic Research



Manuela Freire and Catarina Abrantes

**Abstract** The integration of advanced data analytics and decision support systems represents a pivotal advancement in the modern health sector, adopting improved decision-making and operational efficiency. This study explores the transformative impact of business analytics techniques and data infrastructure within health organizations. Key findings include enhanced integration of diverse health data sources, optimized resource allocation through decision support systems (DSS), and improved health data. Challenges such as data quality and interoperability were addressed, emphasizing the need for continued innovation and ethical considerations in health sector data analytics. This research underscores the critical role of data-driven strategies in shaping the future of health sector delivery and management.

**Keywords** Decision support · Business analytics · Health data · Data analysis

## 1 Introduction

A period of global digital transformation is currently being experienced, marked by the rapid expansion of new technologies [1, 2], with the health sector being no exception. Significant benefits can be achieved by stakeholders across the spectrum, from health system administrators to patients, academics and health professionals, from the connectivity and information provided by information systems and technologies. Horani, Khatibi [3], highlights the critical role of organizational, technological, and environmental factors in influencing the adoption of business analytics processes. However, a significant volume of data is produced by the increase of digital health systems, requiring sophisticated tools, adequate resources, and advanced technological abilities to extract, process, and convert this data into useful information.

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According to Freire, Antunes [4], decision-makers must gather relevant information to enhance their understanding of the available alternatives for a given choice, using data extraction and analysis to make swift and well-informed decisions based on the results obtained.

When information is derived from data, opportunities for improvement can be identified, and more informed, data-driven decisions can be made by academics and health professionals. Plans and strategies can be developed to support decision-making in both academic and organizational contexts. Furthermore, national and global responses to health emergencies can be formulated, and decision-makers in various health-related domains can be informed using this data.

The enhancement of health systems is consistently followed through activities aimed at improving the health sector [1, 2]. However, these advantages are not ensured from the beginning. Data collection represents only the initial step in a continuous cycle of data utilization. To maximize the benefits of data, the incorporation of technological factors and methodologies from the fields of computer science and data science is essential. The relative advantage of new technology over existing alternatives, its compatibility with the organization's systems, and the perceived complexity by users in understanding and utilizing the technology are encompassed by these technological factors [3]. As the requirement for data-driven health services increases between academics and health system managers, the ability to quickly collect, analyze, visualize, interpret, and utilize this data becomes ever more important [5].

This study was developed to ensure the efficient utilization of large volumes of data stored in the databases of a health organization. It was found that some data had been obtained through ineffective and time-consuming techniques and tools, resulting in multiple CSV and TXT files that were not easily understood by researchers and health professionals, thus making it difficult to extract existing knowledge from this data.

The objective of this study was to simplify the analysis of health data to improve academic research and decision-making, thereby enhancing the efficient utilization of health data across various contexts. Challenges identified encompassed information fragmentation, diverse data sources, and formats, files with varying naming conventions, unstructured data, and data duplication. Given the historical nature of the health data spanning from 2009 to 2022, the goal was to aggregate and standardize the data for subsequent utilization in both academic research and by health professionals.

The main objective was the extraction of health data knowledge with a focus on a dataset for academic study and decision support, using techniques from computer science, such as business analytics and decision support systems for large volumes of data. The process involved the analysis, extraction, transformation, and storage of health data, enabling simple analysis and the generation of reports and statistics according to the goals defined by academics and health professionals.

Business analytics techniques and decision support systems were used to analyze complex and large volume of data to expose important information, patterns, and correlations that support the purpose of an academic study [6]. Extensive records and

other health-related information were examined to enhance operational efficiency, improve outcomes, and optimize data utilization.

The literature on business analytics has evolved rapidly, underscoring the increasing significance of big data analysis [7, 8]. Tools such as data mining, text mining, machine learning, and artificial intelligence are extensively explored to enhance prediction and optimization capabilities. According to Elragal, Elragal [1], business analytics technologies are ever more being employed to extract knowledge and convert it into valuable information and analytical tools for health professionals. However, gaps persist in the effective application of business analytics in the analysis of health sector data.

Within the health sector, business analytics techniques and decision support tools are extensively utilized to extract value from large volumes of data [2]. These methods are applied across various domains, including public health [5, 9], pharmacovigilance [10, 11], ethical issues, [12–14], supply chain management in healthcare [15–17], and clinical decision support [18–21], among other areas.

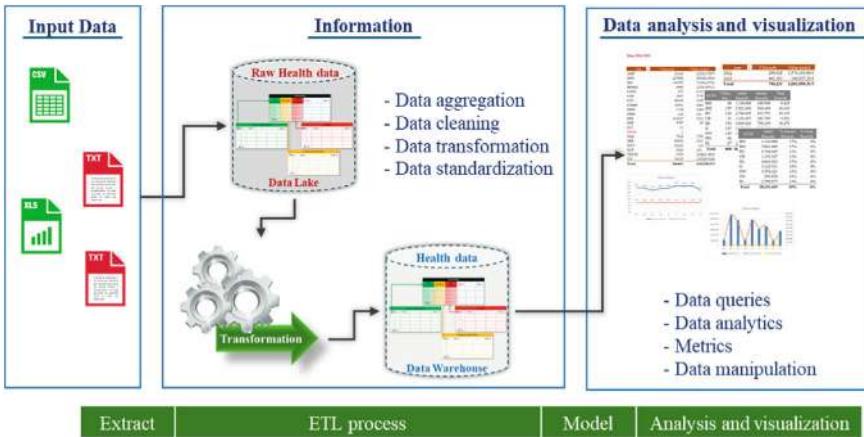
The extraction of critical information from large volumes of both structured and unstructured, typically textual, data is improved through the combination of business analytics methods and decision support systems. These technologies provide an insightful understanding of the information contained within health data.

The remainder of the paper is structured as follows. Section 2 provides strategies, approaches, and relevant topics in business analytics and data warehouse. Section 3 describes the methodology and related studies conducted by using a large volume of data. Finally, Sect. 4 presents the conclusions drawn from the study.

## 2 Strategies Approaches

Collecting and integrating data from heterogeneous sources and multiple systems can be complex and time-consuming [22, 23]. Ensuring data quality and accuracy was crucial to avoid making inaccurate decisions. Additionally, preserving privacy and complying with regulations were a challenge that must be continuously managed.

In this study, the implementation of business analytics techniques and a decision support system in the health sector to integrate big data required careful planning and strategic approaches. An end-to-end view of integrated processes was essential to deliver a seamless and functional solution. The strategies for integrating health data are depicted in Fig. 1. A workflow strategy for structuring health data based on academic requirements was carefully designed and implemented. The process begins with a health data input phase, progresses through various stages that generate valuable data, and concludes with multiple outputs. Initially, all files were aggregated. Specifically, in the medication study, 419 files comprising a total of 1,190,813 records were included, and in the statins study, 868 files comprising a total of 28,131,415 records were utilized. Algorithms based on MS Excel's Visual Basic for Applications (VBA) were employed to aggregate these files for storage in respective databases.



**Fig. 1** Workflow strategy for structuring health data

Database tables were created, and the next step involved synchronizing the data sources into the data lake. The data lake functions as an operational database that ensures the original (raw) data stays unchanged. The two databases depicted in the figure are the data lake and the data warehouse, which store the unprocessed source data and the processed and structured data, respectively.

Subsequently, the ETL (Extract, Transform, Load) process was employed to extract, transform, and load the data for subsequent use. During this stage, the ETL process was utilized not only for data processing and normalization but also for data cleaning. Specific problems and inconsistencies were addressed through data transformation, after which the data was transferred into the data warehouse. Furthermore, business analytics technologies were employed to extract useful information, and MS Excel was used for visualizing and manipulating the data.

## 2.1 Data Warehouse

To develop a model that integrates health data from different sources, the use of data warehouse was crucial for providing both academics and health professionals with the best evidence, enhancing decision-making processes, and reducing the occurrence of missing, inaccurate or uninterpretable data. Data warehouse can be defined as a data storage system where large amounts of data from different sources are logically linked [24]. In this study, the purpose was to provide data outputs and reports, enabling the transformation of data into useful information to academic studies and facilitating informed decisions. Historical data from 2009 until 2022 was consolidated in one place within data warehouses, serving as the sole reliable source for information extraction.

**Table 1** Resolved issues in data processing and standardization

| # | Problems and inconsistencies                                                                   | Resolution                                                                                                                                    |
|---|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | Columns and lines were unnecessary                                                             | Columns and lines that were unnecessary were removed                                                                                          |
| 2 | CSV headers were repeated as many times as there are months in the file                        | CSV headers repeated unnecessarily were eliminated                                                                                            |
| 3 | Information about health unit, month, and year in headers, not attributes of each record       | Information about health unit, month, and year in headers was transformed into attributes for each record                                     |
| 4 | Numeric values in text format                                                                  | Numeric values in text format were converted to numeric values                                                                                |
| 5 | Ambiguous semantic values entered by system users, e.g., “= Unknown =”                         | Ambiguous semantic values entered by system users, such as “= Unknown =”, had their “=” symbols eliminated and were standardized to “Unknown” |
| 6 | Different abbreviations for the same designation, e.g., “Centro de Saúde Celas” and “CS CELAS” | Health unit names across the table were standardized, addressing different abbreviations for the same designation                             |

To ensure effective data integration, another data storage component, known as a data lake, was included. The data lake serves as a repository for storing and processing large volumes of data in its original format, accommodating raw data in various formats such as structured, semi-structured, and unstructured data [24]. On the other hand, the structure of large volumes of data for analysis was facilitated by the data warehouse, which utilizes specific tables to support rapid queries. According to Gorelik [24], the core of a data warehouse is its database.

One of the main challenges in integrating large volume of data is interoperability [23], which refers to the standards, protocols, and technologies that allow data to flow between various systems with minimal human intervention. The primary challenges related to interoperability among different health data systems were linked to semantic interoperability, particularly the lack of universal standards for coding and structuring data. Overcoming this obstacle required the standardization of these practices, as illustrated in Sect. 3.1 and Table 1. To ensure interoperability, it was essential to utilize ETL technology for extracting, processing, and exchanging data.

## 2.2 Business Analytics Technologies

Implementing business analytics techniques in the health sector presents several challenges. The collection and integration of data from heterogeneous sources and multiple systems are complex and time-consuming processes [22, 23]. Ensuring data quality and accuracy is essential to prevent inaccurate decision-making. Data quality, defined as the level of accessibility, consistency, and completeness necessary

for conducting analytics, must be maintained [3]. Additionally, the preservation of privacy and the management of cybersecurity concerns are ongoing challenges that require continuous attention [14].

Despite the challenges, significant opportunities for leveraging business analytics techniques in the health sector are present. The increased use of data technology and data-sharing platforms, resulting from the implementation of digital strategies in the health sector, creates a wealth of data that can be leveraged for analysis [23]. By benefiting from these opportunities, the crowded potential of large volume data integration and business analytics can be unlocked to drive meaningful change and improve results in the health sector.

The implementation of business analytics in the health sector is vital in enhancing the quality of data [3] used by both academics for research purposes and health professionals aiming to improve the performance of health institutions, optimize resource utilization, and adopt evidence-based practices. This enhancement is achieved through process optimization and decision support. Several aspects of practical computer science and technological solutions are encompassed by business analytics techniques, responsible for processing, transforming, and managing data [7].

Decision-making is aided through the creation of data warehouses, the provision of reports, and the application of analytics. These resources assist to monitor not only the quality of health data but also the production of useful data, reports with performance indicators predefined by academics and health professionals, depending on the intended objectives. Furthermore, the focus has been on in-depth analysis of health data and information to support decision-making processes using business analytics techniques. In this study, reports, exploratory and complex data analyses were developed using statistical and mathematical tools and algorithms. When implementing business analytics techniques, tools such as Excel were utilized for creating interactive dashboards and customizing them [25, 26].

### 3 Methodology and Related Studies

The study adopted the Kimball methodology [27] due to its alignment with the objectives. This methodology of dimensional modeling outlines key principles for organizing data in data warehouses to improve data analysis and utilization [28]. Context is provided by dimension tables with descriptive attributes, facilitating the interpretation of quantitative measures stored in fact tables. Metrics such as the cost of medicines or the number of patients is stored in fact tables, which are linked to dimension tables for context. Granularity defines the level of detail in fact tables, essential for data analysis aligned with research needs. The methodology balances normalization to reduce redundancy with denormalization to boost query performance, ensuring robust and flexible information systems optimized for analysis.

Throughout the study, the development process was guided by the above principles, where mutual influence was exerted between the data analyst and the researcher. Close collaboration between them was considered essential, with a focus on planned

interventions to adjust the study's requirements when necessary. The streamlining of activities in constructing, testing, and modifying was facilitated by synchronized efforts among the academic, professional, and end-user of the information produced, alongside the data analyst. Furthermore, two primary objectives were achieved: a model for data analysis was developed, and consistent data for research and decision support were obtained. These objectives were realized through the strategic alignment of synergies and mutual contributions, balancing the practical utility of the solution with its scientific rigor, and resolving practical issues occurred during the process.

Initially, an analysis was conducted on the various data sources required for each study. It was determined that the volume of data was significant, posing challenges in providing researchers and health professionals with readily usable data. This complexity hindered the extraction of meaningful insights, encompassing data on medicine consumption, invoicing eligibility, and statin prescriptions over time. The goal was to optimize data use, allowing valuable output information and streamlining of the entire process of data manipulation for research and decision-making through intuitive and simple queries. Additionally, the aggregated data was validated to ensure data quality and reliability.

### ***3.1 Implementation of Dimensional Modeling***

The data initially provided by the health organization, in formats such as CSV, TXT, and Excel files, was stored in the data lake database and made accessible through the data warehouse. Here, it underwent transformation and structuring. These datasets encompass details on medication consumption, statins, related diseases, and patient information. Based on the available data and predefined objectives, data models were delineated and scaled. After processing, the data was stored within the data warehouse. The fact tables within the model are interconnected through dimensions of time and health unit centers.

During the initial phase of the medication consumption study, data from two separate datasets were merged. The first dataset focused on statins and associated diseases, consisting of 214 files. The second dataset contained 205 files with patient information. These datasets covered the period from 2009 to 2022 and were organized into annual files categorized by specific disease types. Data were extracted from the health organization, which is divided into nine health unit centers.

The primary objective of structuring these datasets was twofold: firstly, to analyze the total number of patients, including those with dyslipidemia, hypertension, and diabetes between 2009 and 2022; and secondly, to investigate the progression of patients with diabetes and hypertension who experienced cerebral vascular accidents and heart attacks during the same period, aiming to identify potential differences.

Another goal was to assess the trend in statin prescriptions over time, focusing on identifying the most commonly prescribed statins for cases of diabetes and hypertension, including patients who experienced cerebral vascular accidents and heart

attacks. This involved examining whether there was a decline or increase in prescriptions of simvastatin, atorvastatin, and rosuvastatin. The analysis was conducted by health units and by type of statin to uncover potential regional differences.

Regarding the study of statins, related diseases, and patients, 868 files of drug consumption and invoicing were aggregated during the initial phase. This dataset spanned from 2009 to 2022 and was organized into annual files, each corresponding to specific health unit centers. The files contained information regarding all medications prescribed by the health centers, including cost or economic value, number of medication packages, and number of prescriptions.

The objective was to extract a dataset concerning antidiabetic medications, encompassing 27 distinct types, and calculate the Defined Daily Dose (DDD) metric. DDD is defined for each drug based on recommendations from scientific literature and manufacturers. Using DDD as a unit of measure enables the examination of changes in medication consumption over time and the assessment of effects on prescription patterns, among other analyses.

### ***3.2 Data Processing via ETL Processes***

After data exploration, several data inconsistencies were identified that needed rectification directly from the data sources. These problems and their resolutions are shown in Table 1. Subsequently, the processed data was loaded into the data warehouse, as outlined in the data dimensions and application case.

Throughout the study, rigorous procedures were implemented to ensure data quality and validation. This involved the application of cleaning and normalization rules during the transformation process to maintain consistent, error-free data. Automatic validation scripts were employed to verify adherence to defined standards. Furthermore, periodic manual reviews were conducted by experts to identify and correct any inconsistencies or errors not captured by automated checks.

### ***3.3 Data Analysis and Visualization***

A data development and visualization environment were established using Excel, aimed at extracting data from the data warehouse and generating analytical reports and intuitive dashboards with key indicators to enhance the researcher's data analysis and decision-making process.

Excel was selected for its user-friendly interface, direct access to data warehouse information, and flexibility in creating customized visualizations aligned with study objectives. Guerrero [29] identifies Excel as a crucial tool for data management, while Perkins, Redmond [30] underscore its effectiveness in handling complex interconnected data. Additional measures were implemented to support comprehensive data

analysis and achieve predefined objectives, including the use of Excel functionalities to derive metrics such as DDD.

## 4 Conclusion and Results

This study led to the development of a model that enables knowledge extraction from health data, simplifying data acquisition and providing useful information for academics and health professionals. Previously, retrieving such data relied on manual, time-consuming processes hindered by complicated techniques, which impeded data aggregation and understanding by academics and health professionals. Now, with the automation and enhancement of the health data analysis process, this data is easily and intuitively accessible through Excel, offering relevant insights for analysis and supporting decision-making.

The aggregated health data proved essential for various analyses and academic decision-making processes based on its availability and relevance for each study. ETL processes were developed and implemented, producing important and comprehensible information. Additionally, a data warehouse was created, and a data dimension model was established to accommodate the data warehouse along with its corresponding tables.

In conclusion, structured data and reports were generated, presenting information in an easy and intuitive manner, facilitating analysis and decision-making processes. The culmination of this work aimed to fulfill the primary objective of extracting knowledge to support academic research. In summary, this study enabled improved utilization of data stored in health organization databases, ensuring the quality of information derived from these sources. This empowers academics and health professionals to derive scientific evidence from analyzed and manipulated health data, aiding in their research and decision-making processes.

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## References

1. Elragal R, Elragal A, Habibipour A (2023) Healthcare analytics-A literature review and proposed research agenda. *Front Big Data* 6:1277976. Epub 2023/10/23
2. Liu Q, Yu M, Xiong B, Cai Z, Zhang P, Tan C-W (2023) Health analytics in business research: a literature review. *J Manag Anal* 10(3):447–476
3. Horani OM, Khatibi A, AL-Soud AR, Tham J, Al-Adwan AS (2023) Determining the factors influencing business analytics adoption at organizational level: a systematic literature review. *Big Data Cogn Comput* 7(3):125
4. Freire M, Antunes F, Costa JP (2023) Enhancing decision-making support by mining social media data with social network analysis. *Social Network Analysis and Mining*

5. Zhang D, Pee LG, Pan SL, Wang J (2024) Information practices in data analytics for supporting public health surveillance. *J Am Soc Inf Sci* 75(1):79–93
6. Woods G (2020) Business analytics in context: an introduction to mathematical methodologies: Goodfellow Publishers Limited
7. Favaretto M, De Clercq E, Elger BS (2019) Big Data and discrimination: perils, promises and solutions. A systematic review. *J Big Data* 6(1):12
8. Huda M, Maseleno A, Atmotiyoso P, Siregar M, Ahmad RB, Jasmi KA et al (2018) Big data emerging technology: insights into innovative environment for online learning resources. *Int J Emerg Technol Learn* 13:23–36
9. Cruz M, Guimaraes T, Abelha A, Santos MF (2022) Business analytics components for public health institution - nursing decision area. *Procedia Comput Sci* 198:347–352
10. Davazdahemami B, Delen D (2018) A chronological pharmacovigilance network analytics approach for predicting adverse drug events. *J Am Med Inform Assoc* 25(10):1311–1321
11. Nord M, Ysander M, Sullivan T, Patel M (2021) Practical considerations for creating a strategic and proactive clinical safety and pharmacovigilance organization for the future. *Int J Risk Saf Med* 32(3):243–258
12. Nunes P, Antunes M, Silva C (2021) Evaluating cybersecurity attitudes and behaviors in Portuguese healthcare institutions. *Procedia Comput Sci* 181:173–181
13. Someh IA, Davern MJ, Breidbach CF, Shanks GG (2019) Ethical Issues in Big Data Analytics: A Stakeholder Perspective. *Commun Assoc Inf Syst* 44:34
14. Iphofen R, O'Mathúna D (2022) Ethical Issues in Covert. Emerald Publishing Limited, Security and Surveillance Research
15. Javan R, Mohammadi M, Beheshti-Atashgah M, Aref MR (2024) A scalable multi-layered blockchain architecture for enhanced ehr sharing and drug supply chain management
16. Arora M, Gigras Y (2018) Importance of supply chain management in healthcare of third world countries. *Int J Supply Oper Manag* 5:101–106
17. Raut RD, Yadav VS, Cheikhrouhou N, Narwane VS, Narkhede BE (2021) Big data analytics: Implementation challenges in Indian manufacturing supply chains. *Comput Ind* 125:103368
18. Thompson S, Whitaker J, Kohli R, Jones C (2019) Chronic disease management: How it and analytics create healthcare value through the temporal displacement of care. *MIS Quarterly* 20
19. Nenova Z, Shang J (2022) Chronic disease progression prediction: Leveraging case-based reasoning and big data analytics. *Prod Oper Manag* 31(1):259–280
20. Kamalzadeh H, Ahuja V, Hahsler M, Bowen ME (2021) An analytics-driven approach for optimal individualized diabetes screening. *Prod Oper Manag* 30(9):3161–3191
21. Ichijuji M, Asakura L, Cain C, Aye N, Kolevska T, Chen D et al (2024) Improving routine use of clinical pathway decision support through integration of an EHR with a clinical library resource designed to provide evidence-based guidance within oncology workflows. *BMC Health Serv Res* 24(1):1–8
22. Jabeen H (2020) Chapter 3 big data outlook, tools, and architectures, p 35–55
23. Rehman A, Naz S, Razzak I (2022) Leveraging big data analytics in healthcare enhancement: trends, challenges and opportunities. *Multimedia Syst* 28(4):1339–1371
24. Gorelik A (2019) The enterprise big data lake: Delivering the promise of big data and data science: O'Reilly Media
25. Deckler G, Powell B, Gordon L (2022) Mastering Microsoft Power BI: Expert techniques to create interactive insights for effective data analytics and business intelligence: Packt Publishing
26. Winston W (2021) Microsoft excel data analysis and business modeling (Office 2021 and Microsoft 365): Pearson education
27. Kimball B (1998) Practitioner methodology for entry-level hiring assessment: issues for academic outcomes assessment. *J Educ Bus* 73(3):168–171
28. Kimball R, Ross M (2013) The data warehouse toolkit: The definitive guide to dimensional modeling: Wiley

29. Guerrero H (2019) Excel data analysis: Modeling and simulation: springer international publishing
30. Perkins L, Redmond E, Wilson J (2018) Seven databases in seven weeks: A guide to modern databases and the NoSQL movement: Pragmatic Bookshelf

# Predictive Analytics for Fleet Reserve Estimation



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and Mario Leonardo Nieto Antolínez

**Abstract** This paper introduces a practical methodology that utilizes predictive analytics to determine the necessary reserve fleet in transport business units within the Mexico City BRT system. The aim is to ensure the availability of buses to meet operational schedules, all while maintaining operational efficiency. The research emphasizes the need for an additional fleet to handle preventive and corrective maintenance and regulatory inspections mandated by transportation authorities. A comprehensive formula calculates the percentage of the fleet required as a technical reserve, safeguarding the company's operational efficiency. The methodology is illustrated through a case study involving five companies, demonstrating its effectiveness in bus fleet planning and management. This research contributes to resource optimization in the public transport sector, offering a robust and adaptable tool for fleet management. This study's comprehensive analysis and practical application provide a robust framework for other public transport entities seeking to enhance their fleet management practices.

**Keywords** Preventive maintenance · Corrective maintenance · Markovian model

## 1 Introduction

This research defines a methodology supported by predictive analytics to ensure operational availability and efficiency in bus fleet management. In the context of public transportation, maintaining an optimal level of operability and availability of

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vehicles is crucial to ensure the fulfillment of scheduled services and user satisfaction. The technical reserve is essential to cover daily operational needs, manage unforeseen contingencies due to mechanical failures, and schedule preventive maintenance and regulatory inspection requirements. The users' satisfaction is a key outcome of this methodology, as it ensures that their needs are consistently met [1].

In many transportation systems, an inadequate reserve fleet can lead to significant service disruptions, negatively affecting users and the company's financial viability [2]. Therefore, it is essential to have a robust methodology to accurately calculate the number of vehicles that should be available in technical reserve. This ensures service continuity and the optimization of available resources, minimizing vehicle downtime and improving operational efficiency. Doing so relieves the transport business units, knowing they have a reliable tool to prevent service disruptions.

The methodology proposed in this paper considers multiple critical factors, including preventive maintenance, which is based on mileage and manufacturer's recommendations; corrective maintenance, which addresses unexpected failures; and regulatory inspections, which are mandatory according to local regulations. In addition, a Markovian model is employed to model the transition probabilities between vehicle states (available and decommissioning) based on historical data. This stochastic approach allows for a more accurate prediction of future maintenance needs and proper planning of the standby fleet.

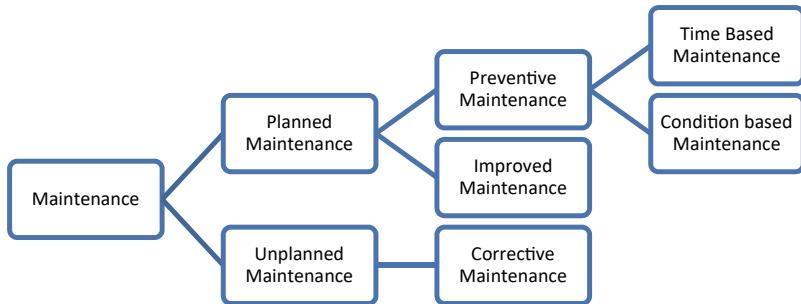
The document also includes a case study applied to five companies, illustrating how the methodology can be effectively implemented in a real-world context. The results demonstrate the model's feasibility and ability to improve fleet management, ensuring optimal vehicle operability and availability.

## 1.1 Maintenance

According to the Organization for Economic Cooperation and Development, maintenance is “the set of technical, administrative and management actions during the lifetime of an element, to preserve it or return it to a state in which it performs its function efficiently” [3].

The main objective of maintenance is always to achieve the availability of the equipment, system, or components, preserve and prolong the useful life of all the assets of the organization, and increase the safety involved in the operation of the equipment, whether operators or technicians, cost control, environmental responsibility, management of all the resources available and necessary for the operation of the equipment, to mention the most relevant ones [4].

In the universe of events that can affect the operation of the machinery, there are two significant items: the events that occur in the equipment but do not put in critical condition the operation and those that put a total stop to the operation of the machinery: this is where the segmentation of maintenance tasks begins and determines each action to follow to establish the necessary path according to the needs of each company.



**Fig. 1** Composition of maintenance types [5]

For these cases, at least three types of maintenance have been raised that are universally handled in all industries [5], and at least they are the minimum that the maintenance department should have as a classification: preventive maintenance, corrective maintenance, and predictive maintenance.

There are different levels of maintenance (Fig. 1. Composition of maintenance types). However, in this document, only these three are considered, given the research objective to determine the fleet needed based on operational needs, the behavior of failure events, the recurrence of preventive maintenance, and compliance with the regulations estimated for each region or locality. Having said the above, where only three types of maintenance are considered, the following definitions are proposed.

Corrective maintenance can be defined as the activity required to be performed on equipment, systems, or components when they no longer perform the function for which they were manufactured, i.e., when some type of failure has occurred. Some authors consider this type of maintenance to have advantages since it does not require previous intervention or attention that anticipates any failure.

Typically, this maintenance is focused on failure that may or may not put the equipment in a critical state, and this is addressed once there are some noticeable symptoms in the machinery [4]. This type of maintenance remained in force during the Industrial Revolution until the First World War. The machinery that existed in those years did not require discipline in maintenance; it was enough to replace the components that failed or required a minor intervention such as lubrication and equipment cleaning.

Failure can have different levels of impact, including critical failure and programmable failure. In a critical failure, the equipment is inoperable for some time because some central component is affected, which disables the natural operation [3], and it is necessary to intervene to put the machinery back into operation immediately. The attention of these events in the priority list becomes the first in the list of maintenance execution; the main reason why this happens is that the service or production has been compromised, and consequently, the possible affectation to the operation chains, supplies, deliveries, and income of the organization.

Basing maintenance on this type of activity has high risks; it puts the machinery at constant critical stops, affecting the production of goods or services and, most probably, affecting the component's useful life. The fact that equipment is constantly undergoing corrective repairs can incur cost overruns at various levels. Examples of the extra costs or losses that can be incurred by corrective maintenance include shutting down equipment during repair hours, investment in additional hours on technical equipment, delay in other maintenance activities, loss of functional life of equipment, asset write-offs due to poor profitability and efficiency, unbudgeted investments for unplanned overhauls, and perhaps most seriously, removing equipment for replacement without recovering the cost of the equipment [2].

Some industries adopt corrective maintenance as part of this department's programs, with the premise of being prepared to withstand the impact that machine downtime will have. This method will be applied according to each organization's operational needs. It is recommended that the result of this method be continuously measured to validate that the impact is irrelevant and that the organization can withstand it.

In the case of non-critical events in corrective maintenance, those reported by operators or equipment indicators do not put the machinery in functional shutdown and can continue to operate until they are attended to [2]. Usually, these events are programmed according to the level of priority that maintenance establishes and according to the protocols of each organization, which is a general tendency for those reports that threaten the safety of users and then the equipment in order of priority. Finally, these reports are attended to progressively without knowing if the equipment will withstand the stress until the failure is attended to. Programming tools help them pay attention to the activities.

When referring to preventive maintenance, we usually consider attending to the equipment before it fails; this is correct at a certain level since different variables are involved that make this type of maintenance go beyond this activity.

Maintenance can be defined as "the planned, constant, regular and projected supervision, as well as the distribution of tasks foreseen as unavoidable, carried out in all installations, machines or equipment, to reduce emergency cases and allow a longer time of continuous operation." [2, 3].

In most cases, preventive maintenance is based on the equipment manufacturer's recommendations and is known as preventive maintenance letters. The main activities are lubrication, component replacements, overhauls, inspections, adjustments, calibration, validation, and cleaning. These activities do not evaluate the condition of the component; they are focused on performing the replacement.

These replacements are calculated by the expiration date that the manufacturer has already measured with different techniques that establish the life span of each element and that aim to avoid failures that lead the equipment to corrective maintenance. However, it is always advisable to maintain constant observation and measurements of the components involved in these tasks [5]; this will give certainty about the performance of the equipment and level of functionality. The objective of constantly supervising these replacements is to find efficiencies in the equipment and, if applicable, adjust preventive maintenance activities.

At least three variables must be known in different measures and dimensions that allow estimates to perform preventive maintenance, such as when the preventive activity must be performed, depending on the machinery, distances, or time that can be used [2]. It is necessary to know the intervals of each set of preventive activities to calculate the preventive maintenance, the last preventive maintenance for each set of preventive activities, and the updated record of the time and distance the equipment has been working. With the interaction of these three variables, the recurrences that the equipment will need to be intervened throughout its operational life are planned.

For preventive maintenance to be highly effective, it is necessary to discuss maintenance planning. This tool helps optimize the maintenance department's general processes and is vital for preventive activity. In the planning, everything is focused on the plan of activities that the equipment will require over the years.

The main function of preventive maintenance is to conserve the useful life of equipment and, in the best cases, to lengthen its life. Preventive maintenance can be improved over time, which is possible through experience with the machinery since the conditions of the environment can significantly affect the performance of the equipment. It has been demonstrated that machinery, even when manufactured with manufacturing standards so that it can operate in certain areas, there are conditions that affect the operation of the equipment and generate experiences in the company and the manufacturers of the equipment [2]. That said, maintenance charts are nurtured over time and are modified by learning; activities can be added, and activities are hardly removed or even adjusted in the intervals of execution of maintenance.

## 1.2 *Fleet Management*

The efficient management of bus fleets has been a constant challenge for public transportation companies since the emergence of mass transit systems. Over the years, various strategies and practices have been developed to optimize vehicle maintenance and operability. Traditionally, fleet management has been based on reactive maintenance programs, where interventions were performed after mechanical failures or problems occurred [1].

With the advancement of technology and the increasing complexity of transportation systems, the need for more proactive and predictive approaches has become evident. In this context, preventive maintenance has emerged as a crucial practice to extend vehicle life, improve safety, and reduce operating costs. This type of maintenance is based on scheduled interventions according to mileage intervals, working hours, and manufacturers' recommendations.

The lack of an adequate reserve fleet can lead to significant service disruptions, affecting customer satisfaction and the company's financial viability. The reserve fleet must ensure vehicles are always available to meet operational needs and manage unforeseen contingencies.

In recent years, predictive models have expanded in various industries, including transportation fleet management [6, 7]. These models make it possible to predict maintenance needs and optimize standby fleet planning more accurately. However, despite the advances, challenges, and areas for improvement, research and development are still required, in addition to the existence of reliable databases for analysis.

## 2 Literature Review

Numerous research studies have examined the management of bus fleets in public transportation systems. This literature review analyzes the primary studies and approaches that have contributed to the development of standby fleet optimization and vehicle maintenance methodologies [8].

Preventive maintenance has been widely studied as a crucial strategy for extending vehicle life and improving reliability. According to Kumar [9] preventive maintenance involves scheduled interventions based on mileage intervals and manufacturer recommendations. It highlights the importance of effective preventive maintenance planning to improve fleet availability and operability, promoting the benefits of performing interventions at optimal intervals, given the associated costs.

On the other hand, corrective maintenance addresses unexpected failures that preventive maintenance cannot foresee. Landowski et al. [10] highlight the importance of using predictive models to anticipate these failures and optimize corrective maintenance planning, using a semi-Markov decision process to model the bus operation-maintenance process.

Predictive models in fleet management have gained importance in recent years. Markovian models have been used to forecast future vehicle behavior from historical data. However, data quality and accuracy are crucial to the success of predictive models. According to Landowski et al. [10], obtaining accurate and reliable data is critical for developing models that can effectively predict maintenance needs and optimize fleet management. The use of advanced data analysis techniques and the integration of varied data sources can significantly improve the accuracy of models.

Recent studies have explored integrating emerging technologies such as the Internet of Things (IoT) and Big Data in fleet management. The article “Preventive Maintenance Scheduling of Multi-Component Systems with Interval Costs” by Muluken Assefa [11] discusses how IoT can provide real-time data on vehicle conditions, improving the accuracy of predictive models and enabling more efficient fleet management.

In this context, Markovian models have emerged as practical tools for modeling the transition probabilities between vehicle availability and failure states since they allow optimization of corrective maintenance based on historical data. According to Szubartowski [12], these models facilitate the estimation of transition probabilities between different operational states, which is fundamental in fleet planning in operation, standby, and maintenance management [8].

Multiple studies have highlighted the need to maintain an adequate reserve fleet. Laxmi and Laxmi [13] note that a reserve fleet is essential to ensure service continuity and manage contingencies. A lack of sufficient reserve can lead to service disruptions, negatively affecting users' and companies' financial viability.

### 3 Methodology

#### 3.1 Preventive Maintenance

Preventive maintenance consists of actions planned and executed regularly to prevent premature wear, deterioration, and possible breakdowns of vehicles [2, 7]. This type of maintenance is based on scheduled interventions that are carried out before significant failures or damage to the buses occur. By anticipating problems, preventive maintenance improves the safety and reliability of vehicles, prolongs their useful life, and reduces long-term operating costs.

Preventive maintenance actions include a variety of tasks, such as oil changes, checking and replacing filters, inspecting and adjusting brakes, checking suspension systems, inspecting tires, and checking electrical and electronic systems. Each task is designed to keep vehicle components in optimal operating condition and prevent failures that could cause service interruptions.

Preventive maintenance is scheduled based on kilometers traveled intervals (KmTI), engine working hours, or according to elapsed time, always following the vehicle manufacturer's specific recommendations. These recommendations are based on studies and tests carried out by the manufacturers to determine the optimum maintenance periods to ensure the performance and durability of their products.

In addition to mileage and manufacturer's recommendations, the frequency of preventive maintenance is determined by the index of odometer kilometers per bus per month (IOKB), which measures the average use of each vehicle. This index is calculated by dividing the kilometers traveled by the operating fleet (OF) during a month by the number of buses in operation. With this information, the average time between maintenance required for each vehicle can be estimated.

$$IOKB = \frac{\text{Total average kilometers per month}}{\text{Total operating fleet}}$$

To calculate the preventive maintenance frequency (PMFr), the recommended preventive maintenance mileage (KmTI) is divided by the odometer kilometers per bus per month (IOKB). This calculation provides days between maintenance required to ensure the vehicles remain in optimal operating condition.

$$PMFr = \frac{KmTI}{IOKB}$$

Implementing an effective preventive maintenance program requires detailed tracking and recording of the activities. This ensures that all interventions on the operating fleet are performed on time, so it is also necessary to calculate the monthly fleet under maintenance (MFM). This is calculated by dividing the total fleet assigned to the business unit (OF) by the frequency of preventive maintenance.

$$MFM = \frac{OF}{PMFr}$$

Considering that the average number of days for each month is 30 days, the daily fleet for preventive maintenance (DFPm) can be calculated as follows:

$$DFPm = \frac{MFM}{30}$$

### ***3.2 Inspections by Standard or Transportation Authority***

Periodic inspections are mandatory according to local regulations and transport authorities. In each city where our business units operate, there may be different obligations regarding periodic inspections, either by the transportation authority and regulatory body or local regulations. The fleet required by authority (FRA) is estimated by dividing the operating fleet by the number of days between inspections (DI).

$$FRA = \frac{OF}{DI}$$

Note: If the transport authority requires at least one annual inspection, the “DI” would take the value of 360.

### ***3.3 Corrective Maintenance***

Corrective maintenance addresses unexpected and mechanical failures that cannot be programmed. Therefore, based on historical data, Markovian models are proposed to predict and model the transition probabilities between states (available and unavailable) [11].

### 3.3.1 Markovian Model

*Algorithm.* The algorithm has four parts: data transformation, transition count, calculation of probabilities, and Initial distribution [12]. This distribution calculates the fleet.

**Data transformation:** Data are transformed to represent the states of the units in binary form, facilitating the analysis of transitions. At this stage, the data are transformed so that any value (indicative of being available) is replaced with NaN (indicating that it is available) is replaced by 0, and any value *no – NaN* (indicative of a disincorporation) is replaced with 1. This transformation allows the data to be represented as a series of binary states, facilitating analysis of the transitions between these states.

**Transition count:** The number of transitions between each pair of possible states for each vehicle (0–0, 0–1, 1–0, and 1–1) is counted for each vehicle. This is done by a loop that iterates over each row of the transformed data frame. At each iteration, the code compares the current state with the previous state and updates the corresponding transition counters. This process allows for determining how many times each possible transition between states occurs.

**Calculation of probabilities:** Transition probabilities are calculated by dividing the number of each transition type by the total number of transitions from the corresponding initial state. Transition probabilities are calculated by dividing the number of each transition type by the total number of transitions from the corresponding initial state. For example, the transition probability of 0 a 0 (00) is calculated as the number of transitions of 0 a 0 divided by the total number of transitions from 0 (the sum of transitions of 0–0 and 0–1). This calculation is performed for all possible transitions. (00, 01, 10, 11). If there are no transitions from a state (avoiding divisions by zero), the probability is set at 0.

$$P = \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$$

**Initial distribution:** The initial distribution of states is calculated by determining the proportion of days that each state occurred in the data set. This is achieved by counting the occurrences of 0 y 1 in the transformed data frame and dividing it by the total number of days. The initial distribution of states is calculated to understand the proportion of days that each state occurred in the data set.

$$\pi P = \pi$$

$$\pi = [\pi_0 \ \pi_1]$$

$$[\pi_0 \ \pi_1] \begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix} = [\pi_0 \ \pi_1]$$

$$\pi_0 P_{00} + \pi_1 P_{10} = \pi_0$$

$$\pi_0 P_{01} + \pi_1 P_{11} = \pi_1$$

$$\pi_0 + \pi_1 = 1$$

Once the transition probabilities and initial distribution are available, the Markovian model can predict the likelihood of being in a specific state, given the current state.

$$FCM = \pi_0 OF$$

*Code:* The code was developed in Python with the help of Google Colab.

### 3.4 Percentage of Technical Reserve (%RT)

With the above calculations, we estimate the minimum percentage of reserve fleet, or technical reserve (%RT), required to guarantee the availability of units necessary to meet the business unit's Operating Program.

$$\%RT = \frac{DFPm + FRA + FCM}{OF} * 100$$

## 4 Cases of Study

The methodology is illustrated through a case study involving five companies, demonstrating its effectiveness in bus fleet planning and management. Each company provided specific data that was analyzed to calculate the technical reserve fleet required to ensure operational efficiency. Some data and names will be omitted not to violate the secrecy of the companies involved in this exercise (Table 1).

The above data allows calculating the index of odometer kilometers per bus per month (IOKB). This index is crucial for determining the frequency of preventive maintenance required for each company (Table 2).

With the IOKB determined, we can now calculate each company's preventive maintenance frequency (PMFr) and monthly fleet under maintenance (MFM). These calculations are essential to maintain the buses regularly without disrupting service (Table 3).

After calculating the monthly fleet under maintenance, the daily fleet for preventive maintenance (DFPm) and the number of days between inspections (DIN) are

**Table 1** Companies and specifications

| Companies | Total fleet assigned | Total operating fleet (OF) | Total km per month (average) | Km recommended for preventive maintenance (KmTI) |
|-----------|----------------------|----------------------------|------------------------------|--------------------------------------------------|
| Company A | 42                   | 40                         | 196,000                      | 10,000                                           |
| Company B | 93                   | 90                         | 570,000                      | 20,000                                           |
| Company C | 33                   | 29                         | 175,000                      | 20,000                                           |
| Company D | 68                   | 65                         | 550,000                      | 30,000                                           |
| Company E | 89                   | 89                         | 516,000                      | 30,000                                           |

**Table 2** IOKB

| Companies | Total operating fleet (OF) | Total km per month (average) | Index of odometer kilometers per bus per month (IOKB) |
|-----------|----------------------------|------------------------------|-------------------------------------------------------|
| Company A | 40                         | 196,000                      | 4,900                                                 |
| Company B | 90                         | 570,000                      | 6,333                                                 |
| Company C | 29                         | 175,000                      | 6,034                                                 |
| Company D | 65                         | 550,000                      | 8,462                                                 |
| Company E | 89                         | 516,000                      | 5,798                                                 |

**Table 3** PMFr and MFM

| Companies | Total Km per month (average) | Index of odometer kilometers per bus per month (IOKB) | Preventive maintenance frequency (PMFr), | Monthly fleet under maintenance (MFM) |
|-----------|------------------------------|-------------------------------------------------------|------------------------------------------|---------------------------------------|
| Company A | 196,000                      | 4,900                                                 | 2.0                                      | 20                                    |
| Company B | 570,000                      | 6,333                                                 | 3.2                                      | 29                                    |
| Company C | 175,000                      | 6,034                                                 | 3.3                                      | 9                                     |
| Company D | 550,000                      | 8,462                                                 | 3.5                                      | 18                                    |
| Company E | 516,000                      | 5,798                                                 | 5.2                                      | 17                                    |

computed. This provides a clearer picture of the maintenance schedule and regulatory compliance requirements (Table 4).

Next, we incorporate corrective maintenance into our analysis. Using a Markovian model, we predict the likelihood of each vehicle requiring maintenance based on historical data, which informs the corrective maintenance needs.

One of the problems encountered for the application of the Markov model was the database, since it is not completely reliable to the extent of knowing which is the component that causes the failure. For this first exercise, we used only the criterion of whether the failure causes a disruption in the service (Table 5).

**Table 4** FBMp

| Companies | Total operating fleet (OF) | Monthly fleet under maintenance (MFM) | Daily fleet for preventive maintenance (DFPm) | Fleet required by authority (FRA) |
|-----------|----------------------------|---------------------------------------|-----------------------------------------------|-----------------------------------|
| Company A | 40                         | 20                                    | 0.65                                          | 0.11                              |
| Company B | 90                         | 29                                    | 0.95                                          | 0.25                              |
| Company C | 29                         | 9                                     | 0.29                                          | 0.08                              |
| Company D | 65                         | 18                                    | 0.61                                          | 0.18                              |
| Company E | 89                         | 17                                    | 0.57                                          | 0.25                              |

**Table 5** Markov

| Companies | Total operating fleet (OF) | Markov machine factor | Corrective maintenance (Markov machine) |
|-----------|----------------------------|-----------------------|-----------------------------------------|
| Company A | 40                         | 0.031                 | 1.24                                    |
| Company B | 90                         | 0.069                 | 6.21                                    |
| Company C | 29                         | 0.051                 | 1.48                                    |
| Company D | 65                         | 0.055                 | 3.58                                    |
| Company E | 89                         | 0.031                 | 2.76                                    |

Finally, the technical reserve fleet percentage (%RT) is calculated to determine the minimum reserve needed to ensure operational availability. This comprehensive approach considers preventive maintenance, inspections, and corrective maintenance (Tables 6 and 7).

**Table 6** %RT (technical reserve fleet)

| Companies | Total operating fleet (OF) | Daily fleet for preventive maintenance (DFPm) | Fleet required by authority (FRA) | Corrective maintenance (Markov machine) | %RT (Technical reserve fleet) |
|-----------|----------------------------|-----------------------------------------------|-----------------------------------|-----------------------------------------|-------------------------------|
| Company A | 40                         | 0.65                                          | 0.11                              | 1.24                                    | 5                             |
| Company B | 90                         | 0.95                                          | 0.25                              | 6.21                                    | 8                             |
| Company C | 29                         | 0.29                                          | 0.08                              | 1.48                                    | 6                             |
| Company D | 65                         | 0.61                                          | 0.18                              | 3.58                                    | 7                             |
| Company E | 89                         | 0.57                                          | 0.25                              | 2.76                                    | 4                             |

**Table 7** Technical reserve fleet

| Companies | Total fleet | %RT (Technical reserve fleet) | Technical reserve fleet |
|-----------|-------------|-------------------------------|-------------------------|
| Company A | 40          | 5                             | 2.0                     |
| Company B | 90          | 8                             | 7.0                     |
| Company C | 29          | 6                             | 2.0                     |
| Company D | 65          | 7                             | 4.0                     |
| Company E | 89          | 4                             | 4.0                     |

## 5 Results and Discussion

Applying our predictive analytics methodology across five bus companies has yielded significant insights into optimizing their reserve fleets. Each company presented unique operational characteristics, demonstrating the approach's flexibility and effectiveness.

The Markov model played a crucial role in predicting the corrective maintenance needs of each company. By analyzing historical data, the Markov model helps understand the transition probabilities between different states of vehicle availability. This stochastic approach allows for a more accurate prediction of future maintenance needs, thereby aiding in effectively planning the technical reserve fleet. This technical fleet does not consider the necessary fleet for maintenance; it only guarantees the operational functionality of each company's fleet.

For instance, in Company A, the Markov model identified a transition probability of 0.031 for corrective maintenance needs, resulting in an estimated 1.24 buses requiring maintenance at any given time. This predictive insight is invaluable for fleet managers, allowing them to allocate resources and minimize downtime proactively. Similarly, Company B, with a higher transition probability of 0.069, requires a more substantial corrective maintenance reserve of 6.21 buses.

The accuracy of the Markov model in predicting maintenance needs is contingent on the quality and granularity of historical data. In this work, it was only possible to use two states, available or unavailable, due to the lack of detail in the information. The model's effectiveness is demonstrated by its ability to forecast the likelihood of each bus transitioning between operational and non-operational states. This enables fleet managers to balance having enough buses available to meet operational demands and ensuring that those needing maintenance are adequately attended to without disrupting service. To increase the degree of reliability of the model, it is necessary to get to the root cause of each case for each bus.

The results from this case study highlight the importance of a tailored predictive maintenance approach for each company. The varying percentages of technical reserve fleets (%RT) across the companies underscore the necessity of adapting maintenance strategies to specific operational contexts. The use of predictive models, particularly the Markovian model, has proven effective in anticipating corrective maintenance needs enhancing fleet operations' reliability and efficiency.

By implementing this methodology, each company can optimize its reserve fleet, ensuring operational availability and efficiency. This approach not only improves service reliability. This study's comprehensive analysis and practical application provide a robust framework for other public transport entities seeking to enhance their fleet management practices, just by having a database that reports when a mechanical failure creates a disruption in the service. This could be taken to a component analysis if the database is built correctly, and with the integration of IoT, this analysis could go further down to tell us when, and why the component is failing in each bus.

The results allow the companies to have a better estimate of the amount of fleet that is required in reserve to ensure adequate maintenance and compliance with the schedule requested by the managing entities. This is because each company in the analysis has different brands of vehicles, different types, different ages, and even different maintenance schemes, since some of these companies have outsourced maintenance.

After the results shown above, the companies that provide service in the BRT system in Mexico City, decided to show the exercise to their management entity to display that the operational fleet should be more, so that the fleet can be given the maintenance it requires. The authorities responsible for planning and creating transportation systems must consider the responsibility they place on companies to adjust to minimum fleet sizes that could jeopardize the operability of the service.

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## References

1. Dantas RDJAGaMP (2018) A performability model for the BRT system. *Int J Data Min, Model Manag* 11(1):1–8
2. Marjanović AKGTPaĐŽ (2011) Applications of predictive maintenance techniques in industrial systems. *SerbN J Electr Eng* 8(3)
3. Ángel Medrano J, Leví González V, Miguel Díaz V (2017) Mantenimiento Técnicas y aplicaciones industriales, Grupo Editorial Patria
4. Mora A (2019) Mantenimiento. Planeación, ejecución y control (Primera ed.), Alfaomega
5. Medina R (2022) TiOF de mantenimiento en las unidades de medición de producción de pozos petroleros [Online]. Available: <https://www.redalyc.org/journal/6219/621972217002/html/#:~:text=Puede%20entonces%20conceptualiz%20arse%20al%20mantenimiento,da%C3%B1%C3%A9%C3%BC%C3%BC%C2%20en%20caso%20que%20haya>
6. Haramina MSDaDA (2013) An approach for reducing energy consumption in rail transport systems. In: Proceedings of the Institution of Mechanical Engineers, Part F: J Rail Rapid Transit 227(3):300–310
7. Kwaghori KLMOESATaIJA (2019) Derivation of a stochastic labour market model from a semi-markov model. In: Book of Proceedings: 6th International Conference on Mathematical Analysis and Optimization. Theory and Applications (ICAPTA 2019), Abuja

8. Narahari Y, Viswanadham N (1994) Transient analysis of manufacturing systems performance. *IEEE Trans Robot Autom*
9. Kumar APaU (2006) Effective preventive maintenance scheduling: a case study. *J Qual Maint Eng* 12(3)
10. Muślewski BŁaŁ (2017) Decision model of an operation and maintenance process of city buses. In: 58th ICMD 2017, Prague
11. Assefa M (2019) A Maintenance Model for Multi-Component Systems with Economic Dependence. University of Toronto, Dept. of Industrial Engineering
12. Szubartowski M (2013) Semi-markov model of the operation and maintenance process of city Buses. In: The Archives of Transport, Vols. XXV-XXVI
13. Laxmi K, Laxmi V (2019) Condition-based maintenance strategy for vehicles using hidden markov models. *J Mech Eng Res Dev* 42(2):102–114

# Microeconomic Determinants of Employment for Sustainability in Ecuador



Lizethe Méndez-Heras and Diego Linthon-Delgado

**Abstract** This research aims to measure the microeconomic determinants of adequate employment, underemployment, other unfulfilling employment forms, and unemployment in Ecuador after the COVID-19 pandemic breakout. A multinomial Probit model was estimated to test the impact of human capital components (scholarship and age) and discrimination factors (gender, race, and marital status) in the Ecuadorian labor market. The data comes from the National Survey on Employment, Unemployment, and Underemployment (ENEMDU). The results show that Ecuador's labor market had a substantial inequality among workers in 2022. Those inequalities were closely linked to inequalities of opportunities in access to education, in the treatment that people receive based on their gender, discrimination based on the color of their skin, and due to their marital status. These results are relevant for designing and evaluating public policies aimed at reducing inequality in the Ecuadorian labor market.

**Keywords** Employment · Unemployment · Multinomial probit model

## 1 Introduction

According to the INEC (National Institute for Statistics and Census) during the first quarter of 2023, 55.5% of employees above 15 years old work in unsuitable jobs, about 39.6% of suitable jobs, and 4.9% in unemployment. Underemployment in Ecuador has some serious repercussions on employees' working lives since it affects their earnings, productivity, working satisfaction, and security over working

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positions. Furthermore, underemployment is a social issue that impacts productivity in diverse sectors, along with life quality for Ecuadorians. Over the past years, underemployment has increased, and it affects the most vulnerable population.

This problem has strengthened ever since the COVID-19 pandemic breakout, which affected both the composition of the labor supply and the demand of the workforce [1]. On the one hand, the COVID-19 pandemic resulted in a drop over the demand and production of goods and services, resulting in a drop over suitable jobs and an increase of jobs with short shifts and low earnings. On the other hand, there was a significant drop over female workforce. These factors led to a change over the structure and the working conditions for employees in the Ecuadorian labor market. Moreover, due to underemployment mainly affecting the most vulnerable employees, resulting thereof in more inequality and less job opportunities among workers.

The problem of working conditions disparity in Ecuador has been looked through different perspectives and it is caused by diverse factors. According to Esteves [2], the drop of suitable jobs and the increase of informality, underemployment, and unemployment was due to the assemble of restrictive measures implemented during the pandemic, which dropped household consumption and the whole economy. In addition, the reduction over female workforce and an increase over discrimination are key factors in the Ecuadorian labor market, and these endorse discrimination among employees and impact the composition of the working conditions for employees.

In contrast, García and Cortez [3] identified, by using a logit model, that age and scholarship are key factors for female workforce between 1990 and 2011 in Ecuador. Additionally, they found significant differences over female workforce per region, proving that the problem of female labor enrollment is heterogeneous.

Castillo, Ortiz, and Encalada [4] found through a research on underemployment for Ecuador between 2009 and 2019 that the microeconomic determiners for underemployment are: being a migrant, family size, age, and sex.

When it comes to unemployment, Arellano and Ayaviri [5] analyzed the determiners of unemployment in Ecuador from a macroeconomic perspective and by using a Vector Error Correction Model (VECM) and through Granger's causality technique, they found that unemployment greatly depends on the Manufacturing GDP, the barter terms of trade index and the economic growth.

Carlosama and Moraales [6] used the data of the ENEMDU-2019 and a logit model to identify the determiners of underemployment in Ecuador, which are: being a man, no social security contributions, and living in a rural area.

The problems of inadequate employment and underemployment have been studied for several developing countries. For example, Pratomo [7] studied for Indonesia the demographic and economic factors that influence unemployment and its effect on well-being, measured by the individual's poverty status. He used a multinomial logit model that includes the categories: underemployed, part-time employee, and full-time employee, for the dependent variable. He found that underemployed workers are more likely to be in poverty due to their situation in the labor market. In addition, he found differences in the incidence of unemployment by gender and age. Their results indicate that men and younger people have more difficulty getting full-time

jobs than their counterparts. From the demand perspective, the author found that workers employed in the industry are less likely to be underemployed, and that wages and part-time occupation have a strong relationship.

Similarly, for Sri Lanka, Himali [8] applied different statistical techniques: Chi-square tests, logistic regression for binary data, and Cox regressions to investigate the determinants of unemployment and the duration of unemployment. According to their results, the place of residence, language barriers, and education are the main determinants of unemployment, while age, gender, and education are the factors most associated with the duration of unemployment. In sum, they found robust evidence of differences in the odds of being unemployed between groups of workers.

The determinants of the duration of unemployment were also studied by Tansel and Mehmet [9] for several developing countries. These authors used parametric and non-parametric techniques for cross-sectional data. They found that gender and age significantly influence the duration of unemployment, with women and the youngest spending the most time looking for a job.

From a macroeconomic perspective, Eita and Ashipala [10] studied, using the Engle and Granger procedure, the relationship between unemployment, inflation, wages, and production. They carried out this study for Namibia during the period 1971–2007. Among its main results are that unemployment responds positively to wages and negatively to production and investment. For this reason, they suggest making the labor market more flexible and promoting investment and aggregate demand in that country.

Although we can find research on employment and unemployment, just few of them tackle the problem from an integrative perspective, meaning, considering that the determinant factors for labor conditions might be connected.

Therefore, the aim for this research is to identify the microeconomic determiners for suitable jobs, underemployment, other unfulfilling employment and unemployment in Ecuador. This will broaden the perspectives on the problem of undermining working conditions in the country. Over the following section, we will present the methodology and the description of data, then the results, and finally our conclusions.

## 2 Methodology and Data Description

### 2.1 *Methodology*

In order to identify the microeconomic determiners dictating whether an individual is in a suitable job, underemployed, in other unfulfilling employment or unemployed, we estimated a multinomial probit model. These models are used when the dependent variable has multiple results and allows to calculate and compare the probability of occurrence between the categories of the dependent variable according to certain characteristics.

Multinomial probit models are an extension of the probit binary response models:

$$p_{ij} = Pr(y_i = j) = F_j(x_i, \varepsilon), j = 1, \dots, m, i = 1, \dots, N. \quad (1)$$

This means the dependent variable,  $y_i$ , for the  $i$  individual has  $m$  alternatives; we establish  $y_i = j$  if the result is the alternative  $j$ . On the other hand, these models estimate the probability of the results for individual  $i$  of the alternative  $j$ , depending on the explanatory variable [11].

The expression  $F_j$  in Eq. 1 refers to the distribution function which restricts the value of the estimated probabilities of the model to be between 0 and 1. For probit models,  $F_j$  it is the standard Normal Cumulative Distribution Function,  $\alpha(\cdot)$ .

On the other hand, due to the multinomial models' coefficients are not directly interpretable, we proceed, as usual, to calculate the marginal effects. The Marginal Effect (ME) measures the change over the probability of alternative  $j$  being the result of  $y_i$  as a change of the explanatory variable,  $x_i$ :

$$EM_{ijk} = \frac{\delta Pr(y_i = j)}{\delta x_{ik}} = \frac{\delta F_j(x_i, \varepsilon)}{\delta x_{ik}}. \quad (2)$$

For every explanatory variable there will be  $m$  marginal effects, which corresponds to the  $m$  possible alternatives of the variable  $y_i$ .

## 2.2 Description of the Empiric Model

The estimated multinomial probit model to identify the determinants of the conditions over employees' economic activities (suitable jobs, underemployment, unfulfilling employment or unemployment) is the following:

$$\begin{aligned} Pr(suitjob = m | X) = & \varepsilon (\beta_0 + \beta_1 primary + \beta_2 highschool + \beta_3 undergrad \\ & + \beta_4 highered + \beta_5 postgrad + \beta_6 25a34 + \beta_7 35a44 + \beta_8 45a54 \\ & + \beta_9 55a65 + \beta_{10} man + \beta_{11} married + \beta_{12} indigenous \\ & + \beta_{13} black + \beta_{14} montuvian + \beta_{15} white), \end{aligned} \quad (3)$$

where  $suitjob = 1$  the person has a suitable job, when it equals to 2 it is underemployed, when it equals 3 it has a unfulfilling employment and if it equals 4 it is unemployed;  $primary = 1$ , they have basic education, 0 they have a different education level;  $highschool = 1$ , they hold a high school diploma, 0 they have other education level;  $undergrad = 1$ , they have an undergraduate education, 0 they have a different education level;  $highered = 1$ , they hold a bachelor's degree, 0 they have a different education level;  $postgrad = 1$  they have a postgraduate education degree, 0 they have a different education level;  $25-34 = 1$  they are between 25 and 34

years old, 0 they belong to a different age group; 35–44 = 1 they are between 35 and 44 years old, 0 they belong to a different age group; 45–54 = 1 they are between 45 and 54 years old, 0 they belong to a different age group; 55–65 = 1 they are between 55 and 65 years old, 0 they belong to a different age group, men = 1 is a man, 0 is a woman; *married* = 1 is married or lives in free union, 0 has a different marital status; *indigenous* = 1 consider themselves indigenous, 0 consider themselves from a different ethnicity; *black* = 1 consider themselves black, 0 consider themselves from a different ethnicity; *montuvio* = 1 consider themselves Montuvian, 0 they consider themselves from a different ethnicity; *white* = 1 consider themselves white, 0 consider themselves from a different ethnicity.

It is essential to highlight that this model only focuses on the supply factors of employment, such as level of education, age, gender, ethnicity, and marital status. Future research could also consider the demand factors of employment, such as occupation and region.

### 2.3 Describing Data

We use the data from the National Survey on Employment, Unemployment and Underemployment (ENEMDU) by the National Institute for Statistics and Census (INEC) [12]. The sample corresponds to the annual data for 2022 and it was restricted to people living in an urban area, heads of households and they are between 18 and 65 years old. Table 1 shows descriptive statistics of the used variables in the model. STATA 17 software was used to manage the database along with the estimations of the previously established multinomial probit model.

The sample considers 61,076 individuals, heads of households with ages ranging between 18 and 65 years old and who live in the urban area. Data shows a high incidence over underemployment, since 41.9% of all employees are underemployed and/or in another unfulfilling employment, and only 3.5% is unemployed. We can also see how the percentage of underemployed men and in other unfulfilling employments drops accordingly to the participation in suitable jobs, suggesting that underemployment and other unfulfilling employments strike women harder than men.

It is also clear that young employees (18–24 years old) and those older ones (55–65 years old) raised for the underemployment categories. When it comes to scholarship, data from the sample suggest a plausible positive impact between scholarship and suitable jobs. Moreover, indigenous or black, self-identified employees experience an increase in their belonging to the underemployment category in comparison to other ethnicities.

Concerning unemployment, we can also see that it is higher for women than for men. Youngsters also double their numbers over unemployment compared to other age groups, who experience minor bumps or even drops over unemployment rates. We cannot see a notorious change over unemployment due to scholarship, except for postgraduate degrees, whose unemployment rate drops.

**Table 1** Descriptive statistics

|                  | All    | Suitable job | Underemployed | OUE*   | Unemployment |
|------------------|--------|--------------|---------------|--------|--------------|
| Man              | 65.7   | 76.7         | 63            | 59.1   | 59.8         |
| <i>Age</i>       |        |              |               |        |              |
| 18–24            | 3.1    | 2.2          | 3             | 3.8    | 6.1          |
| 25–34            | 15.4   | 17.8         | 15.4          | 13.9   | 19           |
| 35–44            | 25.1   | 29.5         | 26.6          | 21.7   | 24.3         |
| 45–54            | 27.8   | 29.6         | 30            | 27     | 26.1         |
| 55+              | 28.7   | 20.9         | 25            | 33.6   | 24.6         |
| <i>Education</i> |        |              |               |        |              |
| No education     | 1.1    | 0.3          | 1.5           | 2.2    | 1.2          |
| Primary          | 24.7   | 15.5         | 33.4          | 37.9   | 23.7         |
| High school      | 43.2   | 41.5         | 46.9          | 45.2   | 43.8         |
| Undergraduate    | 3.9    | 5.4          | 2.7           | 2.2    | 4.5          |
| Higher education | 22.7   | 29.9         | 14.2          | 11.6   | 23.8         |
| Postgraduate     | 4.4    | 7.4          | 1.3           | 0.8    | 2.9          |
| <i>Ethnicity</i> |        |              |               |        |              |
| Indigenous       | 3.2    | 2.3          | 3.9           | 5.6    | 2.9          |
| Black            | 4.6    | 3.3          | 5.7           | 5.6    | 8.3          |
| Montuvian        | 1.3    | 1            | 1.5           | 1.7    | 1.6          |
| Mixed-race       | 89.5   | 91.9         | 87.8          | 85.6   | 85.2         |
| White            | 1.5    | 1.5          | 1.2           | 1.5    | 2            |
| Married          | 59.7   | 69.2         | 54            | 53.2   | 48.4         |
| N                | 61,076 | 29,229       | 11,338        | 11,047 | 1,849        |
| %                | 100    | 54.7         | 21.2          | 20.7   | 3.5          |

Note Own elaboration using data from ENEMDU-2022

\*Other Unfulfilling Employment

On the other hand, black, self-identified employees show an upturn over unemployment, whereas the other ethnicities show a small drop in the same category.

Summarizing, underemployment has its biggest stake with employees with the following characteristics: young, single, woman with low education level, self-identified as indigenous or black. When it comes to unemployment, the prevailing characteristics for unemployed people are: young, black, single woman. Therefore, according to the database, there are differences in terms of gender, ethnicity, age, and scholarship which lead to preponderant conditions for underemployment (including unemployment). The Wald test of exogeneity was used to test endogenous variables, and the null hypothesis of no endogeneity was rejected in all models.

Table 2 shows the labor conditions by socioeconomic groups in Ecuador in 2022. First, a gender gap can be observed, since women have less participation in adequate employment and greater representation in underemployment, inadequate employment, and unemployment. Second, young people had less opportunities to be

**Table 2** Labor conditions by socioeconomic groups. Ecuador, 2022

| LC | Gender     |         | Age        |           |            |          |           |
|----|------------|---------|------------|-----------|------------|----------|-----------|
|    | Male       | Female  | 18–24      | 25–34     | 35–44      | 45–54    | 55+       |
| AE | 60.28      | 41.83   | 41.89      | 58.88     | 59.55      | 55.77    | 46.63     |
| UE | 19.2       | 25.8    | 22.76      | 19.75     | 20.81      | 21.91    | 21.62     |
| IE | 17.55      | 27.79   | 27.97      | 17.38     | 16.54      | 19.21    | 28.3      |
| UN | 2.97       | 4.58    | 7.39       | 3.98      | 3.1        | 3.11     | 3.46      |
| LC | Education  |         |            |           |            |          |           |
|    | Illiteracy | Primary | Highschool | Undergrad | Highgraded | Postgrad |           |
| AE | 14.79      | 35.05   | 52.17      | 71.5      | 72.39      | 88.1     |           |
| UE | 32.68      | 29.24   | 22.87      | 13.69     | 13.33      | 6.13     |           |
| IE | 48.05      | 32.33   | 21.48      | 11.02     | 10.64      | 3.56     |           |
| UN | 4.47       | 3.38    | 3.48       | 3.79      | 3.64       | 2.21     |           |
| LC | Ethnicity  |         |            |           |            | MS       |           |
|    | Indigenous | Black   | Montuvian  | Mestizo   | White      | Married  | Unmarried |
| AE | 37.82      | 40.77   | 43.01      | 56.14     | 55.6       | 61.09    | 44.22     |
| UN | 24.64      | 26.94   | 24.85      | 20.8      | 17.84      | 18.48    | 25.65     |
| IE | 34.59      | 25.81   | 27.83      | 19.77     | 21.74      | 17.73    | 25.44     |
| UN | 2.95       | 6.47    | 4.32       | 3.29      | 4.82       | 2.7      | 4.7       |

Own elaboration using data from ENEMDU-2022

LC Labor Condition AE Adequately employed; UE Underemployed;

IE Inadequately employed; UN Unemployed. MS Marital Status

adequately employed, while the oldest people had more inadequate jobs. Third, more educated people had higher opportunities to be adequately employed. Fourth, white and mestizos people had better jobs than indigenous and black ones. And, married people had also more adequately employed and less underemployed and unemployed than unmarried persons.

### 3 Results

Table 3 shows the results for the marginal effects of the estimated multinomial probit model. These results were calculated using STATA 17 software.

Results show that education has a significant and positive impact over the probability of securing a suitable job. Concerning employees with no school background, employees with primary education have 17% higher probability of securing a suitable job, employees with high school education have 31% more probabilities of having a suitable job, employees holding undergraduate studies have up to 49% more probability, higher educated employees raise up to 51% probability, and finally postgraduate employees hold up to 72% more probability.

**Table 3** Determinants of working conditions. Ecuador, 2022

| Variables        | Suitable job | Underemployment | OUE*         | Unemployment |
|------------------|--------------|-----------------|--------------|--------------|
| Primary          | 0.1706085**  | -0.0629996**    | -0.0899368** | -0.0176714*  |
| High school      | 0.3119675**  | -0.124022**     | -0.1675484** | -0.0203962** |
| Undergraduate    | 0.4906962**  | -0.2094776**    | -0.2668625** | -0.0143549   |
| Higher education | 0.517196**   | -0.2162099**    | -0.2849715** | -0.0160133*  |
| Postgraduate     | 0.7254441**  | -0.2981217**    | -0.4082644** | -0.0190562*  |
| 25–34            | 0.0993725**  | -0.0056404      | -0.0718676** | -0.021864**  |
| 35–44            | 0.1253592**  | -0.0019244      | -0.0940489** | -0.0293852** |
| 45–54            | 0.1049696**  | -0.0000649      | -0.0747656** | -0.0301384** |
| 55–65            | 0.0288616*   | -0.0053048      | 0.0021987    | -0.025755**  |
| Man              | 0.1216923**  | -0.0320911**    | -0.0834209** | -0.0061798** |
| Indigenous       | -0.0829693** | 0.0071918       | 0.0786**     | -0.0028226   |
| Montuvian        | -0.0537078** | 0.0095776       | 0.0334638*   | 0.0106661    |
| Black            | -0.0944075** | 0.0357539**     | 0.035081**   | 0.023572**   |
| White            | -0.0289875   | -0.0156845      | 0.0311482*   | 0.0135235*   |
| Married          | 0.094154**   | -0.0543422**    | -0.0250713** | -0.0147401** |

Own elaboration using data from ENEMDU-2022. \*Other unfulfilling employment

\* and \*\* indicate statistical significance at 5 and 1%

Concerning age, we can see that youngsters between 18 and 34 have less probability of finding a suitable job when compared to the other age groups, although the gap is smaller with people between 55 and 65 years old. We can also see that men have 12% more probability of securing a job than women, and that black and indigenous people show the lowest probability at 9 and 8%, respectively, to secure a suitable job when compared to mixed-race employees.

About underemployment and other unfulfilling employment, we found that people with higher education have less probability of belonging to any of these categories, but the increase in scholarship drops significantly the probability of being in another unfulfilling employment in opposition to being unemployed; for instance, employees with higher education have 21% less probability of being underemployed and 28% less probability of being in a unfulfilling employment, compared to employees with no school background.

When it comes to underemployment and age, marginal effects show that statistically speaking, age is not a significant variable for people being underemployed; however, it does impact negatively over the probability of being in a unfulfilling employment; in other words, young employees are the most likely to be in other unfulfilling employments.

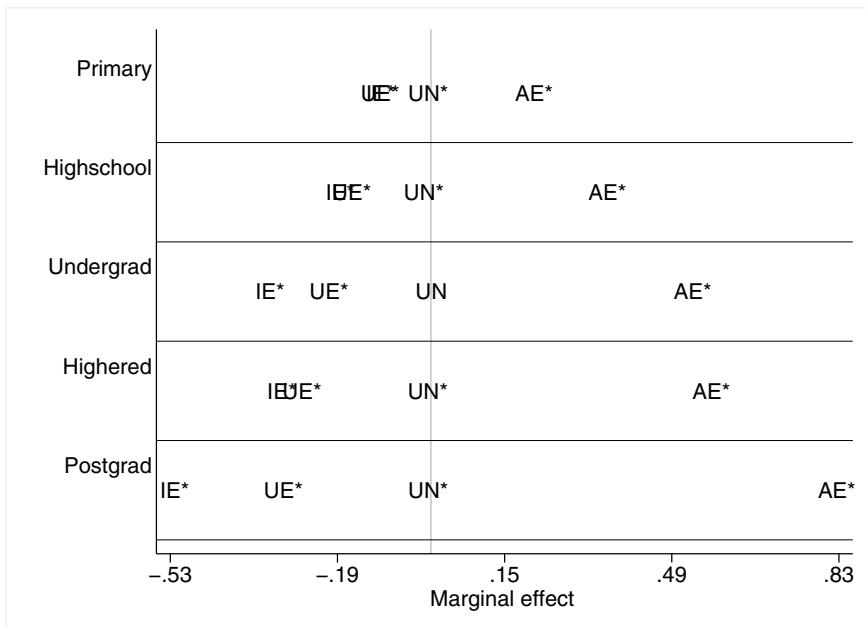
Women have between 3 and 5% more probabilities of being underemployed and in unfulfilling employments when compared to men. We can also see differences based in ethnicity; black employees are those with an statistically relevant probability of

3% of being underemployed in contrast with mixed-race employees, while indigenous people have a 7% higher probability of being in other unfulfilling employment compared to mixed-race employees.

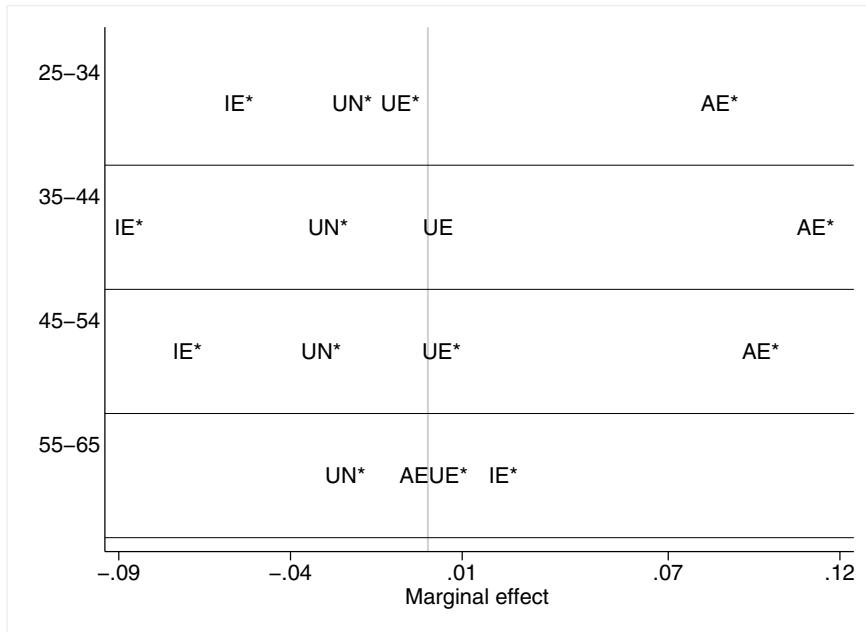
Finally, when it comes to unemployment, higher education minimally reduces the probability of being unemployed; for example, employees with higher education have 1% less probability of being unemployed compared to employees with no education background. Once more, youngsters have an average higher probability of 2% of being unemployed compared to other age groups. Self-identified black employees have 2% more probability of being unemployed in contrast with mixed-race employees. We did not find any statistically significant evidence over unemployment probabilities for indigenous people, montuvians, and mixed-race.

Therefore, education and age are the main determinants of the labor condition of workers in Ecuador. Figures 1 and 2 show the marginal effects of education and age on the probability of being adequately employed, underemployed, inadequately employed, or unemployed.

Figure 1 shows the marginal effects on the labor conditions of workers according to their level of education. It is clearly observed that schooling has a positive and increasing impact on the probability of being in suitable jobs, and a negative and growing impact of being in inadequate or underemployed jobs, although to a greater



**Fig. 1** Education and labor market conditions, Ecuador, 2022. Own Elaboration using data from ENEMDU. AE: Adequately employed; UE: Underemployed IE: Inadequately employed; UN: Unemployed



**Fig. 2** Age groups and labor market conditions, Ecuador, 2022. Own Elaboration using data from ENEMDU-2022. AE: Adequately employed; UE: Underemployed IE: Inadequately employed; UN: Unemployed

extent for the first case (IE). An interesting result is that the probability of being unemployed does not depend on the level of education. Therefore, workers with low education, partly due to their lack of human capital, are the ones who face the greatest difficulties in finding suitable jobs.

Figure 2 shows the marginal effects on labor conditions of workers according to their age. The figure shows that the youngest workers, 18–24 years old, who conform the base group, are the ones with the lowest probability of getting a suitable job, followed by people between the ages of 55 and 65. This result is expected, and shows that the lack of work experience and the outdated knowledge of workers between the ages of 18–24 and 55–65, respectively, constitute barriers to obtaining a suitable job. This pattern is replicated for the other labor conditions but in the other way, that is, the youngest are more likely to be unemployed or in inappropriate jobs.

To sum up, the results of the estimated marginal effects show that people with higher education, between 25 and 44 years old, men, mixed-race and married, are the ones with higher probabilities of being in suitable jobs. However, be a women and indigenous increase the probability to have an unfavorable position in the labor market.

## 4 Discussion

In this research, it was found that the positive determinants of adequate employment in Ecuador are the education and age of the worker. On the other hand, workers with low education and young people are the most affected by unemployment, underemployment, and other inadequate jobs. These microeconomic results are complementary to those found by Arellano and Ayaviri [5], who from a macroeconomic perspective found that unemployment is determined by the participation of the manufacturing sector in GDP, and ITI, capital accumulation, and economic growth.

The results of this research also coincide with those for Ruiz-Quintanilla and Claes [13], who applied a multinomial probit model to find the determinants of underemployment of young adults. They examined two groups (technology office workers and machinery operators) in six European countries (Belgium, England, Italy, Portugal, Spain, and the Netherlands). They found that underemployment is associated with educational level, occupation, work experience, and perceptions of the labor market that workers have.

Likewise, it was found that women are the most likely to be in underemployment and in other non-fulfilling jobs and unemployment. This finding is closely linked to the fact that female labor participation is subject to other factors such as age, marital status, and education [3].

In summary, this work contributes to the empirical literature by identifying the microeconomic factors that influence the labor condition of salaried workers in Ecuador. These results are relevant for the design and evaluation of public policies aimed at reducing inequality in the labor market.

## 5 Conclusions

The central objective of this research was to estimate the determinants of adequate employment, underemployment, other non-full employment and unemployment in Ecuador. Using a multinomial logit model with annual data from the ENEMDU, the factors with the greatest impact on the worker's working condition were identified.

Ecuador's labor market shows marked inequality among workers. The accumulation of schooling and experience favors the working condition of workers. Furthermore, women and indigenous people are in an unfavorable position in the labor market. Therefore, inequalities in the labor market are closely linked to inequalities of opportunities in access to education, in the treatment that people receive based on their gender, discrimination based on the color of their skin, and due to their marital status. To improve the working conditions of workers, it is imperative to address the inequalities present before entering the labor market.

The results of this research also align with the Sustainable Development Goals (SDGs) adopted by the United Nations [13], and highlight the necessity of applying political policies to reduce inequalities of gender, age, ethnicity, marriage status, and education.

## References

1. Leon R, Redroban C, Loaiza V, León P (2021) Analysis of the access to the financing of the ecuadorian companies in the framework of the sanitary emergency of COVID 19 and the economic sectors of unemployment. In: International conference on innovations in bio-inspired computing and applications. Springer, Heidelberg, pp. 713–722
2. Esteves A (2020) El Impacto Del COVID-19 En El Mercado De Trabajo De Ecuador. Mundos Plurales—Revista Latinoamericana De Políticas Y Acción Pública 7(2):35–41
3. García J, Cortez P (2012) Análisis de la participación laboral de la mujer en el mercado ecuatoriano. Analítek 4(2)
4. Castillo E, Ortiz C, Encalada J (2022) Labor informality in Ecuador: analyzing its determinants under a quantitative approach. Int J Bus Manag Technol 6
5. Arellano P, Ayaviri D (2021) Los Determinantes del Desempleo en el Ecuador. Perspectivas 48(5):9–36
6. Carlosana E, Morales C (2021) Determinantes del subempleo en Ecuador. Periodo. Revista Cuestiones Económicas. Edición Especial
7. Pratomo D (2015) The analysis of underemployment in Indonesia: determinants and its implication. Soc Behav Sci 211
8. Himali L (2020) Determinants of unemployment duration. Int Res J Adv Eng Sci 5:113–119
9. Tansel A, Mehmet H (2004) Determinants of Unemployment Duration for men and women in Turkey. IZA Discuss Pap Ser 1258
10. Eita J, Ashipala J (2010) Determinants of unemployment in Namibia. Int J Bus Manag 5(10)
11. Cameron A, Trivedi P (2010) Microeometrics using Stata. Stata Press College, Texas, USA
12. INEC (2022) Encuesta Nacional de Empleo, Desempleo y Subempleo. Instituto Nacional de Estadísticas y Censos, Quito, Ecuador
13. Ruiz-Quintanilla A, Claes R (2010) Determinants of underemployment of young adults: a multi-country study. Ind Labor Relat Rev 43(3)

# Effective Growth of the Money Supply and Inflation in Russia and the USA, Effects of Cryptocurrencies



Pavel Zhukov 

**Abstract** The concept of the effective growth of the money supply is introduced, on the basis of the quantity theory of money. That is M2 growth with correction for real GDP growth and changes in the velocity of money circulation. Theoretically, this indicator should be exactly equal to the GDP deflator, and the GDP deflator should be equal to inflation, however, in practice, these indicators differ. A panel study of annual indicators of the GDP deflator, inflation, and effective growth of the money supply is carried out on the example of Russia and the United States. It is shown that, despite the radical differences in the financial systems of Russia and the United States, as well as different inflation rates, the main causes of inflation are monetary. The possible impact on the financial stability of the use of cryptocurrencies is analyzed. It is shown that their use as exotic investment instruments with high risk is permissible, but subject to the control of regulators. Only the emergence of stable cryptocurrencies with the possibility of settlements is unacceptable, as this will create a direct threat to financial stability due to uncontrolled money supply growth.

**Keywords** Financial stability · Monetary policy · Money supply · GDP deflator · Inflation · Cryptocurrencies

## 1 Introduction—The Impact of an Increase in the Money Supply to GDP Deflator and Inflation

The causation between an increase in the money supply and inflation is obvious from the theory and has been repeatedly confirmed in practice [1–3]. Nevertheless, it is still a subject of debate. When considering data on money supply growth and inflation, this relationship is usually not obvious, since it depends on GDP growth and the velocity of money circulation, and also because consumer inflation (CPI) differs from the general depreciation of money, as measured by the GDP deflator.

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For this purpose, the concept of effective money supply growth is proposed, including correction of money supply for GDP growth and the velocity of money circulation which is proxy to the GDP deflator (but not the same in practice).

After the Great Depression, caused (or intensified) by excessively tight monetary and fiscal policies of the authorities [1], it became obvious that, in order to achieve financial stability, it is necessary to apply both fiscal methods of regulating the economy (J. Keynes) and monetary methods (M. Friedman and A. Schwartz) [1]. The main paradigm is that the monetary authorities should maintain a stable rate of growth in money supply, allowing neither too high inflation nor deflation [1, 2].

The average global inflation rate in 2014–2022 was 3.2% (see Table 3), and in developed countries and in China it was at the level of 2% (see Table 3). Based on the analysis of these data, it may be assumed that the optimal inflation rate is the level of 2–3%, which is typical for developed countries, as well as for developing countries with a stable financial system (except India and Brasilia, where inflation is 7–8%). At the same time, it should be noted that even in developed countries (the United States and the EU countries) there may be periods of inflationary shocks when inflation rises to a high level. In 2022, as a result of compensation payments after the COVID-19 pandemic, inflation in many countries experienced a jump, and in the United States and EU countries, it reached 8–10% (see Table 3).

Some researchers noted that if high inflation were stable, then economic entities could adapt to it and it would not have a destructive effect on the development of the economy. However, in the practice of such relatively prosperous countries with high inflation as Turkey and Argentina (not to mention Zimbabwe, Niger, Libya, Venezuela, etc.), it can be seen that high inflation usually cannot be stable. In these countries, inflation is subject to constant fluctuations, due to attempts by the financial authorities (from time to time) to reduce it (or to print more money), as well as due to high fluctuations of inflation expectations [3].

Since the 10-year average (2014–2024) level of 3.2% for the global inflation (see Table 3) is the median, a level exceeding it by 3 times (mean plus 2 standard deviations) can be considered high. Such inflation above 10% over 10 years (2014–2024) is typical only for a small number of countries with an unstable financial system. It can be assumed (from the historical data) that prolonged inflation at a level above 10% undermines the population's confidence in the national currency and contributes to “flight from inflation” [3] by investing in foreign assets, gold, real estate, and other assets that “hedge” inflation. Such an escape increases the velocity of money circulation, and hence the effective growth rate of the money supply, which accelerates inflation and contributes to its instability.

In a period of high inflation, there are many losers and some winners. Everyone pays an inflation “tax” equal to the depreciation of money, but at the same time producers of goods and trade enterprises enjoy additional (inflationary) profit. However, a decrease in the real value of current assets can make this gain negative, as everyone loses one way or another due to a decrease in incentives for economic development. For example, fixed-rate borrowers win, while fixed-rate lenders lose. But as a result, this leads to an increase in the loan rate, taking into account the expected inflation plus inflation risks. And since the inflation is uncertain, the loan

becomes more expensive for borrowers. Then banks are experiencing a shortage of resources and high risks. For long-term loans in conditions of high inflation, banks usually use either loans in stable currency, or a floating loan rate, transferring inflation risks to a borrower. Further, both banks and borrowers usually use futures, options, and swap agreements to hedge their interest rate risks. The problem is that the higher the risks, the more expensive hedging becomes. Hence, game of high inflation is not a zero-sum game, because the economy as a whole loses. Of course, there are winners, usually “smart” businessmen who use insider information for risky speculations. The classical identity of exchange [1, 2] leads to the concept of the effective money supply:

$$P = (M V) / Y \quad (1)$$

This identity makes it possible to explain changes in the GDP deflator ( $P$ ) by changes in the velocity of circulation of money ( $V$ ), the supply of money (money supply  $M$ ), and real GDP ( $Y$ ). If the supply of money ( $M$ ) is adjusted for changes in real GDP ( $Y$ ) and the velocity of circulation of money ( $V$ ), then the effective money supply  $M^*$  is obtained, on which the price level of  $P$  should directly depend.

Money supply  $M$  in (1) is the amount of money involved in calculations for the turnover of goods and services, the total volume of which is equal to GDP. The aggregate  $M_2$  is usually considered as this money supply in (1), see [4], and in particular, it is the choice of the US Federal Reserve [5]. This choice is not obvious and requires justification. First, the question arises whether quasi-monetary assets such as foreign currencies, gold, bonds, etc., should not be included in the money supply.

However, the inclusion of any “quasi-monetary” assets in the money supply of  $M$  in (1) can be justified if and only if these assets (e.g., foreign currency) are systematically and legally used to pay debts and liabilities for the supply of goods or services. Otherwise, they should be treated as commodities but not as money. The allocation of money as a special commodity in theory occurred in Say’s law, which replaced Walras’s identity. The quantity theory of money (1) is a development of the concept of Say’s law [1]. The main difference between monetary and “quasi-monetary” assets is their legal status—only monetary assets can be a universal tool for settlement and payment. Payments in foreign currency within the country are usually prohibited, as a rule, for reasons of taxation, but also on the basis of the protection of the financial system, the manageability of the money supply.

## 2 Growth of the Effective Money Supply and GDP Deflator in the Russian Federation

From the data in Table 1, one may see that there is no constant relationship between the growth of the money supply and the GDP deflator, even adjusted for GDP growth. But the growth of the effective money supply in Russia, as a rule, is very close to the GDP deflator (see Table 2 and Fig. 1). The exception is 2011 y., when the GDP deflator (15.9%) differs significantly from the growth of the effective money supply (24.3%). But at 2011 y. GDP deflator almost exactly coincides with the growth of M2, minus the growth of real GDP (16%).

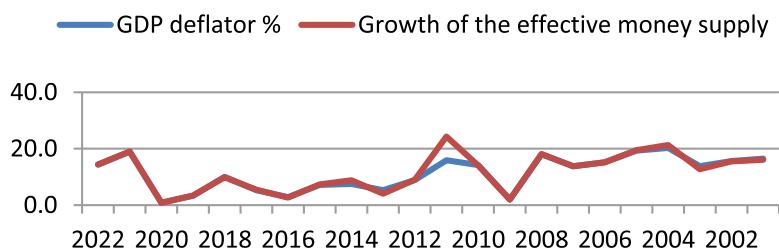
In Table 2 are shown the regression indicators of panel study for Russia (annual periods, correctness confirmed by the regression of residuals by external variables).

**Table 1** M2 growth, GDP, and M2-based effective money supply growth in Russia, compared to GDP deflator and inflation. Created by author on the official data by CBR and Rosstat

| Year | M2 growth (%) | GDP growth (%) | M2/GDP (%) | Effective Money Supply Growth (%) | GDP deflator (%) | Inflation (%) |
|------|---------------|----------------|------------|-----------------------------------|------------------|---------------|
| 2022 | 24,4          | -2,1           | 54,4       | 14,4                              | 14,3             | 11,9          |
| 2021 | 13,0          | 5,6            | 49,0       | 19,0                              | 19,0             | 8,4           |
| 2020 | 13,5          | -2,7           | 54,5       | 0,8                               | 0,9              | 4,9           |
| 2019 | 9,7           | 2,2            | 47,1       | 3,4                               | 3,3              | 3,1           |
| 2018 | 11,0          | 2,8            | 45,4       | 9,9                               | 10,0             | 4,3           |
| 2017 | 10,5          | 1,8            | 46,2       | 5,5                               | 5,3              | 2,5           |
| 2016 | 9,2           | 0,2            | 44,9       | 2,7                               | 2,8              | 5,4           |
| 2015 | 11,3          | -2,0           | 42,3       | 7,4                               | 7,2              | 12,9          |
| 2014 | 1,5           | 0,7            | 40,0       | 8,8                               | 7,5              | 11,4          |
| 2013 | 14,7          | 1,8            | 43,2       | 4,1                               | 5,3              | 6,5           |
| 2012 | 12,2          | 4,0            | 39,9       | 9,0                               | 8,9              | 6,6           |
| 2011 | 21,0          | 4,3            | 40,3       | 24,3                              | 15,9             | 6,1           |
| 2010 | 31,1          | 4,5            | 43,2       | 14,1                              | 14,2             | 8,8           |
| 2009 | 17,7          | -7,8           | 39,3       | 2,0                               | 2,0              | 8,8           |
| 2008 | 0,8           | 5,2            | 31,4       | 18,1                              | 18,0             | 13,3          |
| 2007 | 43,5          | 8,5            | 38,7       | 13,8                              | 13,8             | 11,9          |
| 2006 | 48,7          | 8,2            | 33,3       | 15,2                              | 15,2             | 9             |
| 2005 | 38,5          | 6,4            | 27,9       | 19,5                              | 19,3             | 10,9          |
| 2004 | 35,8          | 7,2            | 25,6       | 21,3                              | 20,3             | 11,7          |
| 2003 | 50,4          | 7,3            | 24,5       | 12,7                              | 13,8             | 12            |
| 2002 | 32,4          | 4,7            | 19,7       | 15,5                              | 15,6             | 15,1          |
| 2001 | 39,9          | 5,1            | 18,0       | 16,1                              | 16,5             | 18,6          |

**Table 2** Regressions data of annual GDP deflator indicators in 2001–2022 on various external variables (created by author)

| External variable                       | Indicator R <sup>2</sup> | Significance (probability of H <sub>0</sub> ) | Correlation coefficient |
|-----------------------------------------|--------------------------|-----------------------------------------------|-------------------------|
| Inflation                               | 0,5                      | 0,0001                                        | 0,7                     |
| M2 growth, adjusted for real GDP growth | 0,12                     | 0.115 insufficient                            | 0,34                    |
| M2 growth                               | 0,45                     | 0,0005                                        | 0,67                    |
| Growth of the effective money supply    | 0,93                     | 8,0E-13                                       | 0,96                    |

**Fig. 1** Growth of effective money supply and depreciation of money (GDP deflator) in 2001–2022 in Russia (created by author)

To illustrate proximity of the GDP deflator and the growth of the effective money supply, see Fig. 1.

### 3 The Relationship Between Inflation and Effective Money Supply Growth in the United States

On average, for the period 2000–2022, inflation in the United States was about 2.5%, and in the EU 2.2% per year, which is significantly lower than the world average (3.6%), but higher than in Germany (1.6%) and France (1.7%), see Table 3. In 2022, many countries showed peak inflation values due to extremely high levels of budget expenditures, due to compensation to businesses and individuals for losses due to pandemic control measures in COVID-19 [4]. In particular, in the United States, inflation in 2022 was 8% (the same as the global average). And, an average inflation 8.5% was in the Eurozone, while, in China, inflation stays at 2% (see Table 3).

As a result of comprehensive measures in the United States, the problem of a surge in inflation was resolved [6]. First of all, by raising the Fed rate to 4.5%. And there was a reduction in the money supply in 2022–\$0.723 trillion (−3.37%), after the adoption of the law to reduce inflation and even more significant in 2023–\$1.06 trillion (−5.13%). For fiscal 2020–2021 (01.10–30.09), the total increase in

**Table 3** Inflation in developed countries 2000–2022. Selected and created by author from the official WB statistics data Source NY.GDP.DEFL.KD.ZG last updated date 28.03.2024

| Year               | World | Euro area | US   | Germany | Canada | Switzerland | France | UK  | Italy | Spain | China |
|--------------------|-------|-----------|------|---------|--------|-------------|--------|-----|-------|-------|-------|
| 2000               | 3,4   | 2,9       | 3,4  | 1,4     | 2,7    | 1,6         | 1,7    | 1,2 | 2,5   | 3,4   | 0,3   |
| 2001               | 3,8   | 2,9       | 2,8  | 2,0     | 2,5    | 1,0         | 1,6    | 1,5 | 2,8   | 3,6   | 0,7   |
| 2002               | 2,9   | 2,3       | 1,6  | 1,4     | 2,3    | 0,6         | 1,9    | 1,5 | 2,5   | 3,1   | -0,7  |
| 2003               | 3,0   | 2,1       | 2,3  | 1,0     | 2,8    | 0,6         | 2,1    | 1,4 | 2,7   | 3,0   | 1,1   |
| 2004               | 3,5   | 2,2       | 2,7  | 1,7     | 1,9    | 0,8         | 2,1    | 1,4 | 2,2   | 3,0   | 3,8   |
| 2005               | 4,1   | 2,5       | 3,4  | 1,5     | 2,2    | 1,2         | 1,7    | 2,1 | 2,0   | 3,4   | 1,8   |
| 2006               | 4,3   | 2,7       | 3,2  | 1,6     | 2,0    | 1,1         | 1,7    | 2,5 | 2,1   | 3,5   | 1,6   |
| 2007               | 4,8   | 2,5       | 2,9  | 2,3     | 2,1    | 0,7         | 1,5    | 2,4 | 1,8   | 2,8   | 4,8   |
| 2008               | 8,9   | 4,1       | 3,8  | 2,6     | 2,4    | 2,4         | 2,8    | 3,5 | 3,3   | 4,1   | 5,9   |
| 2009               | 2,9   | 0,4       | -0,4 | 0,3     | 0,3    | -0,5        | 0,1    | 2,0 | 0,8   | -0,3  | -0,7  |
| 2010               | 3,3   | 1,5       | 1,6  | 1,1     | 1,8    | 0,7         | 1,5    | 2,5 | 1,5   | 1,8   | 3,2   |
| 2011               | 4,8   | 3,3       | 3,2  | 2,1     | 2,9    | 0,2         | 2,1    | 3,9 | 2,8   | 3,2   | 5,6   |
| 2012               | 3,7   | 2,5       | 2,1  | 2,0     | 1,5    | -0,7        | 2,0    | 2,6 | 3,0   | 2,4   | 2,6   |
| 2013               | 2,7   | 1,3       | 1,5  | 1,5     | 0,9    | -0,2        | 0,9    | 2,3 | 1,2   | 1,4   | 2,6   |
| 2014               | 2,4   | 0,2       | 1,6  | 0,9     | 1,9    | 0,0         | 0,5    | 1,5 | 0,2   | -0,2  | 1,9   |
| 2015               | 1,4   | -0,1      | 0,1  | 0,5     | 1,1    | -1,1        | 0,0    | 0,4 | 0,0   | -0,5  | 1,4   |
| 2016               | 1,6   | 0,2       | 1,3  | 0,5     | 1,4    | -0,4        | 0,2    | 1,0 | -0,1  | -0,2  | 2,0   |
| 2017               | 2,3   | 1,4       | 2,1  | 1,5     | 1,6    | 0,5         | 1,0    | 2,6 | 1,2   | 2,0   | 1,6   |
| 2018               | 2,5   | 1,7       | 2,4  | 1,7     | 2,3    | 0,9         | 1,9    | 2,3 | 1,1   | 1,7   | 2,1   |
| 2019               | 2,2   | 1,4       | 1,8  | 1,4     | 1,9    | 0,4         | 1,1    | 1,7 | 0,6   | 0,7   | 2,9   |
| 2020               | 1,9   | 0,2       | 1,2  | 0,1     | 0,7    | -0,7        | 0,5    | 1,0 | -0,1  | -0,3  | 2,4   |
| 2021               | 3,5   | 2,5       | 4,7  | 3,1     | 3,4    | 0,6         | 1,6    | 2,5 | 1,9   | 3,1   | 1,0   |
| 2022               | 8,0   | 8,5       | 8,0  | 6,9     | 6,8    | 2,8         | 5,2    | 7,9 | 8,2   | 8,4   | 2,0   |
| Aver.<br>2000–2022 | 3,6   | 2,1       | 2,5  | 1,7     | 2,2    | 0,5         | 1,6    | 2,2 | 1,9   | 2,3   | 2,2   |

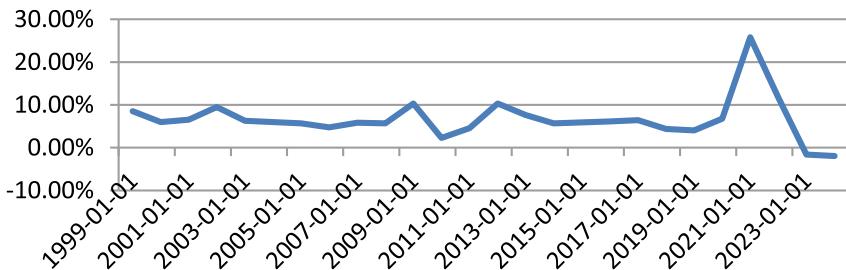
the money supply was \$6.5 trillion, and for 2022–2023, the reduction was – \$1.35 trillion. However, in 2020, M2 growth reached a record high of 25.8% (\$3970 billion), see Fig. 2, which was quite unusual and associated with a high budget deficit.

Further, in 2021, M2 growth was 11.7% (\$2257 billion). In total, in 2020–2021, the M2 money supply grew by \$6.23 trillion [6], which almost coincides with the US federal budget deficit of \$5.9 trillion for the two years of 2020–2021. (In 2020, it was \$3.13 trillion and, in 2021, it was \$2.78 trillion).

The study of the effective growth rate of the money supply  $M^*$  in the USA provided even better results than in Russia, particularly because of longer statistical rows—annual data for the money supply and velocity of money circulation is assessable since 1961 (at least). The statistical results are presented in Table 4.

As in Russia, it was found that the annual values of the GDP deflator and the effective money supply  $M^*$  growth have a high correlation with GDP deflator (see Table 4). However, unlike the Russia, for the United States there is a high correlation between the growth rate of the effective money supply  $M^*$  with CPI inflation on

## M2 growth % in the USA



**Fig. 2** US Money Supply Growth 1999–2023 (Plotted by author on the FRS data <https://fred.stlouisfed.org>)

**Table 4** Dependence of annual GDP deflator indicators in 1961–2022 on effective money supply  $M^*$  growth and inflation (created by author)

| External variable                   | Indicator $R^2$ | Number of observations | St. error | Significance of regression (probability of H0) | Correlation coefficient |
|-------------------------------------|-----------------|------------------------|-----------|------------------------------------------------|-------------------------|
| Effective money supply $M^*$ growth | 0,92            | 62                     | 0,06      | 3,5E-35                                        | 0,96                    |
| Inflation                           | 0,92            | 62                     | 0,8       | 1,95E-34                                       | 0,96                    |

annual intervals periods. So, the GDP deflator and inflation correlate well with the growth rate of the effective money supply  $M^*$  (in Russia, the correlation with inflation is somewhat worse, probably due to the peculiarities of its measurement). However, the GDP deflator is usually measured annually, but the growth rate of the effective money supply  $M^*$  in the United States can be measured at least quarterly (as far as the data for money velocity are available). So, that may become a good tool for forecasting GDP deflator and expected inflation by quarter data.

## 4 Discussion—The Admissibility and Possible Effect of Cryptocurrencies on the Inflation and Financial Stability

A stable international cryptocurrency issued by a reputable and representative international community of financial institutions may have some advantages, from a business and economic view, if it reduces transaction costs and inflation risks. It may be used worldwide and it may be protected from inflation by a certain “social contract” (for example, a fairly authoritative community of its issuers, representing a self-regulatory organization). Still, it could pose a serious threat to the ability of

central banks to control the money supply if used as a payment tool for settlements. And thus it could be a threat to financial stability.

Theoretically, Zuckerberg's attempt to create stable cryptocurrency on the basis of Facebook and a number of well-known financial companies could end up creating a powerful "stablecoin" (working title Libra). However, this attempt ended first with harsh rhetoric and criticism in the US Congress, and then with a warning from the US Treasury, the SEC, and the Federal Reserve System about the inadmissibility of creating private currencies as a competitor to the US dollar and other conventional (common, "fiat") currencies. After that, Visa, MasterCard, and other companies withdrew from the Libra project. In 2019, EU finance ministers decided to ban settlements in the EU in Libra or in any other stable cryptocurrency, including those pegged to the reserves of conventional currencies, gold, or other goods.

But at the same time, the central banks of the EU, the United States, and other countries, including China and Russia, have begun to develop their own digital currencies. In China, the digital Yuan project has already been launched, and settlements in Bitcoin and other digital currencies are prohibited, as well as "mining". But purchase and sell Bitcoin outside of China is allowed. It is obvious that the projects of central banks to create their own "digital currencies" are aimed, firstly, to limit the use of other cryptocurrencies, and possibly to limit the use cash settlements (in the Sweden this was declared explicitly). Both cash and cryptocurrencies allows anonymous payments. But use cash for deposit may involve control procedures that confirm the legality of their origin in accordance with the legislation against money laundering. So, perhaps the same procedures may be applied to cryptocurrencies at the time of converting into "fiat" money in bank.

The answer for the question of whether cryptocurrencies may pose a threat to financial stability depends, mainly, on whether they will add money supply (see paragraph 1). That is—whether cryptocurrencies will be used as money (for settlements) or as "quasi-monetary" investment assets (even if they are questionable and unstable). For example, M3 usually includes foreign currency (prohibited for domestic payment) and exchange-traded bonds, which are highly liquid commodities with a relatively stable price. With the same reason, the following "quasi-monetary" assets can be considered: listed shares, bonds, some of exchange commodities (contracts, derivatives, etc.). For the same logic, any obligations to pay money—receivables, bills, etc., (any of "financial contracts") can be considered as the next following "quasi-monetary aggregates." Ultimately, cryptocurrency can also be seen as a "quasi-monetary" aggregate of some sort M4 + + + (even if questionable one).

If a cryptocurrency is not involved in the legal trade settlements, then it will not add money supply (e.g., in the Swiss canton Zug cryptocurrencies have legal status equal to foreign currency). So, the main "red line" in relation to cryptocurrencies is a ban on use for trade settlements—this is what distinguishes the special commodity "money" from other commodities first in the Say's theory and later in the quantity theory of money (by I. Fisher). And that is particularly what distinguishes domestic cash from foreign currency, bonds, gold contracts, and other "quasi-monetary" assets.

Thus, the ban on a use of cryptocurrencies in payments for the supply of goods (services) and other types of trade settlements (payments) is a necessary and sufficient

condition for the financial safety, as cryptocurrencies will not increase the money supply, and therefore not threaten the financial stability.

Thus, as long as cryptocurrencies remain a risky and exotic investment vehicle, they cannot harm financial stability on a national scale, although some of them may hurt investors. Theoretically, any cryptocurrency has properties of a classical “bubble”, since these “digital assets” do not bring any income and therefore the price is completely based on the expectations of investors.

However, if some customer need (request) is satisfied, then the asset has a user value and therefore there is no reason to consider it as a “bubble”. For example, the same argument can be made to a value of masterpiece, works of art, and even shares of certain funds, the prices of which are based on “alternative investments.” The value of these assets also is sometimes (or maybe typically) artificially inflated. There are various options for Bitcoin’s growth forecasts, but two statements seem to be the most likely. The first is that Bitcoin will rise in peaks (probably providing the return above the market due to high risk). Secondly, this growth usually (surely) will be accompanied by sharp falls. For example, the capitalization of Bitcoin was \$1.16 trillion at 10/01/2021, then fell to \$317 billion at 11/16/2022 and jumped again to \$1.36 trillion at 07.03.2024. At the same date, the total capitalization of cryptocurrencies amounted to \$2.42 trillion, so Bitcoin makes up more than 50% of this market. Nevertheless, it is known that some of cryptocurrencies may turn into Ponzi financing (“financial pyramid”), especially if they are created for this purpose. Thus, there is still a need to regulate cryptocurrencies as investment instruments for the interests of investors.

## 5 Conclusion

In paragraph 1, it is stated that the money supply is most adequately reflected by the aggregate M2, which is conventionally used for this purpose. In theory, it is believed that three players are involved in the creation of the M2 money supply—depositors, banks, and the central bank of country (or EU), but it is obvious that the central bank plays the main role. As shown in paragraphs 2 and 3, the depreciation of money in Russia and in the United States is well explained by the quantity theory of money, using the concept of growth of the effective money supply. There is no doubt that this is a general pattern and the reasons for high long-term inflation should always be sought in the excessive growth of the effective money supply, that is, in the growth of the money supply, which exceeds the growth of GDP minus the average inflation and changes in the velocity of money. The separate issue is—how nonmonetary factors of inflation may be reflected in this model. The obvious answer is—in the short-term changes in the velocity of money circulation. However, this question may deserve a special research, as well as the question of optimal level of inflation.

In the US in the medium term (5–10 years), inflation risks seem to be well managed by the Fed. Concerns exist in the long term (10–15 years) due to the rapid growth of public debt. If the US monetary authorities fail to reverse the trend of rapid growth

of public debt, its financing may require significant Fed bond purchases [6], which will inevitably lead to higher inflation. And there are always risks of external shocks (similar to COVID-19). To avoid this, the US will ultimately have to make politically difficult and unpopular decisions to cut spending and increase taxes.

In Russia, in 2022–2023, there was an unusual, extraordinary acceleration in the growth rate of the money supply—an average of 23.8% per year, which is more than 2 times higher than the average of 2014–2021. The growth rate of the money supply is unstable and much higher than the growth of GDP. This creates high inflation risks, which may materialize in the short term (3–5 years) if this policy is not adjusted.

For cryptocurrencies—the ban on use in payments for the supply of goods (services) and other types of settlements is a necessary and sufficient condition for not to increase the money supply, and therefore not to threaten the financial stability of states and the global financial system. However, there is still a need to regulate cryptocurrencies as investment instruments for the interests of investors, and, in order to exclude the misuse of cryptocurrencies for money laundering.

## References

1. Sachs J, Larraín F (1993) Macroeconomics in the global economy. Prentice Hall, New York
2. Mishkin FS (2010) The Economics of Money. Banking and Financial Market. Columbia University Press, New York
3. Hall R (1982) Inflation: causes and effects. University of Chicago Press, Chicago
4. Investopedia. <https://www.investopedia.com/terms/m/m2.asp#last> accessed 2024/06/22
5. Federal Reserve. [https://www.federalreserve.gov/news\\_events/speech/bernanke20061110a.htm](https://www.federalreserve.gov/news_events/speech/bernanke20061110a.htm), last accessed 2024/06/22
6. Cochrane JH (2023) The fiscal theory of the price level. Princeton University Press, Princeton

# AI Applications in the Business Model



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**Abstract** Integrating AI in energy businesses (EB) is essential for achieving the goals set by international energy and climate change agreements. Business models (BMs) play a pivotal role in this framework by facilitating the adoption of renewable energy technologies and promoting energy efficiency practices. AI's predictive capabilities, optimization techniques, and fault detection methods are instrumental in managing energy systems' safety, reliability, and stability. Furthermore, AI supports demand-side management and distributed energy optimization, enabling prosumers to participate actively in energy production and consumption. The rapid advancement of AI technologies is transforming the energy sector, providing innovative solutions for energy resource management and enhancing grid resilience. This article addresses the adoption of Artificial Intelligence (AI) in operating Energy Business Models (EBMs) in an economy driven by building a more sustainable future. The study aims to provide an overview of AI applications in BMEs. Under this logic, three sections were structured. The first section describes the development of EBMs, while the second section discusses AI applications. The following section discusses the possible impacts of using AI in BMEs. Finally, conclusions and references are presented.

**Keywords** Artificial intelligence · Business models · Energy business

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## 1 Introduction

The 2030 Agenda calls for reducing dependence on fossil fuels and using and developing sustainable renewable energy [1]. The electrification of passenger transport in urban areas is crucial to drive the transition towards more sustainable energy sources and reduce greenhouse gas emissions [2].

For example, IRENA (2009) is an intergovernmental organization that supports countries in their transition to a sustainable energy future and is a leading platform for international cooperation [3]. AI technologies offer significant potential for facilitating the transition to renewable energy sources in developing economies, where infrastructure and financial resources may be limited. These regions can improve energy efficiency and reliability by leveraging AI-driven predictive analytics and optimization techniques, making renewable energy more accessible and sustainable.

## 2 Development of Energy Business Models (EBMs)

Chen and Folly [4], Danish [5], and Višković et al. [6] have suggested several AI techniques employed in energy provider businesses to improve the performance of their systems and reduce operating costs. These techniques include data analytics, machine learning, energy resource optimization, energy price prediction, and intelligent infrastructure development.

To understand the relevance of sustainable business models in meeting international agreements that promote sustainable development and emission reductions, it is essential to consider the United Nations Sustainable Development Goals (SDGs), the Paris Agreement on Climate Change, the International Renewable Energy Agency (IRENA), and the Marrakech Agreement on Climate Change (see Table 1). These agreements set clear targets for expanding clean energy infrastructures, reducing emissions, and promoting renewable technologies. Which primarily focuses on reducing CO<sub>2</sub> emissions into the atmosphere and promoting the use of renewable sources in energy production.

Energy companies have faced this transition as the biggest challenge when seeking new forms of clean energy generation. This includes pursuing efficiency through innovation and preparing and adapting their systems, infrastructure, and professionals. Sustainable business models facilitate implementing these goals through decentralized and innovative solutions, fostering investment in energy projects and transferring knowledge and technologies.

Integrating artificial intelligence (AI) techniques and applications is fundamental in deploying key technologies to achieve net zero emissions and improve efficiency and effectiveness in various sectors. In the electrification of heating and transportation, AI optimizes smart grids for efficient electricity distribution, predicts energy consumption patterns, and schedules electric vehicle charging, ensuring a cost-effective and environmentally sustainable process. For carbon capture, utilization,

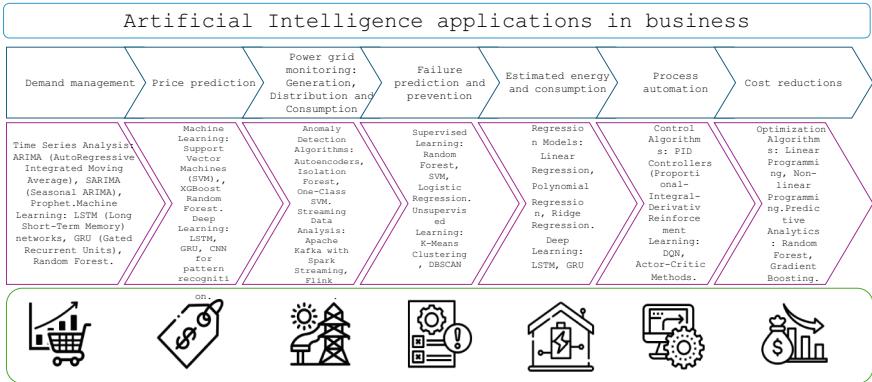
**Table 1** Role of BM in the framework of international agreements for sustainable development based on [7]

| Agreement                             | Description                                                                                                                                                                  | Role of business models                                                                                                                                                                                                                      |
|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sustainable development goals (SDGs)  | The UN adopted them in 2015. Include universal access to affordable and sustainable energy for all by 2030. Promote clean energy technologies and infrastructure development | These models can facilitate the expansion of energy infrastructure in areas with limited access through decentralized solutions and innovative technologies                                                                                  |
| Paris agreement on climate change     | The UN member countries adopted it in 2015. Establishes emission reductions and promotes renewable energy                                                                    | These models can address emissions reductions by adopting clean energy technologies, such as solar, wind, and other renewable sources                                                                                                        |
| International renewable energy agency | Created in 2009 to promote global public goods activities, such as energy security, energy efficiency, and renewable energies                                                | Energy BMs can encourage investment in energy projects and facilitate knowledge transfer and technologies                                                                                                                                    |
| Marrakech agreement on climate change | Agreement and promoting clean energy technologies and emission reductions                                                                                                    | Energy BMs can contribute to adopting clean energy technologies and reducing greenhouse gas emissions. In addition, they help support the planning and implementation of mitigation and adaptation measures in the context of climate change |

Note Own elaboration based on [8]

and storage, AI improves the efficiency of carbon dioxide capture and storage by predicting optimal conditions, monitoring storage sites with high precision, identifying suitable locations, and developing innovative utilization methods for carbon. In hydrogen and low-carbon hydrogen fuels, AI optimizes electrolysis processes for hydrogen production, improves storage and distribution networks by predicting demand, and refines production methods with advanced models. Additionally, AI contributes significantly to bioenergy utilization by optimizing the biomass supply chain, forecasting yields, scheduling harvests, and maximizing energy production while minimizing waste. Through these applications, AI increases the efficiency and scalability of these technologies and accelerates the transition to a sustainable energy future, underscoring its indispensable role in combating climate change and achieving net-zero emissions.

AI applications in Energy Business (EB) have been highlighted for their contribution to the development of solutions for complex problems in areas such as demand side management, power grid optimization, creation of intelligent energy resource infrastructures, the prediction of energy prices and the development of machine learning algorithms to improve the efficiency and security of energy systems [7]. According to Marinakis [9], Mohamad et al. [10], Salem et al. [11], and Lugofer and Sayed-Mouchaweh [12].



**Fig. 1** Applications of AI in business models, taken from Torres et al. [8]

Energy storage through distributed batteries can increase grid resilience and reliability due to aggregated stored energy that can be used during outages or peak demand hours, knowing that disturbances in the distribution system cause most outages [13]. Figure 1 shows the different applications of AI in energy production and distribution, improving operational efficiency, optimizing decision-making, reducing costs, and increasing safety.

Consequently, it is imperative to forge management and control tools that guarantee energy systems' safety, reliability, efficiency, and stability. In this context, AI techniques and resources contribute to predictive capabilities [10, 11], optimization, and fault detection. AI applications in demand-side management, in the context of the energy transition, address challenges related to energy efficiency through automated forecasting and control [14].

In the context of users with an active, productive position (called prosumers), an expansion in the capacity of the electrical network is triggered [15]. Thus, with a global increase in the rate of electrification and energy consumption, there is a need for a higher level of flexibility and coordination, which requires an increase in large database processing capacity, professional skills, collaboration, and monitoring in real-time in the generation, storage, distribution, and consumption of energy.

By generating energy on a small scale, consumers establish connections to more extensive distribution networks, which is achieved through various technological options, such as installing photovoltaic solar panels, implementing natural gas fuel generators, and adopting electric vehicles and charging management control [16]. AI applications will play a strategic role in the functioning of energy systems:

- The use of AI in the generation of renewable energy.
- The use of AI in controlling supply and demand management; and
- Recent advances in artificial intelligence technology in homes, networks, and renewable and non-renewable energy production.

Artificial Intelligence (AI) techniques and applications are pivotal in integrating and optimizing critical technologies to achieve net-zero emissions. AI enhances the

electrification of sectors such as heating and transportation by managing smart grids, predicting energy consumption patterns, and optimizing electric vehicle charging schedules. In carbon capture, utilization, and storage, AI improves the efficiency of carbon capture systems, predicts optimal storage conditions, and identifies the best locations for carbon sequestration. Furthermore, AI optimizes hydrogen production through electrolysis, enhances storage and distribution networks, and aids in developing low-carbon hydrogen-derived fuels. In bioenergy, AI forecasts biomass yields, optimizes harvesting schedules, and maximizes energy output while minimizing waste.

Companies are innovating their business models to improve competitiveness, market share, and structure in the electricity market. They focus on reconfiguring the energy matrix, enhancing the security and reliability of energy supply, and promoting decentralization and digitalization. Efforts also include efficient demand management, increased electricity coverage, and a review of institutional and regulatory frameworks. These efforts aim to develop an energy system that reduces greenhouse gas emissions and fosters economic growth and development through the opportunities presented by the Energy Transition. Additionally, companies are promoting knowledge and innovation to support the Energy Transition.

### 3 Potential Challenges and Limitations

Integrating AI into these technologies enhances efficiency and scalability and supports companies' innovative business models to stay competitive. By leveraging AI, these businesses can reconfigure their energy matrices, improve supply reliability, and promote decentralization and digitalization. This comprehensive approach ensures efficient demand management, more excellent electricity coverage, and alignment with regulatory frameworks. Ultimately, the combination of AI and innovative business strategies drives the development of a sustainable energy system that reduces emissions, stimulates economic growth, and advances the Energy Transition through continuous innovation and knowledge sharing.

With technological advances in the energy sector, utilities, power system operators, and independent power producers will implement AI applications to be competitive. The rapid pace of AI development, data analytics, and the emergence of new services and products in digital energy markets will be applied quickly and efficiently. Various AI techniques are used to establish business models for the energy sector. The most widely used models are Backward Propagation, Multilayer Perceptron (MLP), Whale Optimization Algorithm (WOA), Radial Network Function Neural Network (RBFN), Bayesian Regularization (BR), and the Damped Least Squares method.

Applying AI, such as using machine learning algorithms and creating simulation environments, improves energy efficiency [17]. The techniques also help energy providers enhance the performance of their systems and reduce operating costs.

Despite the promising benefits of AI adoption in EBMs, several challenges must be addressed. Regulatory barriers can impede the deployment of AI technologies,

necessitating the development of supportive policies and frameworks. Data privacy concerns are also paramount, as AI systems require access to vast amounts of data, raising questions about data security and ownership. Furthermore, technological readiness varies across regions, affecting the scalability and effectiveness of AI applications.

Table 2 [2] briefly describes AI applications for energy resource optimization, energy price prediction, and developing intelligent energy resource infrastructure and domestic applications in households. Artificial neural networks are applied to predict power flows in power grids and estimate line loads and magnitudes of bus voltages in distribution networks with a high percentage of distributed energy resources.

Accurate estimation of power flows is crucial to quickly and reliably identify critical load situations and energy losses, particularly in low-voltage networks. The objective is to improve real-time monitoring of power systems, particularly at low and medium voltage levels, for network planning and operation. The application of AI in the energy sector has become a priority due to the growing use of data

**Table 2** Algorithms of AI used in energy [2]

| Algorithm                             | Description                                                                                                                                         | Applications in the energy sector                                                                                             |
|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Backward propagation                  | A training method for neural networks in supervised learning adjusts the connection weights to minimize output and goal error                       | Electricity demand forecasting, power grid operation optimization, and time series analysis                                   |
| Multilayer perceptron (MLP)           | Type of artificial neural network composed of multiple layers of units, including hidden layers. It performs supervised learning by backpropagation | Solar and wind power generation forecasting, control of energy storage systems, and energy efficiency analysis                |
| Whale optimization algorithm (WOA)    | Inspired by whaling behavior. It applies exploration and exploitation techniques to optimize numerical and engineering problems                     | Optimization of the location and operation of generation plants, planning of power grids, and energy management in microgrids |
| Radial branch network function (RBFN) | A neural network with a hidden layer of radial neurons modeling a radial basis function. Used for approximation and classification                  | Classification of electrical load patterns, detection of network anomalies, and estimation of transmission losses             |
| Bayesian regularization (BR)          | An approach that combines Bayesian inference techniques with machine learning models to improve generalization and avoid overfitting                | Estimating uncertainty in generation and demand forecasts, optimization under uncertainty, and energy risk analysis           |
| Damped least squares method           | Addresses data fitting problems by minimizing the sum of squared residuals and a penalty to avoid oscillations                                      | Parameter estimation in generation models, adjustment of load models, and analysis of historical consumption data             |

Note Own elaboration based on [2]

analysis technologies and the development of increasingly advanced systems. Nazari and Musilek [18] have approached the application of AI from different perspectives, such as using machine learning algorithms, AI systems for data analysis, and creating energy industry simulation environments.

Danish [5] provides some examples of AI applications in the energy transition. For example, data sets on failures in critical components are generated to diagnose and prognosis failures in wind turbine systems based on wind turbine dynamics (the phenomenon of wind energy transformation into mechanical energy and then into electrical energy, the phenomena of energy conservation and dissipation).

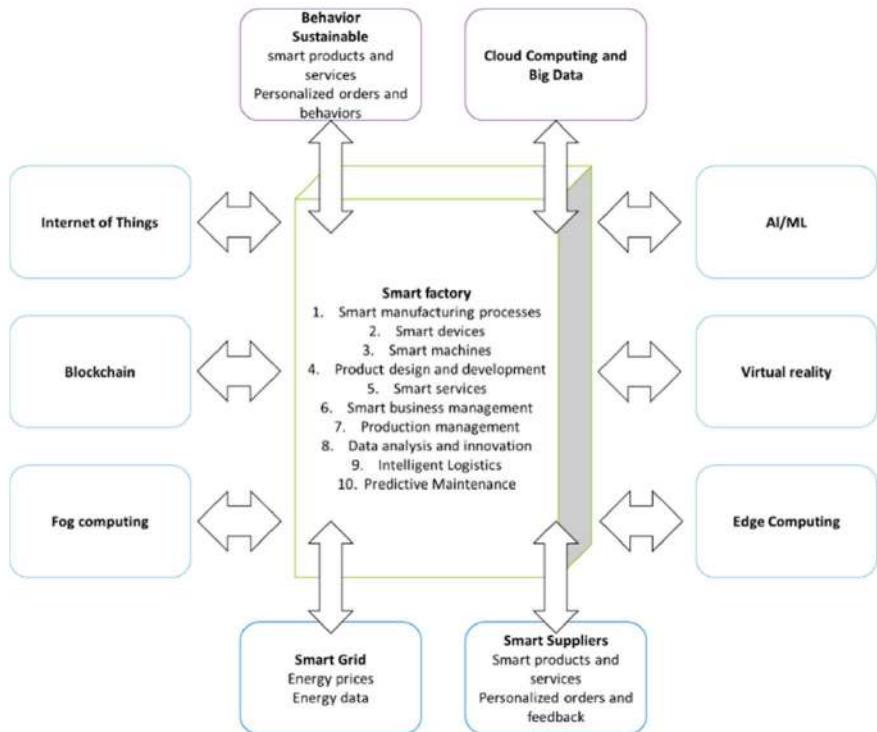
Machine learning techniques in detecting vulnerability to cyber-attacks on smart grids provide an overview of the primary attacks on the different components (generation, transmission, distribution, communication, consumption) of a smart grid in three categories: confidentiality attacks (gaining access to data belonging to others), integrity attacks (someone other than the legitimate device fraudulently claims to be that component) and availability attacks (generating too much traffic to overwhelm the target devices' ability to provide the services).

Neural networks are an AI technique that supports the fault diagnosis of conversion systems. They have broad applications, such as photovoltaic power pumps or desalination units. Failures in these systems can affect both their mechanical and electrical parts. Once the faults have been detected, isolation is performed to determine which component is malfunctioning.

## 4 Vision for the Development of EBMs

The smart factory is the deployment of AI in the energy sector, analyzed based on the scenario shown in Fig. 2. In the intelligent factory scenario, also known as Industry 4.0, digital technology makes connecting different energy sector components to the digital network possible. In terms of the security of innovative power systems, intelligent systems can increase the security of energy systems by detecting and preventing cyber-attacks, improving grid reliability, and reducing the risk of power outages. Researchers have also identified new AI techniques to improve power system security, such as threat detection and prevention, data anomaly detection, and system reliability analysis.

IoT-based smart grids with fog computing-assisted architecture facilitate the implementation of AI and blockchain to achieve demand-side management, generation forecasting, intelligent forecasting of network stability, and better security and Energy management. Machine learning (ML) is used to identify the active state of devices using two categories: event-based models and probabilistic models [2]. Another application is digital twins, which are used in smart grids and virtual power plants with Metaverse and IoT for energy analysis [2]. A digital twin is a digital reproduction of a tangible product or component created by combining simulations and service metadata. Using a digital twin provides constantly restructured data to forecast current and future situations in operational and design environments, thus



**Fig. 2** Smart factory, taken from Torres et al. [8]

improving decision-making [17]. These applications include smart home devices, home energy management systems, smart metering, and home energy generation units [6].

The reliability of results generated with AI depends on data in a specific format for large-scale training and testing derived from the increasing complexity and variability of configurations. Database quality and the implementation of AI techniques involve costs and investments in areas that will positively impact decision-making.

Companies are continuing to invest in digitalization. This is partly due to the need to adapt quickly and efficiently to the energy market's new challenges. Additionally, they recognize the advantages that artificial intelligence, data analytics, process automation, and technologies that enable communication between networks, smart meters, and Internet of Things devices offer in terms of efficiency and cost savings. According to Frantzis et al., 2008 Nimmons and Taylor, 2008 Schoettl and Lehmann-Ortega, 2010 (cited by Richter [19]), with the increase of energy generation with renewable sources, BMEs are focused on:

- The reorientation of supply from commodity suppliers to comprehensive, customer-focused energy service providers.
- To support decision-making for the integration and reliability of renewable energies,
- In the regulation of pricing and market functioning. Uses of AI in the energy sector highlight the topics of smart homes, smart grids, and renewable and non-renewable energy production and its benefits.

The customer-side renewable energy business model involves generating power in small-scale systems close to the point of consumption. The leading technologies for this application are solar photovoltaic (PV) systems, solar thermal collectors, geothermal heat pumps, wood pellet stoves, micro wind turbines, and micro combined heat and power (micro-CHP) systems [20].

The value proposition offered by the utility can range from simple consulting services to a complete package of services, including financing, ownership, and operation of the asset on the customer's property [21]. While this business model is in the corporate context, it is also known as the term "contracting" in this study, which refers to small-scale systems, mainly for private customers, in the range of a few kilowatts and around 1 megawatt in this study.

## 5 Trends in MNES Innovation with the Use of Artificial Intelligence

Christensen and Bower (1996) point out that companies can lose their leadership due to technological changes unrelated to technology but to the business model. Danish [5] emphasizes that creating new business models is equally or more important than technology, especially in sustainable innovations. From this perspective, the energy transition implies the innovation of the business model with a strategic approach for public service companies. With the increasing demand for data collection, exploration, and analysis, as well as proper energy supply and demand planning, AI has priority in handling these large data sets and automated operations of various platform forms.

Furthermore, data science integrates evidence-based decision-making and stakeholder requirements with a systemic view of the structure of the different levels of energy policy operation [3] to optimize and automate the system and objectives of energy policy. Therefore, the energy policy structure includes institutional arrangements and administrative frameworks that govern energy policy development, implementation, and evaluation.

Meanwhile, integrating renewable energies seeks to diversify the energy matrix and reduce emissions, boosting business opportunities in developing and installing renewable technologies. In this sense, carbon mitigation and neutralization are aligned with the growing need to quantify and reduce greenhouse gas emissions, which can generate opportunities in carbon credit trading, capture, and storage

projects. Meanwhile, restructuring the energy market seeks to boost competition and innovation, which technology startups and consulting services could take advantage of.

Data management is a fundamental pillar in the era of digitalization. Monitoring and controlling energy production, distribution, and consumption in real-time generates opportunities for developing technological solutions and data analysis platforms. For example, promoting intelligent transportation is related to sustainable mobility and the adoption of electric vehicles, creating opportunities in charging infrastructure and mobility solutions.

Finally, international cooperation underlines the importance of sharing knowledge and resources at a global level. This energy transition can generate opportunities for international research and development projects, the export of energy technologies, and collaboration in joint initiatives. The interaction between these components and business opportunities in the energy transition suggests that the application of AI with the emergence of new actors in the field of energy and information plays a fundamental role in the formulation of inter- and intra-institutional collaboration strategies. Between various levels of government, national agencies, international partners, multinational companies, and local prosumers [2, 4]. This coordinated interaction aims to drive collective action to reduce carbon emissions and the benefits inherent to such reductions.

## 6 Conclusions

Implementing artificial intelligence techniques to predict and optimize the sustainable use of energy is an analysis tool available to any organization. Anticipating energy consumption as a function of time is vital to optimizing and seeking energy efficiency [20]. If a composition that integrates different renewable energy sources is used, then variability adds considerable complexity to achieve predictive accuracy [22].

Changes in demand, derived from the emergence of digital technologies typical of the Fourth Industrial Revolution, further exacerbate the complexity of the predictive landscape by advancing decentralized power generation, infrastructure, energy efficiency parameters, behavior and economics of energy storage, demand side management, virtual power plants, microdevices, energy, and plug-in vehicles.

In this scenario, each agent has an objective function incorporating user constraints and demand response incentives. The optimization measures the reduced bill and the energy imported into the grid for different amounts of fixed consumption (fixed load) to be satisfied and amounts of flexible consumption (shiftable load and removable load) over a given period [11]. Monitoring is performed through data acquisition, feature extraction, and inference using machine learning approaches (supervised, unsupervised, semi-supervised) and other AI techniques.

In conclusion, integrating AI into energy business models offers numerous benefits, such as efficiency, reliability, and sustainability. Future research should focus on

developing scalable AI solutions adapted to different regional contexts and companies to maximize the benefits of the energy transition. Policymakers should create supportive regulatory frameworks encouraging AI adoption while addressing data privacy and security concerns. Industry professionals should prioritize investments in AI technologies that align with their strategic objectives and operational capabilities. The energy sector can make significant progress towards a more sustainable future by addressing these challenges and harnessing the potential of AI.

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## References

1. Naciones Unidas (2015) Agenda 2030 para el Desarrollo Sostenible. Recuperado de <https://www.un.org/sustainabledevelopment/es/>
2. Singh R, Akram S, Gehlot A, Buddhi Dy, Priyadarshi NTB (2022) Energy system 4.0: digitalization of the energy sector with inclination towards sustainability 22(17)
3. Hoppe T y, Miedema M (2020) A governance approach to regional energy transition: Meaning, conceptualization and practice. *Sustainability (Switzerland)* 12(3)
4. Chen Q y, Folly KA (2023) Application of artificial intelligence for EV charging and discharging scheduling and dynamic pricing: A Review 16(1)
5. Danish MSS (2023) AI and Expert Insights for Sustainable Energy Future 16(8)
6. ViškoviCA, Franki V y, JevtiCD (2022) Artificial intelligence as a facilitator of the energy transition
7. Garfik B (2022) Application of artificial intelligence in the unit commitment system in the application of energy sustainability 15(9)
8. Torres-Rivera A, Gutierrez K, Rendón A, Cerda y F, Díaz-Torres (2023) Aplicaciones de la Inteligencia Artificial en los Negocios sostenibles, Alfaomega
9. Marinakis V, Koutsellis T, Nikas y A, Doukas H (2021) AI and data democratisation for intelligent energy management 14(14)
10. Mohamad S, Sayed-Mouchaweh y M, Bouchachia A (2020) Online active learning for human activity recognition from sensory data streams 390
11. Salem H, Sayed-Mouchaweh y M, Tagina M (2020) A review on non-intrusive load monitoring approaches based on machine learning, de *Artificial Intelligence Techniques for a Scalable Energy Transition* 109–131
12. Sayed-Mouchaweh M (2020) Artificial intelligence techniques for a scalable energy transition: advanced methods, digital technologies, decision support tools, and applications, Springer Nature
13. Sioshansi F (2019) Consumer, Prosumer. How Service Innovations Will Disrupt the Utility Business Model, Academic Press, Prosumager
14. Zhang X, Biagioni D, Cai M, Graf y P, Rahman S (2020) An edge-cloud integrated solution for buildings demand response using reinforcement learning. *IEEE Trans Smart Grid* 12 (1)
15. Poulton y G, James G (2010) Coordination of distributed energy resource agents. *Appl Artif Intell* 24(5)
16. Zhao y N, You F (2020) Can renewable generation, energy storage and energy efficient technologies enable carbon neutral energy transition? *Appl Energy* 279
17. Danish MSS (2023) AI in energy: Overcoming unforeseen obstacles 4(2)

18. Nazari y Z, Musilek P (2023) Impact of digital transformation on the energy sector: A review 16(4)
19. Richter M (2011) Business model innovation for sustainable energy: German utilities and renewable energy
20. Lytras KTCMD (2019) The recent development of artificial intelligence for smart and sustainable energy systems and applications 12(16)
21. Evans S, Vladimirova D, Holgado M, Van Fossen K, Yang M, Silva y E, Barlow C (2017) Business model innovation for sustainability: Towards a unified perspective for creation of sustainable business models. Wiley Online Library 26(5)
22. Saheb y T, Dehghani M. Artificial intelligence for sustainability in energy industry: A Contextual Topic Modeling and Content Analyses

# Artificial Neural Networks for Speaker Verification



Jose Luis Medellin-Garibay and Juan C. Cuevas-Tello

**Abstract** Speech recognition systems are becoming popular because nowadays it is easy to capture audio signal through mobile devices. Moreover, biometric recognition systems are also popular because fingerprints, voice, retina, and face are specific to individuals and cannot be stolen easily as passwords and PINs. There are many datasets for speech recognition tasks. This research focuses on the benchmark for speaker verification SRE-08. There are different approaches for the automatic speaker verification task: prediction, regression, and classification. This research focuses only on classification with Probabilistic Neural Networks (PNN) and Emphasized Channel Attention, Propagation, and Aggregation in Time-Delay Neural Network (ECAPA-TDNN) methods. We use the Equal Error Rate (ERR) metric to measure the performance, and we found that the best performance corresponds to the classification approach (PNN) with the average EER = 13.3% (Accuracy 88%). The classification approach (PNN) achieves the single best with EER=0% (Accuracy 100%) on five speakers out of nine.

**Keywords** Speaker verification · Speaker recognition · Artificial neural networks · PNN · ECAPA-TDNN · Mel frequency cepstral coefficients

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## 1 Introduction

The main motivation of this research is the biometric recognition systems [9]; biometric cues such as fingerprints, voice, and face are specific to an individual. Contrary to passwords and PINs, the use of biometric recognition systems has many advantages including that cannot be forgotten and cannot easily stolen. The human speech is the least obtrusive biometric measure, and it is simple to acquire thanks to the pervasive wave in society [18]. In recent years, the smart device technology has been increased extensively, in fact there are 294 million of smartphone users in 2020<sup>1</sup> and 37% of households in the United States owned a smart home device in 2020.<sup>2</sup> Voice-controlled smart devices require improved user authentication and security due to their Internet connectivity and control over smart home and other devices.

Speech processing has various applications including speech recognition, language identification, and speaker recognition. Sometimes, additional information is stored and associated to speech. Therefore, speaker recognition can be either text dependent or text independent. Moreover, speaker recognition involves different tasks such as [3]: (i) speaker identification, (ii) speaker detection, (iii) speaker diarization, and (iv) *Speaker Verification* (SV).

This research focuses on the latter. Automatic Speaker Verification (ASV) is defined as the use of a machine to verify a person's claimed identity from his voice [3]. Identity claims involve using an employee number, smart card, and other methods. ASV is crucial in biometrics for access-control applications, differing from speaker identification, which determines if the speaker is a specific person or part of a group.

The benchmark for *Speaker Verification* is ruled by the Linguistic Data Consortium<sup>3</sup> (LDC) and the National Institute for Standards and Technology (NIST). It is called the NIST Speaker Recognition Evaluation<sup>4</sup> (SRE), which focuses on text-independent speaker recognition tasks. So the LDC collected multiple telephone calls, which were audited for language, speaker identity, and other features, see Cieri et al. [5]. Other important speech recognition benchmarks include YOHO [14] and TIMIT<sup>5</sup> [10]. More datasets for speech recognition can be consulted in C. Cieri and M. Liberman [6].

There are different types of feature extractors across the literature, and this research focuses only on the widely used Mel-Frequency spaced Cepstral Coefficients (MFCCs) [7, 18]. Nevertheless, some research includes *i*-vectors as feature extractors and perceptual linear prediction (PLP) features [2]. The state-of-the-art algorithms for ASV include Gaussian Mixture Models (GMM) [2, 18]. Table 1 summarizes papers with few speakers comparing accuracy, methods, and feature extraction techniques. Cloud services from Google, IBM, Microsoft, and other providers

<sup>1</sup> <https://www.statista.com/statistics/201182/forecast-of-smartphone-users-in-the-us/>.

<sup>2</sup> <https://www.statista.com/topics/6201/smart-home-in-the-united-states/>.

<sup>3</sup> <https://www.ldc.upenn.edu/>.

<sup>4</sup> <https://www.nist.gov/itl/iad/mig/speaker-recognition>.

<sup>5</sup> <https://catalog.ldc.upenn.edu/ldc93s1>.

**Table 1** Review on publications with datasets studying few speakers. Comparing the Accuracy (Acc)

| Method                                                         | Metric (Acc) | Feature extraction   | Speakers-dataset                                                        | Refs. |
|----------------------------------------------------------------|--------------|----------------------|-------------------------------------------------------------------------|-------|
| Vector quantization, k-means, Euclidean distance               | 88.8%        | MFCC                 | 10 speakers, 5 samples for training, own dataset one sample for testing | [12]  |
| Backpropagation (BPNN)                                         | 92%          | MFCC                 | 10, 20, 30, 40 and 50 users, own dataset                                | [20]* |
| SCNN (Siamese Convolutional Neural Network): VGG and ResNet 50 | 81.2%        | Spectrogram with FFT | 10 speakers, from LibriSpeech database                                  | [19]  |
| DNN                                                            | 43.6–58.9%   | T-MFCC, i-vectors    | 7 speakers, own dataset                                                 | [1]   |
| Backpropagation                                                | 93.1%        | MFCC                 | 14 speakers, own dataset                                                | [11]  |
| PNN ECAPA-DNN                                                  | 41–88%       | MFCC                 | 9 speakers for training, and 111 for testing (SRE-08)                   | This  |

\* text-dependent

are promising but can be complex to setup and often lack publicly disclosed accuracy metrics.

This paper covers Artificial Neural Networks (ANN): Probabilistic Neural Networks (PNN) [17] and ECAPA-TDNN [8], which are classification methods. The main contribution of this paper is the methodology based on PNN for speaker verification, and also the comparison between PNN and ECAPA-TDNN on SRE data. The results show that the best results stand on PNN (classification).

This paper is organized as follows: the audio data (training and testing) in Sect. 2, speech features in Sect. 3, proposed approaches and methods are in Sect. 4, and results and conclusions at the end.

## 2 Audio Data

As we mentioned above, the audio recordings are obtained from NIST-SRE.<sup>6</sup> The audio samples are represented as time-domain waveforms, and they correspond to

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<sup>6</sup> <https://www.nist.gov/itl/iad/mig/speaker-recognition>.

the NIST Year 2008 Speaker Recognition Evaluation Plan<sup>7</sup> (SRE-08). The audio samples have a duration of 2 min on average.

NIST-SRE provides audio samples for training, and it also provides a different set of audio samples for testing. Training samples contain only target speakers, and test samples have both target and non-target (impostor) speakers. So researchers can measure the performance of their speaker recognition model.

## 2.1 SRE-08

The SRE-08 is limited to the **speaker detection** task, which is to determine whether a specific speaker is speaking during a given segment of conversational speech [13]. The speaker detection task is divided into 13 distinct and separate tests involving six training conditions and one or four test conditions. There are 1,270 speakers for training and 98,777 for testing. This research focuses only on the core test, i.e., the following combination: the training condition *short2* and the test condition *short3*. Both conditions consist of a two-channel telephone conversational excerpt of approximately five minutes total duration. The conversation involves the target speaker and an interviewer (non-target) [13]. The datasets are given by NIST in SPHERE<sup>8</sup> audio files. NIST and LDC have tools for converting SPHERE audio files in conventional formats such as WAV files.<sup>9</sup>

## 2.2 Dataset

In Table 2, we show the training list<sup>10</sup> corresponding to the training condition *short2* and the test condition *short3* of SRE-08 [13]. Additionally, it is not expected to examine performance results over all trials of the core test.<sup>11</sup> Therefore, common conditions can be considered in order to build a subset of the core test trial. We consider the following condition: “All trials involving only English language telephone speech spoken by a native U.S. English speaker in training and test” [13]. Moreover, we only evaluate male voice (‘Sex = m’, in Table 2). Therefore, our training data contain speech from nine speakers.

Table 2 shows the entire dataset employed in this research. There are 9 speakers for training, and there are 111 test speakers, voice excerpts, with only 21 targets. For

<sup>7</sup> <https://catalog.ldc.upenn.edu/LDC2011S08>.

<sup>8</sup> NIST provides software for manipulating SPHERE files; see <http://www.nist.gov/itl/iad/mig/tools.cfm>.

<sup>9</sup> <https://www.ldc.upenn.edu/language-resources/tools/sphere-conversion-tools>.

<sup>10</sup> The full training list is provided by NIST through the following file NIST\_SRE08\_short2.model.key.

<sup>11</sup> The list of testing data is provided by the file NIST\_SRE08\_short2-short3.trial.key.

**Table 2** SRE-08 training data and test cases

| Model Id | Sex | Segment Id:<br>channel | Speaker Id | Speech type | Channel type | Lang. | Speaker native language | #test cases | #targets |
|----------|-----|------------------------|------------|-------------|--------------|-------|-------------------------|-------------|----------|
| 10371    | m   | tjiv:a                 | 105088     | Phonecall   | phn-main     | ENG   | USE                     | 11          | 2        |
| 12459    | m   | ttqco:a                | 110372     | Phonecall   | phn-main     | ENG   | USE                     | 10          | 1        |
| 12499    | m   | trbf:a                 | 110667     | Phonecall   | phn-main     | ENG   | USE                     | 19          | 1        |
| 13076    | m   | tahak:b                | 103394     | Phonecall   | phn-main     | ENG   | USE                     | 14          | 4        |
| 13845    | m   | tbjem:a                | 111590     | Phonecall   | phn-main     | ENG   | USE                     | 15          | 1        |
| 14692    | m   | txkzs:b                | 103675     | Phonecall   | phn-main     | ENG   | USE                     | 10          | 4        |
| 14856    | m   | txqmx:b                | 102578     | Phonecall   | phn-main     | ENG   | USE                     | 14          | 5        |
| 15604    | m   | ttwkz:b                | 107851     | Phonecall   | phn-main     | ENG   | USE                     | 9           | 1        |
| 16295    | m   | tlskl:b                | 104179     | Phonecall   | phn-main     | ENG   | USE                     | 9           | 2        |
|          |     |                        |            |             |              |       |                         | Total       | 111      |
|          |     |                        |            |             |              |       |                         |             | 21       |

example, the speaker one, Model ID 10371, has 11 test cases with 2 targets, where 9 are impostors.

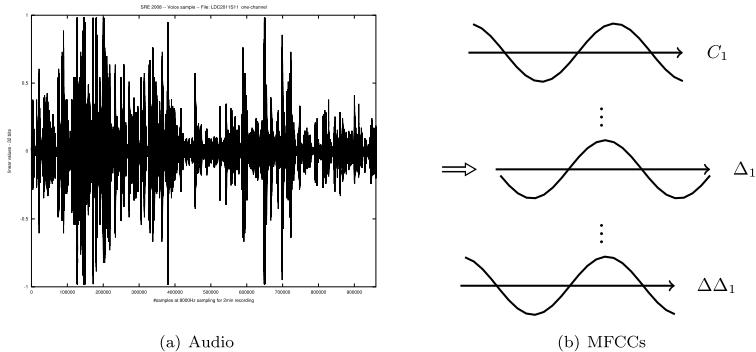
### 3 Speech Features

The first step for most speech recognition systems is feature extraction from the time-domain sampled acoustic waveform (audio); see Fig. 1a. The time-domain waveform is divided into overlapping *frames*, each generated every 10 ms with a duration of 25 ms. A feature is then extracted for each frame. Several methods for feature extraction (acoustic representation) have been explored, including Linear Prediction Coefficients (LPCs), Perceptual Linear Prediction (PLP) coefficients, and Mel-Frequency Cepstral Coefficients (MFCCs). The latter is widely used and some researches proofed that are the best option for feature extraction [7]. MFCCs are based on the Fast Fourier Transform (FFT), Mel-spaced filter bank values, and Cepstral analysis [18]. In order to capture dynamic information between frames, the MFCCs vector is concatenated with the first ( $\varepsilon$ )-, second ( $\varepsilon \varepsilon$ )-, and even third-order derivative ( $\varepsilon \varepsilon \varepsilon$ ) approximations [7, 18]. There are several tools for generating MFCCs including Voicebox<sup>12</sup> and HTK MFCC MATLAB® by Kamil Wojcicki.<sup>13</sup>

The speech features used along this paper correspond to MFCCs; see Fig. 1b. We denote standard MFCCs as  $C_1, C_2, \dots, C_N$ ; first-order derivative MFCCs as  $\varepsilon_1, \varepsilon_2, \dots, \varepsilon_N$ ; and second-order derivative MFCCs as  $\varepsilon \varepsilon_1, \varepsilon \varepsilon_2, \dots, \varepsilon \varepsilon_N$ , where  $N$  is the number of coefficients. Therefore, a single time-domain waveform is represented by

<sup>12</sup> <http://www.ee.ic.ac.uk/hp/staff/dmb/voicebox/voicebox.html>.

<sup>13</sup> <http://www.mathworks.com/matlabcentral/fileexchange/32849-htk-mfcc-matlab>.



**Fig. 1** Audio sample. **a** Audio represented as a time-domain waveform; **b** A set of MFCCs is obtained from the time-domain waveform

$$\mathbf{T} = \left( \begin{array}{cccc|ccccc} C_1^1 & C_2^1 & \cdots & C_N^1 \\ C_1^2 & C_2^2 & \cdots & C_N^2 \\ \vdots & \vdots & \cdots & \vdots \\ C_N^1 & C_N^2 & \cdots & C_N^M \\ \hline \varepsilon_1^1 & \varepsilon_1^2 & \cdots & \varepsilon_1^M \\ \varepsilon_2^1 & \varepsilon_2^2 & \cdots & \varepsilon_2^M \\ \vdots & \vdots & \cdots & \vdots \\ \varepsilon_N^1 & \varepsilon_N^2 & \cdots & \varepsilon_N^M \\ \hline \varepsilon_{\varepsilon_1}^1 & \varepsilon_{\varepsilon_1}^2 & \cdots & \varepsilon_{\varepsilon_1}^M \\ \varepsilon_{\varepsilon_2}^1 & \varepsilon_{\varepsilon_2}^2 & \cdots & \varepsilon_{\varepsilon_2}^M \\ \vdots & \vdots & \cdots & \vdots \\ \varepsilon_{\varepsilon_N}^1 & \varepsilon_{\varepsilon_N}^2 & \cdots & \varepsilon_{\varepsilon_N}^M \end{array} \right), \quad (1)$$

where  $M$  is the number of *frames* obtained from the time-domain waveform. Each column in  $\mathbf{T}$  represents the total number of MFCCs, and each row contains the total number of frames per coefficient.

## 4 Approaches

There are several approaches for speech recognition including prediction, regression, and classification. This research only covers classification for the text-independent speaker recognition task [13].

## 4.1 Classification

For classification, the data is represented by  $\mathbf{P}$  and  $\mathbf{Tc}$ , see Eq. (2).

$$D_1 \left( \begin{array}{c} \mathbf{P} = \begin{matrix} \mathbf{T}_1 & \mathbf{T}_2 & \cdots & \mathbf{T}_U \end{matrix} \\ \downarrow \\ [(N \times 3) \times M] \quad [(N \times 3) \times M] \quad \cdots \quad [(N \times 3) \times M] \\ \mathbf{Tc} = \begin{matrix} class = 1 \\ [1 \times M] \end{matrix} \quad \begin{matrix} class = 2 \\ [1 \times M] \end{matrix} \quad \cdots \quad \begin{matrix} class = 2 \\ [1 \times M] \end{matrix} \end{array} \right) \quad (2)$$

Each matrix  $\mathbf{T}_1, \mathbf{T}_2, \dots, \mathbf{T}_i, \dots, \mathbf{T}_U$  contains the MFCCs of a single user, see Eq. (1), where  $U$  is the number of training users (speakers). The dimension of  $\mathbf{T}_i$  is  $[(N \times 3) \times M]$ .  $\mathbf{Tc}$  contains the class for each user  $\mathbf{T}_i$  (the labels). For illustration purposes, Eq. (2) only shows the data ( $D_1$ ) where the target user is assigned to  $class = 1$ , and all non-target users to  $class = 2$ . The full data for classification is represented by  $\mathbf{D} = D_1, D_2, \dots, D_i, \dots, D_U$ .

## 4.2 PNN

The first classification method is Probabilistic Neural Network (PNN). The PNN architecture is shown in [17]. The input layer has  $\mathbf{X} = x_1, x_2, \dots, x_i, \dots, x_q$  inputs. At the pattern layer, the functions  $\alpha_i$  represent the basis functions, as in Radial Basis Function (RBF) neural networks  $\alpha_i = \exp\left(\frac{-\|\mathbf{X}-x_i\|^2}{2\delta^2}\right)$ , where  $\|\cdot\|$  denotes the Euclidean distance and  $\delta$  the spread, which is the only free parameter. Therefore,  $f_A(\mathbf{X}) = S_w/S_s$  and  $f_B(\mathbf{X}) = S_w/S_s$ , which is a normalized linear combination of Gaussian functions. Here  $f_A$  and  $f_B$  represent only two categories (classes) for illustration purposes, so if there are only two classes then the outputs are binary. The output  $o_i$  is estimated with  $f_A$  and  $f_B$ , and there is an algorithm that determines if the input  $\mathbf{X}$  belongs to the category A, B, or none [17]. However, the PNN can have  $o_1, o_2, \dots, o_i, \dots, o_k$  classes (labels). The more classes, the more hidden units.

## 4.3 ECAPA-TDNN

The second classification method is Emphasized Channel Attention, Propagation, and Aggregation in TDNN (ECAPA-TDNN) [8]. This architecture is designed to enhance the performance of speaker verification systems that rely on Time-Delay Neural Networks (TDNNs). It is based on the original x-vector architecture [16], but ECAPA-TDNN puts more emphasis on Channel Attention. ECAPA-TDNN incorporates several key components to achieve its goals:

- Channel Attention Mechanism: This mechanism emphasizes relevant information extracted from various acoustic channels, allowing the model to concentrate on

important features and acoustic cues. This enhances the model's ability to distinguish between speakers.

- **Information Propagation:** The architecture incorporates mechanisms for efficient information propagation, ensuring that relevant information is accurately transmitted and processed throughout the network. This enables the model to capture essential speaker-specific characteristics.
- **Aggregation Methods:** ECAPA-TDNN employs advanced aggregation techniques to combine information from different parts of the network. This enhances the system's overall performance and robustness, making it well suited for challenging speaker verification tasks.

## 5 Experiments and Results

Two approaches were introduced in Sect. 4.1, the best performance is achieved by the approach where all target users are assigned to  $class = 1$ , and all non-target users to  $class = 2$  (impostors). Therefore, this approach is used for PNN and ECAPA-TDNN classification methods.

### 5.1 PNN

The spread parameter is set to  $\delta = 0.1$  for training and testing. There is a PNN per speaker, and the input and output data are as described in Eq. 2, where  $N = 16$  and  $M = 3000$  frames. We performed our experiments with MATLAB<sup>®</sup>, function newpnn.

Once the PNN is built and trained per speaker, then the testing part is performed by feeding the frames per each test case. Since we have a PNN per speaker, the PNN with the maximum number of frames classified as  $class = 1$  is selected. In order to be consistent with previous approaches, the number of frames classified as target is represented with a number between  $M_{class} = [0, 1]$  and then converted as a minimization problem. Thus,  $error = 1 - M_{class}$ . The results using EER per speaker are in Table 3, the average EER is 13.3%.

### 5.2 ECAPA-TDNN

The methodology employed for classification in this study took a distinctive departure from conventional approaches. In contrast to PNN, and similar to x-vectors, there was no requirement for audio frame splitting. Instead, we directly processed the audio input utilizing the powerful ECAPA-TDNN architecture, emphasizing the

**Table 3** EER: Results from PNN and ECAPA-TDNN

| Speaker | Model Id | PNN     |         |      | ECAPA-TDNN |         |      |
|---------|----------|---------|---------|------|------------|---------|------|
|         |          | EER (%) | Thresh. | Acc. | EER (%)    | Thresh. | Acc. |
| 1       | 10371    | 0.0     | 0.78    | 1.00 | 34.31      | 0.20    | 0.70 |
| 2       | 12459    | 33.3    | 0.82    | 0.82 | 41.24      | 0.06    | 0.57 |
| 3       | 12499    | 22.2    | 0.78    | 0.78 | 0.00       | 0.23    | 0.99 |
| 4       | 13076    | 0.0     | 0.74    | 1.00 | 40.59      | 0.19    | 0.55 |
| 5       | 13845    | 35.7    | 0.84    | 0.66 | 34.03      | 0.02    | 0.68 |
| 6       | 14692    | 0.0     | 0.70    | 1.00 | 58.13      | 0.17    | 0.48 |
| 7       | 14856    | 0.0     | 0.78    | 1.00 | 40.00      | 0.22    | 0.55 |
| 8       | 15604    | 0.0     | 0.77    | 1.00 | 51.67      | 0.16    | 0.53 |
| 9       | 16295    | 28.5    | 0.82    | 0.77 | 69.64      | 0.27    | 0.39 |
|         | Average  | 13.3    |         | 0.88 | 41.39      |         | 0.60 |

extraction of discriminative features through time-delay neural networks (TDNN) with contextual awareness.

A noteworthy aspect of our approach is the meticulous fine-tuning of parameters, with special attention given to those inherent to ECAPA-TDNN, thereby enhancing the model's discriminative capabilities. For this research endeavor, we made a deliberate choice to harness the default configurations of ECAPA-TDNN available within the SpeechBrain toolkit, which is a comprehensive open-source platform dedicated to advanced speech and audio processing [15].

It is important to highlight that our decision to align with the default ECAPA-TDNN configurations in SpeechBrain not only underscores our commitment to methodological transparency but also aligns with contemporary trends in the field. The implementation was conducted using Python 3, leveraging the robust capabilities of the SpeechBrain library, which provides extensive support for cutting-edge speech and audio processing tasks. The results are in Table 3.

## 6 Discussion

The use of well-studied benchmarks such as SRE-08 gives the advantage that the dataset is already divided into training and testing, see Table 2. Thus, the testing part is accurate because this audio was not used during training. From the point of view of machine learning, knowing the ground truth is possible to measure bias and variance and other performance metrics.

ECAPA-TDNN has reported outstanding performance in literature with EER = 0.87–1.22% [8]. Nevertheless, this performance is achieved using VoxCeleb dataset [4]. Comparing the quality of the audio between SRE-08 and VoxCeleb,

the SRE-08 is more challenging because VoxCeleb does not have background noise and other real conditions when recording audio.

This research compares PNN with ECAPA-DNN on the same dataset, SRE-08, see Table 2. The best performance achieved so far is for the classification approach and the PNN method with the average EER = 13.3% (Accuracy 88%), see Table 3. These results are comparable to those reported by other researchers using similar datasets, see Table 1.

## 7 Conclusions

Finally, we believe the best performance is achieved by PNN, with an average EER of 13.3% (88% accuracy). This is because a model for each speaker is built and trained considering both the target speaker and non-targets (impostors), allowing the model to learn which frames belong to the target and which belong to impostors. Moreover, PNN achieved a perfect EER of 0% (100% accuracy) for five out of nine speakers. In contrast, ECAPA-TDNN achieved a perfect EER of 0% for only one speaker. Therefore, PNN demonstrates superior performance with this dataset with few speakers. However, we anticipate that ECAPA-TDNN will achieve better results with the full SRE-08 dataset, as deep learning approaches typically perform better with larger datasets.

## 8 Future Work

Further research can explore several directions. One is to use the full SRE-08 dataset for all evaluation conditions, encompassing 1,270 speakers and 98,777 testing cases. Given that PNN is computationally demanding for testing, parallel computing will be required. Additionally, it is worthwhile to investigate the optimal number of frames per user to minimize training and testing time. Using fewer frames will expedite these processes. Moreover, the PNN's spread parameter ( $\delta$ ) was fixed for all speakers; setting this parameter individually for each speaker could potentially improve results. Since deep learning methods improve with larger datasets, comparing ECAPA-TDNN with PNN using the full SRE-08 dataset is a promising area for further study. Additionally, this research only utilized MFCCs as the feature extraction technique. Future work could explore other techniques such as LPCs, PLP, and i-vectors, as well as hybrid models combining PNN and ECAPA-TDNN, using the proposed approaches on the SRE-08 dataset. Deploying real-time applications, like smart devices, poses significant computational challenges. Cloud computing could provide a substantial advantage in overcoming these limitations.

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## References

1. Aizat K, Mohamed O, Orken M, Ainur A, Zhumazhanov B (2020) Identification and authentication of user voice using DNN features and i-vector. *Cogent Eng* 7(1):1751,557. <https://doi.org/10.1080/23311916.2020.1751557>
2. Alam M, Kinnunen T, Kenny P, Ouellet P, O'Shaughnessy D (2013) Multitaper MFCC and PLP features for speaker verification using i-vectors. *Speech Commun* 55(1):237–250
3. Campbell JP (1997) Speaker recognition: a tutorial. *Proceed IEEE* 85(9):1437–1462. <https://doi.org/10.1109/5.628714>
4. Chung JS, Nagrani A, Zisserman A (2018) Voxceleb2: deep speaker recognition. *arXiv preprint arXiv:1806.05622*
5. Cieri C, Liberman M (2014) Data for empirical foundations of forensic linguistics. In: *Proceedings of LSA symposium*
6. Cieri C, Liberman M (2014) Dimensions of speaker recognition research data. *Data for Empirical Foundations of Forensic Linguistics, LSA Symposium*
7. Davis S, Mermelstein P (1980) Comparison of parametric representations for monosyllabic word recognition in continuously spoken sentences. In: *IEEE transactions on acoustics, speech and signal processing*, vol 28. <https://doi.org/10.1109/TASSP.1980.1163420>
8. Desplanques B, Thienpondt J, Demuynck K (2020) Ecapa-tdnn: emphasized channel attention, propagation and aggregation in tdnn based speaker verification. *arXiv preprint arXiv:2005.07143*
9. Fazel A, Chakrabarty S (2011) An overview of statistical pattern recognition techniques for speaker verification. *IEEE Circ Syst Mag* 11(2):62–81. <https://doi.org/10.1109/MCAS.2011.941080>
10. Hinton G, Deng L, Yu D, Dahl GE, Mohamed AR, Jaitly N, Senior A, Vanhoucke V, Nguyen P, Sainath TN, Kingsbury B (2012) Deep neural networks for acoustic modeling in speech recognition: the shared views of four research groups. *IEEE Signal Process Mag* 29(6):82–97. <https://doi.org/10.1109/MSP.2012.2205597>
11. Kaphungkui N, Kandali A (2020) Classification and real time testing of speaker recognition system. *Int J Innov Res Sci Eng Technol (IJIRSET)* 6
12. Manjula G et al (2015) Speaker recognition using cepstral analysis. *Int J Eng Res Technol* 4(8). <https://doi.org/10.17577/IJERTV4IS080161>
13. NIST (2008) The NIST Year 2008 speaker recognition evaluation plan. <http://www.itl.nist.gov/iad/mig/tests/sre/2008/>
14. Ozaydin S (2017) Design of a text independent speaker recognition system. In: *2017 international conference on electrical and computing technologies and applications (ICECTA)*, pp 1–5. <https://doi.org/10.1109/ICECTA.2017.8251942>
15. Ravanelli M, Parcollet T, Plantinga P, Rouhe A, Cornell S, Lugosch L, Subakan C, Dawalatabad N, Heba A, Zhong J et al (2021) Speechbrain: a general-purpose speech toolkit. *arXiv preprint arXiv:2106.04624*
16. Snyder D, Garcia-Romero D, Sell G, McCree A, Povey D, Khudanpur S (2019) Speaker recognition for multi-speaker conversations using x-vectors. In: *ICASSP 2019-2019 IEEE international conference on acoustics, speech and signal processing (ICASSP)*. IEEE, pp 5796–5800
17. Specht D (1990) Probabilistic neural networks. *Neural Netw* 3(1):109–118
18. Tognetti R, Pullella D (2011) An overview of speaker identification: accuracy and robustness issues. *IEEE Circ Syst Mag* 2(1):23–61
19. Vélez I, Rascón C, Pineda GF (2018) One-shot speaker identification for a service robot using a CNN-based generic verifier. *ArXiv abs/1809.04115*
20. Wali SS, Hatture SM, Nandyal S (2015) MFCC based text-dependent speaker identification using BPNN. *Int J Signal Process Syst* 3(1):30–34. <https://doi.org/10.12720/ijspss.3.1.30-34>

# Preliminary Surface EMG Profiling in Parkinson's Disease: A Foundation for Objective Disease Severity Assessment



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**Abstract** Parkinson's disease presents significant challenges in diagnosis and monitoring due to its progressive nature and complex symptomatology. This preliminary study introduces a novel approach using surface electromyography (sEMG) to objectively assess PD severity, focusing on the biceps brachii muscle. SEMG data was analyzed from five PD patients (age 72–84) and five healthy controls (age 67–80) using the Myoware Muscle Sensor. Key parameters such as Root Mean Square (RMS), Median Frequency (MDF), Mean Frequency, and Sample Entropy (SampEn) were extracted. Results indicate notable neuromuscular differences, particularly in variance and mean frequency during sustained contractions, with the classification model achieving accuracies up to 83%. Despite the small sample size, findings suggest sEMG's potential as a non-invasive tool for PD severity assessment. Future research with larger cohorts is essential to validate these findings and enhance the methodology, aiming for integration into clinical protocols to improve PD evaluation and personalized therapy.

**Keywords** EMG · sEMG · Parkinson's disease · Wearables · PD severity assessment

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## 1 Introduction

Parkinson's disease (PD) is a progressive neurological disorder increasingly prevalent among the elderly, with over 8.5 million individuals affected globally (WHO, 2019) [1]. The most common motor symptoms of Parkinson's disease include tremors (involuntary movement of body parts), stiffness (resistance to external movements), bradykinesia (slow movement), and postural instability, all of which significantly impact daily activities and quality of life [2, 3]. The severity of motor symptoms is often assessed using the Unified Parkinson's Disease Rating Scale (UPDRS), which facilitates diagnosis and, above all, standardization of assessment. However, the scale is time-consuming, subjective, and not very sensitive, especially in early PD stages or when psychological factors may influence results.

In this paper, we present a novel procedure for objectively assessing PD severity using a wearable sensor that measures muscle electrical activity via surface electromyography. This non-invasive method captures critical insights into tremors during muscle activation in elderly individuals engaged in regular physical activity. By analyzing sEMG parameters such as mean frequency, variance, and amplitude, we aim to identify neuromuscular differences between PD patients and healthy controls. This approach is highly relevant for researching muscle behavior, enhancing mobility, and gauging muscle fatigue—areas extensively explored in clinical neurophysiology [4], albeit often challenging to interpret clinically. The discernible patterns underlying movement can contribute to improving the evaluation of neuromuscular responses during diverse activities [5]. Our study specifically focuses on the unique characteristics of the biceps brachii muscle in PD patients compared to healthy elderly participants, due to its significance in Parkinson's disease functioning and the simplicity of measurement owing to the muscle's easy accessibility.

The study aims to develop a new sEMG-based method to objectively assess Parkinson's disease severity, using low-cost wearable sensors for regular symptom monitoring. It seeks to enhance clinical practices with a non-invasive approach. Further research with larger, diverse cohorts is needed to validate and refine this method, and to integrate wearable technologies into routine clinical care for PD patients.

## 2 Related Work

Parkinson's disease certainly requires advanced methods for accurate diagnosis and monitoring of symptoms. The integration of technology, particularly wearable sensors, has shown promise in enhancing clinical assessments and treatment strategies [4]. This section reviews recent studies employing sEMG to evaluate motor symptoms and disease progression in PD patients, serving as a foundation for our subsequent methodology and analysis.

The study conducted by Fundaro et al. [5] aimed to compare sEMG recordings of biceps activity in healthy individuals and PD patients, correlating these recordings with Parkinson Fatigue Scale (PFS) scores. The initial step involved selecting a homogeneous PD group, achieved through a comprehensive survey that gathered patients' demographic data such as age, gender, Body Mass Index (BMI), disease duration, the side of onset of the first rest tremor (left/right), UPDRS total score and its subsections (I–III), PFS score, L-DOPA and D-DOPA treatment status. Furthermore, specific criteria were set, ensuring that patients maintained a consistent L-DOPA dosage for at least two weeks before the experiment, with additional exclusion criteria in place. The examination protocol comprised three types of movements: one induced by a button stimulation electrode, three rapid unstimulated movements lasting three seconds each, and a sustained contraction lasting 30 s. Adequate rest periods (5–10 min between exercises) were implemented to mitigate cumulative fatigue. The authors emphasized a significant correlation between sEMG findings and both the PFS scale and section I of the UPDRS scale. Additionally, they noted no discernible difference in muscle strength between the healthy individuals and the PD group [5].

Kleinholzermann et al. [6] conducted a study to develop a mobile, objective, and non-invasive method for assessing motor symptoms in PD patients. The study involved 45 PD patients whose data were captured using sEMG signal from a wristband. These patients were instructed to perform a tapping task at five-second intervals. Correlation coefficient of 0.739 was found between sEMG activity and UPDRS part III scores. This correlation was further analyzed using various regression models, demonstrating the potential utility of these features in predicting the need for medication adjustments in the future, particularly in telemedicine applications [6].

In a study conducted by Meigal et al. [7], the aim was to explore and compare classical linear sEMG parameters such as Root Mean Square (RMS) and Median Frequency (MDF) with less investigated nonlinear sEMG parameters including kurtosis, Standard Deviation (SD), Percentage of Recurrence (%REC), Percentage of Determinism (%DET), Sample Entropy (SampEn), and Correlation Dimension (CD). This investigation encompassed healthy young individuals, healthy elderly participants, and those diagnosed with Parkinson's disease. The study also delved into establishing correlations between linear and nonlinear parameters and the Unified Parkinson's Disease Rating Scale. During the experimental phase, sEMG signals were captured using electrodes placed bilaterally on the biceps muscle, particularly during isometric contractions without external loads and with 1 and 2 kg loads. Data analysis revealed that the RMS parameter exhibited an increase with load across all groups. However, the MDF parameter showed a significant increase solely in the PD group, particularly at 1 and 2 kg loads, while remaining constant in the other groups irrespective of the load. Moreover, all nonlinear characteristics in the PD group exhibited notable differences compared to the control group, with the most pronounced distinctions observed in the absence of additional load, gradually converging at the 2 kg load. Significant correlations were established between novel sEMG parameters such as %REC, %DET, SEMG kurtosis, and UPDRS scores. Most sEMG characteristics, excluding RMS and MDF, demonstrated significant correlations with the

finger-tapping score derived from the motor UPDRS. These correlations were particularly prominent in the unloaded state (e.g., Kurtosis-RIGHT: 0.650, LEFT: 0.502), gradually diminishing with increased load (e.g., 1 kg: Kurtosis-RIGHT: 0.685, LEFT: 0.308; 2 kg: Kurtosis-RIGHT: 0.270, LEFT: 0.398). The findings underscore the potential of these nonlinear sEMG parameters in assessing motor symptoms and their correlation with disease severity in PD patients [7].

### 3 Methods

In this section we provide a comprehensive description of the study cohort, including both the inclusion and exclusion criteria, detailing the measurement methodology employed, and outlining the approach used for data analysis. This study was approved by the Ethics Committee of Gdańsk University of Technology. All subjects have given their written informed consent before participating in this study.

#### 3.1 Study Cohort

A total of five PD patients (age 72–84) were recruited from the Association for People with Parkinson's Disease and Brain Degenerative Diseases and their Caretakers 'Park On' (Gdańsk, Poland). The general inclusion criteria for the study group was a prior diagnosis of PD. The exclusion criteria encompassed diseases influencing motor functions other than PD, the presence of a pacemaker, an artificial heart valve, or metal implants in the area of upper limbs, and undergoing recent operations or injuries affecting motor functions of upper limbs.

The control group comprised five healthy subjects (age 67–80). The exclusion criteria for the control group were identical to those for the PD patients, with the requirement that none of the participants had a history of Parkinson's disease. All participants completed a survey about their demographic data, presented in Tables 1 and 2.

**Table 1** Characteristics of the study group

| PD patient | Age | Gender | BMI  | PD duration (years) | Medication for PD | Medication duration (years) |
|------------|-----|--------|------|---------------------|-------------------|-----------------------------|
| 1          | 76  | F      | 23,8 | 4                   | Yes               | 3                           |
| 2          | 64  | M      | 22,3 | 12                  | Yes               | 12                          |
| 3          | 84  | M      | 17   | 5                   | Yes               | 3                           |
| 4          | 73  | F      | 24,2 | 6                   | Yes               | 6                           |
| 5          | 72  | F      | 21,9 | 7                   | Yes               | 7                           |

**Table 2** Characteristics of the control group

| Subject | Age | Gender | BMI   |
|---------|-----|--------|-------|
| 1       | 67  | M      | 26,6  |
| 2       | 71  | M      | 31,46 |
| 3       | 71  | M      | 24,91 |
| 4       | 64  | M      | 29,38 |
| 5       | 80  | M      | 33    |

### 3.2 Hardware

The measuring device employed in our study utilizes the Myoware 2.0 Muscle Sensor [8], designed for assessing the electric voltage associated with muscular contraction. This sensor interfaces with gel Ag/AgCl electrodes that comply with ANSI/AAMI EC12 standard for disposal ECG electrodes [9]. The electrodes were positioned bilaterally on the skin surface to capture electrical signals from the biceps brachii muscle.

The non-invasive nature of this methodological approach provides substantial advantages for the research, ensuring minimal discomfort for participants and preserving the integrity of the skin barrier. Signal acquisition is facilitated through jumper wires, transmitting data from the sensor to an ESP32 development board, which subsequently utilizes Bluetooth v4.2 for wireless data transmission.

The Myoware Sensor is designed to extract data from muscles in the form of an analog signal, which is subsequently processed into a digital signal. This data carries crucial information about muscle activity during contraction compared to its relaxed state, stemming from the registration of changes in the polarization of muscle cells. The signal exhibits distinct characteristics, including amplitude, frequency, and waveform shape, all dependent on muscle activity levels.

Data transmitted from the sensor is received through an application on a mobile device via a Bluetooth module and subsequently transferred as text files to a computer. Then, voltage-muscle time dependency graphs are generated, providing valuable insights into muscle activity patterns and changes over time.

### 3.3 Measurement Procedure

To collect sEMG data, we devised a measurement procedure enabling the comparison of muscle activity between healthy individuals (control group) and subjects with Parkinson's disease (study group). The stimulus informing the subject about the onset of the measurement needed not to require the use of systems other than the sensor-motor one. Therefore, we utilized a servo mechanism, with its vibration signaling the start and end of the measurement. The procedure has three stages:

- The first stage involves measuring the resting activity of the biceps muscle for 30 s.
- The second stage entails a 30 s measurement while holding a 2 kg weight with the arm bent at a 90-degree angle, the elbow close to the body, and the forearm parallel to the floor.
- The final stage involves alternating arm flexion and extension with the 2 kg weight at 5 s intervals.

Each of these stages commences with three servo vibrations as a readiness confirmation. The measurement starts and stops with a single vibration and each interval is also separated by vibration.

### 3.4 Data Processing

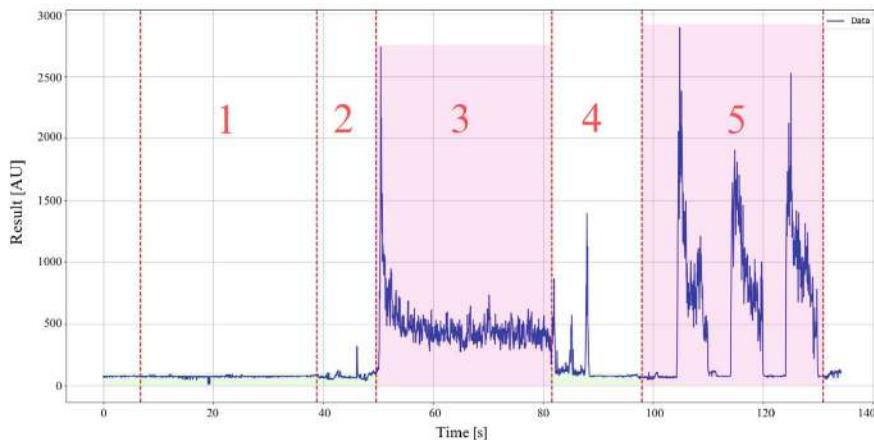
In this study, Python was used to analyze EMG data for assessing Parkinson's disease severity. The analysis pipeline included data collection, cleaning, feature extraction, visualization, and model evaluation to ensure data integrity and quality. SEMG data from both healthy individuals and Parkinson's disease patients were loaded from CSV files. Various statistical features were calculated from the sEMG signals, including RMS, MDF, Mean Frequency, Variance, Skewness, Kurtosis, SD, REC, DET, SampEn, and CD.

In the machine learning model evaluation phase, features and labels were standardized, and the data was split into training and testing sets. Techniques such as Principal Component Analysis (PCA) and Recursive Feature Elimination (RFE) were used to select relevant features. Support Vector Machine (SVM) and RandomForestClassifier models were employed for classification. Models were evaluated using cross-validation, confusion matrices, classification reports, and ROC curves. Results were visualized with box plots comparing features between healthy and PD groups, as well as left and right hand data within each group. An example of an acquired sEMG signal is shown in Fig. 1.

## 4 Results

### 4.1 Linear and Nonlinear sEMG Parameters

The data analysis identified three key sEMG parameters: MDF (Median Frequency), Mean Frequency, and Sample Entropy (SampEn). The MDF values, with a mean of 7.69 ( $SD = 1.91$ ), demonstrated relative stability across samples, indicating consistent frequency content in the EMG signals. This stability is crucial for distinguishing between healthy and PD-affected muscles. Mean Frequency values hovered around zero, reflecting a balanced frequency distribution in the signals. This balance suggests



**Fig. 1** Example of an sEMG signal with marked segments: Segment 1—Relaxation Phase; Segment 2—Preparation for Contraction; Segment 3—Maintenance of Contraction; Segment 4—Preparation for Repetitions; Segment 5—Execution of Repetitions

that the EMG signals maintain a consistent overall frequency profile, which is essential for reliable comparative analysis. Sample Entropy (SampEn), with a mean of 0.898 ( $SD = 0.614$ ), highlighted the complexity and irregularity of the EMG signals. Higher SampEn values suggest more complex and less predictable muscle activation patterns, which are often associated with pathological conditions like Parkinson's disease. These parameters collectively provide a robust basis for assessing motor symptoms in PD patients. Variability in RMS and MDF measurements has been observed. Specifically, the mean RMS was 503.08 ( $SD = 491.26$ , min = 12.84, max = 2548.65), indicating a wide range of values across participants. Similarly, the mean MDF shows variability in frequency domain characteristics. These results corroborate the observations of Fundaro et al. [5], indicating that RMS increases in response to various loads and MDF can reflect differences between groups. However, while Fundaro et al. focused on biceps activity, our study considered a broader range of muscle activities, potentially contributing to the higher variability observed in our RMS values. Furthermore, this study explored nonlinear parameters such as Skewness (mean = 2.47,  $SD = 3.53$ , min = -4.52, max = 19.85) and Kurtosis (mean = 24.83,  $SD = 65.38$ , min = -1.57, max = 426.37). These parameters exhibited significant variability, underscoring their potential utility in assessing motor function under different conditions. Statistical comparison between Healthy and Parkinson Disease groups are presented in Table 3.

Meigal et al. [7] compared classical linear sEMG parameters (RMS, MDF) with less investigated nonlinear sEMG parameters (Kurtosis, SD, %REC, %DET, SampEn, CD). They found that RMS increased with load across all groups, while MDF showed a significant increase only in the PD group. Nonlinear sEMG parameters exhibited significant differences between the PD group and the control group, particularly in the absence of additional load. Our study results show similar trends,

**Table 3** Statistical comparison between healthy and Parkinson disease groups

| Group    | Mean    |         | Std     |         | Min    |         | Max      |         |
|----------|---------|---------|---------|---------|--------|---------|----------|---------|
|          | PD      | Healthy | PD      | Healthy | PD     | Healthy | PD       | Healthy |
| RMS      | 503,080 | 466,990 | 491,260 | 322,040 | 12,840 | 27,640  | 2548,650 | 961,530 |
| MDF      | 7,690   | 6,870   | 1,910   | 3,270   | 0,310  | 0,310   | 9,750    | 9,750   |
| MeanFreq | -0,004  | -0,002  | 0,006   | 0,006   | -0,024 | -0,014  | 0,000    | 0,004   |
| Skewness | 2,470   | 2,690   | 3,530   | 4,050   | -4,520 | -4,520  | 19,850   | 10,170  |
| Kurtosis | 24,830  | 11,590  | 65,380  | 43,890  | -1,570 | -0,840  | 426,370  | 117,030 |
| SD       | 244,710 | 239,390 | 237,570 | 199,520 | 2,020  | 2,020   | 1192,090 | 658,090 |
| REC      | 0,032   | 0,048   | 0,048   | 0,065   | 0,003  | 0,003   | 0,200    | 0,200   |
| DET      | 0,255   | 0,077   | 1,285   | 0,089   | 0,000  | 0,000   | 10,239   | 0,270   |
| SampEn   | 0,898   | 0,684   | 0,614   | 0,512   | 0,044  | 0,044   | 2,306    | 1,760   |
| CD       | 1,290   | 1,060   | 0,560   | 0,640   | 0,000  | 0,000   | 2,090    | 2,107   |

with a mean RMS of 503.08, indicating an increase with load, and a mean MDF of 7.69, with higher values observed in the PD group. Nonlinear parameters, such as REC (mean = 0.032, SD = 0.048), DET (mean = 0.255, SD = 1.285), and SampEn (mean = 0.898, SD = 0.614), exhibited significant variability, corroborating the differences observed by Meigal et al. One notable difference is that while Meigal et al. highlighted the significance of these nonlinear parameters primarily in the absence of additional load, our study observed their relevance under various conditions, including different loads.

Overall, our results contribute to understanding the diverse characteristics of sEMG signals in both healthy individuals and those with Parkinson's disease, highlighting the importance of considering a broad range of muscle activities and conditions in such studies.

## 4.2 Classification Effectiveness of sEMG in PD Assessment

The classification model's effectiveness in distinguishing between healthy individuals and those with Parkinson's disease was evaluated on different data subsets. Despite a small sample size, it showed promising accuracy and reliability. For the complete dataset, the model achieved an average cross-validation accuracy of 0.77 and an overall accuracy of 0.78. For left hand data, the performance improved to 0.81 for both metrics. The best results came from right hand data, with both average cross-validation and overall accuracy at 0.83, demonstrating the model's robustness and effectiveness. Detailed results are shown in Table 4.

These results demonstrate that sEMG features like RMS, MDF, Skewness, and Kurtosis effectively distinguish between healthy individuals and those with Parkinson's disease. The consistent performance of the classification model across

**Table 4** Classification model performance for the complete dataset, right hand data and left hand data

| Metric                  | Healthy vs PD subjects              | Right hand data                     | Left hand data                      |
|-------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Cross-validation scores | [0.772, 0.777, 0.766, 0.774, 0.773] | [0.784, 0.846, 0.825, 0.835, 0.828] | [0.811, 0.806, 0.802, 0.804, 0.804] |
| Confusion matrix        | [[3519, 830], [1005, 2877]]         | [[1863, 282], [410, 1553]]          | [[1755, 422], [379, 1567]]          |
| F1-Score (Healthy)      | 0.79                                | 0.84                                | 0.81                                |
| F1-Score (PD)           | 0.76                                | 0.82                                | 0.80                                |
| Accuracy                | 0.78                                | 0.83                                | 0.81                                |
| Macro avg F1-score      | 0.78                                | 0.83                                | 0.81                                |
| Weighted avg precision  | 0.78                                | 0.83                                | 0.81                                |

different data subsets highlights the potential of sEMG for objective PD severity assessment. Incorporating low-cost sEMG into clinical protocols could improve the diagnosis and monitoring of PD, offering a non-invasive and reliable method to support patient care.

## 5 Conclusion

This study highlights the potential of wearable sensors, specifically surface electromyography (sEMG), to enhance the assessment of Parkinson's disease symptoms. It introduces a novel, non-invasive method for sEMG data collection and analysis to objectively evaluate PD severity, building on previous research demonstrating sEMG's utility in tracking disease progression.

In our study, we observed that in Poland, the Unified Parkinson's Disease Rating Scale is not frequently used in standard PD severity assessments, leading us to rely on more subjective descriptions of PD severity. However, our study utilized the Myoware sensor and specific signal processing techniques to extract meaningful sEMG parameters. Despite the practical challenges prompting us to consider alternative development boards and external analog-to-digital converters for more accurate data acquisition, our study yielded significant findings.

The results show that while mean amplitude did not differ significantly between PD patients and healthy individuals, variance and mean frequency were effective descriptors, especially during sustained contraction tasks. This underscores the importance of examining various sEMG parameters beyond amplitude to gain deeper insights into muscle function and PD-related impairments. The broader Gaussian distribution in variance observed within the PD group suggests early signs of neuromuscular degradation not evident from central tendencies alone. This variability

highlights the dynamic nature of neuromuscular control in PD and the need for comprehensive assessment methods.

These findings have significant implications for clinical practice, offering a means to evaluate the efficacy of pharmacological therapies more accurately. Our sEMG profiling provides an objective measure of tremor severity, facilitating a more individualized approach to therapy, which is highly desirable in contemporary medical practice. When comparing our results with existing studies, such as those by Fundaro et al. [5] and Kleinhöfermann et al. [7], we observed consistent variability in sEMG parameters, both linear (RMS, MDF) and nonlinear (Skewness, Kurtosis). These findings align with previous research, reinforcing the validity of using sEMG in PD assessment. Our study, however, expands on this by demonstrating the effectiveness of variance and mean frequency as distinguishing factors during sustained contraction tasks. Moreover, our procedure utilized low-cost devices, demonstrating the potential for affordable healthcare solutions. The use of cost-effective equipment makes it feasible to implement similar methodologies in various healthcare settings, promoting broader accessibility and routine clinical application.

Future research should address the limitations of our study, such as the small sample size and hardware challenges. Increasing the sample sizes for both study and control groups will provide a more robust dataset, enhancing the reliability of our findings. Additionally, exploring advanced hardware configurations and integrating deep learning for signal processing can significantly improve our methodology.

Standardization of sEMG data collection across different participants was ensured by using the same type of electrodes, consistently positioning them on the center of the biceps brachii muscle, and programming a servo mechanism to print messages indicating the start and end of each measurement stage. Timestamps from these printed messages were compared with the acquired data to ensure precise synchronization.

In conclusion, our research underscores the importance of analyzing sEMG signals in PD severity assessment. While this study provides valuable preliminary insights, future longitudinal studies are necessary to assess changes in sEMG parameters over time in PD patients. We envision our methodology being integrated into clinical standard protocols in the future, ultimately enhancing the diagnostic and monitoring processes for Parkinson's disease.

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## References

1. <https://www.who.int/news-room/fact-sheets/detail/parkinson-disease>, 22 Apr 2024
2. Hoehn MM, Yahr MD (1967) Parkinsonism. *Neurol* 17(5):427–427. <https://doi.org/10.1212/WNL.17.5.427>

3. Sullivan SO', et al. (2008) Clinical outcomes of progressive supranuclear palsy and multiple system atrophy. *Brain* 131:1362–1372. <https://doi.org/10.1093/brain/awn065>
4. Farhani G, Zhou Y, Jenkins ME, Naish MD, Trejos AL (2022) Using deep learning for task and tremor type classification in people with parkinson's disease. *Sens* 22(19). <https://doi.org/10.3390/s22197322>
5. Fundaró C, Gazzoni M, Pinna G, Dallocchio C, Rainoldi A, Casale R (2021) Is fatigue a muscular phenomenon in Parkinson's disease? Implications for rehabilitation. *Eur J Phys Rehabil Med* 57. <https://doi.org/10.23736/S1973-9087.21.06621-1>
6. Kleinholdermann U, Wullstein M, Pedrosa D (2021) Prediction of motor unified Parkinson's disease rating scale scores in patients with Parkinson's disease using surface electromyography. *Clin Neurophysiol* 132(7):1708–1713. <https://doi.org/10.1016/j.clinph.2021.01.031>
7. Meigal AI et al (2009) Novel parameters of surface EMG in patients with Parkinson's disease and healthy young and old controls. *J Electromyogr Kinesiol* 19(3):e206–e213. <https://doi.org/10.1016/j.jelekin.2008.02.008>
8. <https://myoware.com/products/technical-specifications/#muscle-sensor>, 22 Apr 2024
9. <https://www.fannin.eu/wp-content/uploads/2018/06/ECG-Catalogue.pdf>, 30 Apr 2024
10. Amundsen HSL, Van Acker GM, Luchies CW, Cheney PD (2018) Muscle synergies obtained from comprehensive mapping of the cortical forelimb representation using stimulus triggered averaging of EMG activity. *J Neurosci* 38:8759–8771
11. Brückner S et al (2023) A wireless joint communication and localization EMG-Sensing concept for movement disorder assessment. *IEEE J Electromagn RF MicrowS Med Biol* 7(4):440–449. <https://doi.org/10.1109/JERM.2023.3321974>

# Air Pollutant Prediction Using Shallow Architecture Machine Learning Algorithms



Moses Olaifa and Vusumuzi Malele

**Abstract** Over the past few decades, mortality rates associated with air quality pollution have risen in numerous countries around the globe. This pollution stems from different factors such as meteorological conditions, human activities from urban industrialization, vehicular emission, and so on. Air pollution constituents such as NO<sub>2</sub>, CO, SO, and coarse and fine particulate matter for different locations have been analyzed to learn both correlation and inter-dependency for long and short terms. However, many of these studies overlook datasets collected using low-cost tools and equipment. Most of the time, datasets of this nature are marred with inconsistencies and gaps at irregular intervals. This may render the air pollutant data unsuitable. In order to test the suitability of machine learning algorithms on such dataset, this study conducts a time-series forecast analysis using the prophet algorithm. Two additional models including linear regressor and random forest regressor are trained and tested on the same dataset and a comparative analysis of the three models is performed.

**Keywords** Random forest regressor · Prophet · Linear regressor · Prophet algorithm

## 1 Introduction

Pollution of air quality can be caused by nature and human activities. Changes in climatic or weather conditions, volcanic activities, wildfires, and biogenic emissions such as plant decay can introduce harmful components into the air. Human activities embedded in the urbanization and industrialization growth birth all forms of

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emissions. All these activities and more influence the amount of concentration of air pollutants in the atmosphere.

Due to its impact, not only on human health [1] but also on economic development, quality of air prediction has received attention from researchers across the globe. Efforts by governments and different organizations in introducing measures to provide clean air by reducing air pollution have assisted in improving the quality of air. However, there are more related problems that cannot be directly eradicated, such as pollution resulting from seasonal or climatic factors which may influence the changes in concentration of the pollutants at different times. Variation in the concentration and occurrences of pollution is a challenge because of the difficulty in tracking these changes by humans. Furthermore, in predicting the future trends, it is highly impossible to obtain accurate forecast due to high likelihood seasonal changes in meteorological circumstances. This in turn can cause an increased seasonal variation in the time series of these pollutants. It is a huge challenge to describe and extract these patterns by solely relying on traditional approach to forecasting. Hence, proposition of an efficient and effective technique to accurately capture seasonal changes in different climatic and weather conditions is highly imperative.

Application of statistical approaches in prediction or forecast of future pattern and trends has become a widely accepted practice in different fields including agriculture [2–4], healthcare [5, 6], financial management [7], engineering [8, 9], and others. The area of air quality is not excluded in the deployment of statistical models for pattern extraction and trend forecast. The Autoregression Integrated Moving Average (ARIMA) model was proposed in forecasting the concentration of  $\text{SO}_2$  and  $\text{NO}_2$  to determine monthly future air quality in Delhi, India [10]. The challenge with some of the simple statistical models is the lack of capability to accurately forecast from multiple pollution indexes. A preferred solution is to combine the multiple techniques and leverage on the strength of each. The study conducted by Zhu et al. [11] proposed two hybridized models to improve the accuracy of air quality indexes (AQI) forecast. The first model combines empirical mode decomposition (EMD) with support vector regression (SVR). The EMD is applied in the initial preprocessing of the AQI. The sum of the IMF obtained from the preprocessing is predicted using LS-SVR. Seasonal ARIMA is then used in the forecast of remains of EMD-IMF. For short-term prediction of an air quality pollutant, an approach that uses a case-based classifier that combines heuristic and statistical techniques has been proposed [12].

An experiment to determine the influence of some meteorological factors including the direction and speed of wind and precipitation in the distribution of the concentration of fine particulate in two different location is conducted in [13]. Boosted trees and linear support vector machine were applied in the classification of different fine particulate levels. To conduct the time-series analysis to determine the index levels, a neural network model was deployed. Another short-term prediction of PM2.5 pollutant was conducted in [14] by mining data from multiple sources. Using the multi-variate statistical analysis, the correlation analysis of PM2.5 against other pollutant was proposed. The study in [15] introduced the principal component analysis (PCA) to detect possible sources of air pollution such as industrial and vehicle emission. The tree-based ensemble learning model was subsequently applied to

forecast the air quality. Other efforts to improve on air quality prediction proposed the use of variants of neural networks including backward propagated neural networks and feed-forward neural networks to deal with some complex forecast. However, the models lack adequate capability to identify correlations in multi-variate input. To address this, Fu et al. [16] designed an improved feed-forward neural network enhanced with accumulated generating operator (AGO) and rolling mechanism (RM) to address the input direction on a long-term basis.

Even though the machine learning approaches prove to be a step ahead of statistical models, they have limitations in learning long-term correlations between air pollutants. Deep learning, on the other hand, has been discovered to produce a more efficient performance in capturing long-term interdependence in pollutants by considering nonlinear relationship between external variables and the forecast. LSTM variant such as transferred bi-directional LSTM has been designed to learn long-term dependencies in fine particulate matter [17]. In a bid to enhance the performance of deep learning models, Zhang et al. [18] merged variational mode decomposition (VMD) with bi-directional LSTM to produce an hybridized system that can predict any change in the concentration of PM2.5. The VDM served the purpose of breaking down raw fine particulate data into several sub-signals that is employed by the biLSTM for the forecast.

Both the variants and enhanced deep learning algorithms have proven to be more accurate in the forecast of larger temporal resolutions and long-term pollutants' correlation. However, areas with sparse data have received less attention. Most areas with less equipped monitoring station are faced with lack of consistent data collection due to challenges related to low-cost equipments and power instability among others. These translate to large gaps in collected data. In this study, shallow architecture machine learning algorithms are deployed in the forecast of PM2.5 concentration using datasets with high level of inconsistency due to large number of missing data. Three models, namely, prophet, linear regressor, and random forest regressor are trained on this time-series dataset to determine their performance on these types of dataset through the accuracy of the forecast. The remainder of this paper is divided into the following sections: methodology section defines the data preprocessing and analysis adopted by this study. In addition, the prophet algorithm is discussed. Experiment and result discussion section detailed the experiment and findings from the outcome of the experiment.

## 2 Methodology

### 2.1 Dataset Pre-processing and Analysis

In our experiment, we used a 12 months (January 2017–December 2017) of time-series data from air quality station 2, Salterhebble, Halifax. The dataset includes three features of date, time, and the PM2.5 value. To pre-process the data into suitable

time-series data, the date and time columns are merged and converted into a datetime format. After merging the two columns, the dataset has two features of date and PM2.5 values, where the datetime column is converted into an index column for the time-series forecast experiment. In this study, the first 11 months considered for training the model and the 12th month were used for validating the model. For improved model performance and regularization of the PM2.5 values in the dataset, the PM2.5 column was normalized. To normalize the PM2.5 values, Eq. (1) is applied.

$$Z = \frac{x_i - \mu_i}{\sigma_i}, \quad (1)$$

where  $x_i$  denotes the PM2.5 value at the  $i$ th hour and  $\mu_i$  and  $\sigma_i$  represent the mean and standard deviation of the distribution at the  $i$ th hour. The equation normalizes the PM2.5 values by transforming them to a mean of 0 and standard deviation of 1.

## 2.2 The Prophet Model

The FBProphet is a time-series forecasting algorithm that models time-series data in terms of trend, seasonality, and noise components. The data trend determines the direction of the time series over a period of time. This can be upward, downward, or ranging with a nearly constant mean. Seasonality denotes recurring patterns within certain period which can be regular. These patterns are repeated on a timeframe basis such as weekly, monthly, yearly, or daily. The noise component captures parts of the data that is not described in the trend or seasonality. Sometimes, outliers can be a captured as part of the noise.

$$Y_t = g_t + f_t + h_t + \epsilon_t, \quad (2)$$

where  $g_t$  represents the trend that defines non-periodic changes,  $f_t$  is the seasonality that defines periodic changes,  $h_t$  represents the holiday effect, and  $\epsilon_t$  defines the error term. This algorithm models the trend component using a piecewise linear regression model using Eq. (3). Due to the fact that the trend may be a series of pull-backs (change points), the piecewise linear trend of the prophet model combines the linear functions of the pull-backs and the respective gradients. This allows the algorithm to capture flexible patterns in the long-term direction of the time series:

$$g_t = \sum_{k=1}^n (m_k * \max(0, t - t_k)), \quad (3)$$

where  $k$  is the number of change points in the piecewise linear trend,  $m_k$  is the gradient of the trend segment starting at the reversal point  $t_k$ , and  $t_k$  is the  $k$ th datapoint denoting a time when the gradient of the trend changes. To ensure that the trend is zero

before the reversal and that the gradient becomes active, the function  $\max(0, t - t_k)$  is introduced.

The Fourier series [21, 22] is used to model the seasonality aspect of the prophet algorithm.

$$f_t = \sum_{i=1}^{\infty} \left[ a_i \cos\left(\frac{2\pi n t}{T}\right) + b_i \sin\left(\frac{2\pi n t}{T}\right) \right], \quad (4)$$

where  $f_t$  is the seasonality function,  $n$  is the harmonic number representing the frequency of terms, and  $a_i$  and  $b_i$  denote coefficients that determine the size of the sine and cosine terms. These coefficients are computed as shown in Eqs. (5) and (6).

$$a_i = \frac{2}{T} \int_0^T f_t \cos\left(\frac{2\pi n t}{T}\right) dt \quad (5)$$

$$a_i = \frac{2}{T} \int_0^T f_t \sin\left(\frac{2\pi n t}{T}\right) dt. \quad (6)$$

### 2.3 Model Evaluation Metrics

The measurement of the models to determine the efficiency in training on the dataset and forecasting is achieved using the mean squared error (MSE), mean absolute error (MAE), and the coefficient of determination ( $R^2$ ). The MSE computes the average squared difference between the expected values and predicted values of the model. This is computed using equation:

$$MSE = \frac{\sum_{i=1}^n (y_i - \gamma_i)^2}{n}, \quad (7)$$

where  $y_i$  and  $\gamma_i$  are the expected and predicted values at iteration  $i$ , respectively.  $\bar{y}$ .  $R^2$  is used to measure the goodness of fit of the model. That is, how accurate is the model performance in replicating the target variable. The equation for  $R^2$  is given as

$$R^2 = 1 - \frac{\sum_{i=1}^n (y_i - \gamma_i)^2}{\sum_{i=1}^n (y_i - \bar{y}_i)^2}, \quad (8)$$

where  $\bar{y}_i$  denotes the mean of the expected value  $y$ . MAE describes the absolute error between the expected and predicted values. Although MAE is considered to be less sensitive to the presence of outliers in the dataset than the  $R^2$  and MSE, it is used as an additional measurement in this study because the target values are continuous values in which the MAE is best suited. MAE is computed using the equation:

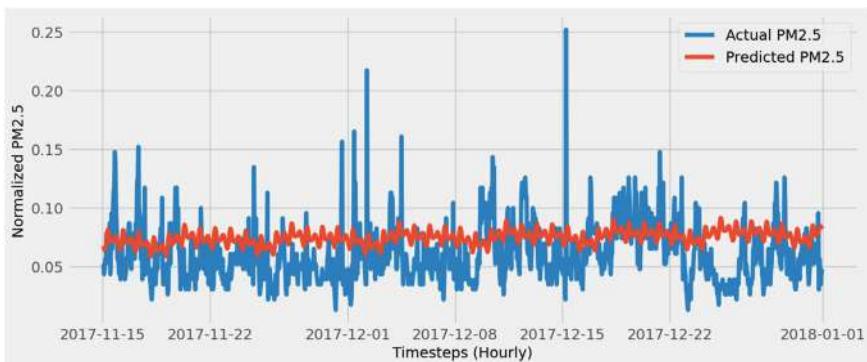
$$MAE = \frac{\sum_{i=1}^n |y_i - \gamma_i|}{n}. \quad (9)$$

### 3 Experiment and Result Discussion

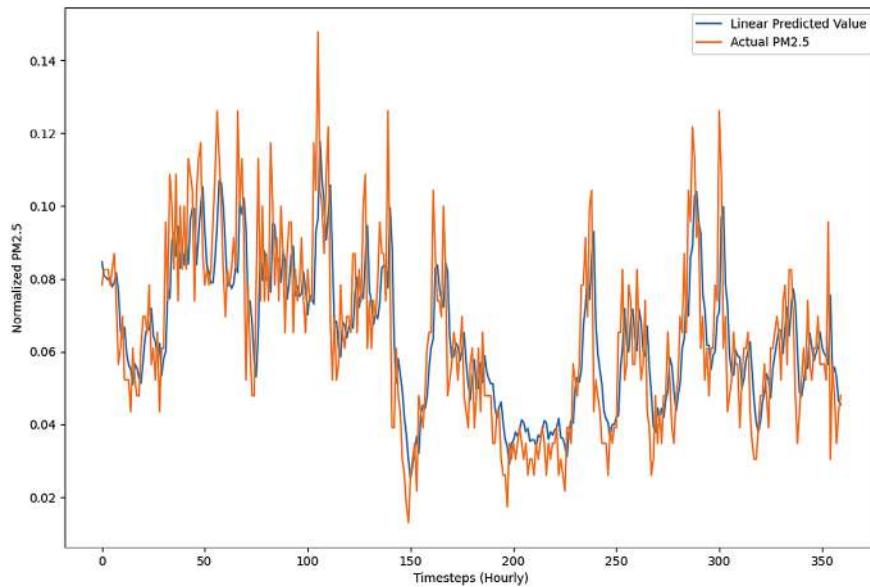
In the conducted experiments, two other shallow architecture algorithms, linear regressor and random forest regressor models, were training along with the prophet algorithms in order to perform a comparative analysis of the models. The first 8395 h (approx. 11 months) were used for the training and the last 360 h (approx. 1 month) were used for the validation of the models. Initially, there were 92 missing PM2.5 values but the missing values were replaced using time interpolation. After the training, the hourly estimation of the particulate matter for the next 360 h (30 d) was predicted using the three models.

The figures below show the forecast of each of the models against the actual (expected) pm2.5 values.

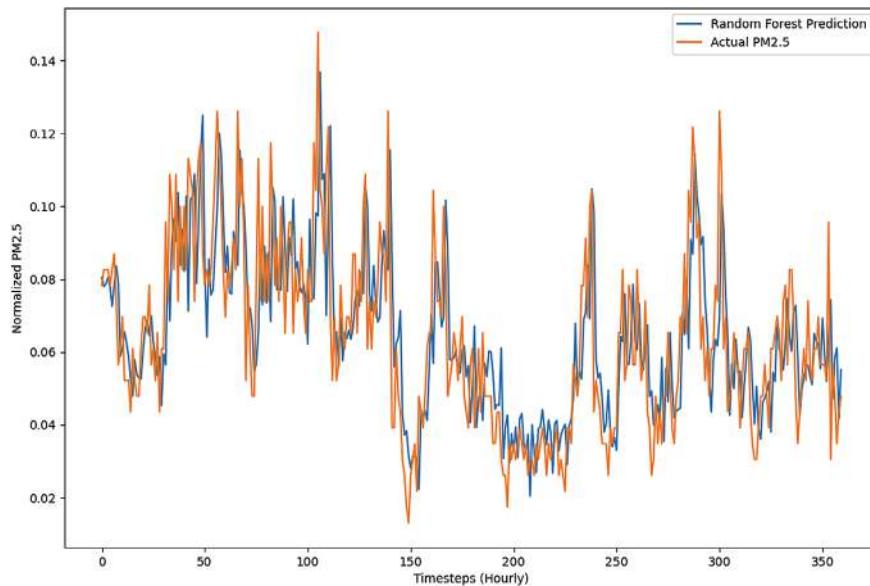
Figure 1 shows the forecast from the prophet algorithm. Figures 2 and 3 present the forecast from the linear regression and random forest models, respectively. In Fig. 1, the prophet model performed poorly in the forecast of the 360 timesteps into the future. When compared to the actual PM2.5 values, the model made a failed attempt to fit the test data. On the other hand, the linear regressor and random forest predicted a better fit. From Fig. 3, the forecast PM2.5 values closely fit most of the peak highs and lows of the actual PM2.5 values. However, there appears to be obvious gaps between the mid-range forecast values and the actual values. From the 120th timestep to around the 300th timestep, it can be observed that the forecast values are running few steps ahead of the expected (actual) values. Unlike the random forest, the linear regressor did not accurately fit the extreme highs and lows of the PM2.5 values. However, it better fits the mid-range values than the random forest.



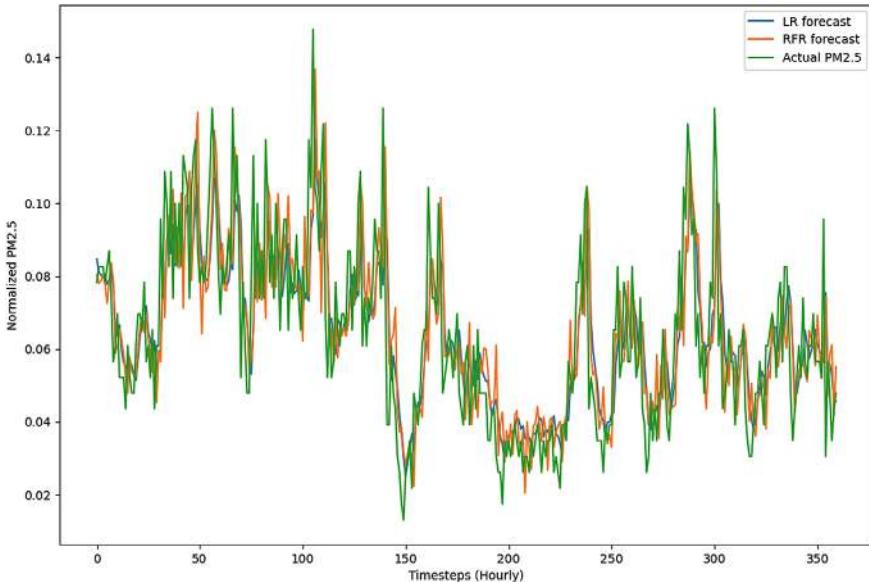
**Fig. 1** Prophet forecast versus actual



**Fig. 2** Linear regression forecast versus actual



**Fig. 3** Random forest forecast versus actual



**Fig. 4** Linear regression versus random forest

Figure 4 shows the forecasts of the linear regression, random forest regressor, and the actual PM2.5 values. From this figure, the linear regression model displays a better fit of the mid-range values except for few timesteps. Furthermore, the figure shows lead with a couple of timesteps ahead in the forecast values of the random forest regression model. However, the model fits some of the high values of the PM2.5 better than the linear regressor. A similar performance can be observed for some of the lows but not as much as the highs. Overall, the linear regressor produced a better performance as it shows a more accurate forecast of the PM2.5 values. Even though the random forest made some better forecasts for the highs and lows, some of these values (especially the highs) are outliers.

Table 1 presents the performance metrics for the three models. The mean square error (MSE), root mean square error (RMSE), mean absolute error (MAE), and the coefficient of determination ( $R^2$ ) were used in the evaluation of the model performance as given in Table 1. There are two parts to the measurements presented in the table, which are the performance of the models over training and test sets, respectively. In the performance measurement over the training set, the linear regressor produced the least *MSE* of 0.00061 for the training and the prophet algorithm produced the highest *MSE* of 0.00138.

This indicates a least error recorded for the linear regression model over the training set and higher error over the training set for the prophet algorithm. The *RMSE* result is similar for the three models with the linear regressor recording the least error and the prophet recording the highest error. However, the random forest model records the lowest *MAE* score and highest  $R^2$  scores over the training set than

**Table 1** Performance metrics for the three models

|               | Training set |         |         |                | Validation set |         |         |                |
|---------------|--------------|---------|---------|----------------|----------------|---------|---------|----------------|
|               | MSE          | RMSE    | MAE     | R <sup>2</sup> | MSE            | RMSE    | MAE     | R <sup>2</sup> |
| Prophet       | 0.00138      | 0.03715 | 0.02303 | 0.11014        | 0.00081        | 0.02846 | 0.02366 | -0.30299       |
| Linear        | 0.00061      | 0.02470 | 0.01384 | 0.25348        | 0.00025        | 0.01581 | 0.01196 | 0.30474        |
| Random forest | 0.00095      | 0.03082 | 0.00552 | 0.91846        | 0.00029        | 0.01703 | 0.01196 | 0.35604        |

the other two algorithms while the prophet algorithm produced the highest *MAE* and lowest *R*<sup>2</sup> scores. This means that with the consideration of the existing outliers in the dataset, the random forest produced the least error between the forecast and actual data points. In addition, a *R*<sup>2</sup> score close to 1 indicates that the model is more suitable for the dataset than the other two models. Consequently, a *R*<sup>2</sup> score of 0.11014 (closer to 0) produced by the prophet model is an indication that it is a poor model for the dataset.

The performance measurement of validating the three models over the test data resulted in a negative *R*<sup>2</sup> score for the prophet model. This can be interpreted as an inability of the model to capture intrinsic patterns in the dataset. This can be confirmed by the low *R*<sup>2</sup> result of the model over the training set. The linear regression model proved to return a lower error than the random forest with a lower *MSE* and *RMSE* scores. Both models produced the same *MAE* score. The random forest generated a higher *R*<sup>2</sup> score than the linear regression model and this can be interpreted as a slightly better model for the dataset. However, when the *R*<sup>2</sup> score of the random forest over the training set is compared with the score over the test set, there is a huge gap. This can be a problem of the model overfitting the training data. As a result of this, a poor generalization of new dataset (test data) may occur. This can be observed from Figs. 3 and 4 with the forecast values generated by the random forest model with a lead of a couple of timesteps beyond the actual PM2.5 values. On the other hand, the linear model records a higher *R*<sup>2</sup> result over the test data than the training data. This can be considered a better model for this dataset than the random forest.

## 4 Conclusion

In this paper, a 360 h forecast of PM2.5 was conducted based on the prophet algorithm. The historical dataset used was pre-processed and analyzed to address the huge gap of missing value in the dataset by using time-based interpolation over linear interpolation. Linear regression and random forest regression models were trained and tested on the same dataset. The performance of the two additional models was compared with the prophet algorithm to determine the suitability of these models on this type of data. The result indicates a poor performance on the prophet

algorithm while the linear regressor produced the most accurate forecast of the three models. In the future, rather than interpolating, shallow architecture algorithms will be considered for predicting the missing values.

## References

1. Goyal P, Chan AT, Jaiswal N (2006) Statistical models for the prediction of respirable suspended particulate matter in urban cities. *Atmos Environ* 40(11):2068–2077
2. Shortridge JE, Falconi SM, Zaitchik BF, Guikema SD (2015) Climate, agriculture, and hunger: statistical prediction of undernourishment using nonlinear regression and data-mining techniques. *J Appl Stat* 42(11):2367–2390
3. Pant J, Pant RP, Singh MK, Singh DP, Pant H (2021) Analysis of agricultural crop yield prediction using statistical techniques of machine learning. *Mater Today Proc* 46:10922–10926
4. Burdett H, Wellen C (2022) Statistical and machine learning methods for crop yield prediction in the context of precision agriculture. *Precis Agric* 23(5):1553–1574
5. Malehi AS, Pourmotahari F, Angali KA (2015) Statistical models for the analysis of skewed healthcare cost data: a simulation study. *Health Econ Rev* 5:1–16
6. Su TL, Jaki T, Hickey GL, Buchan I, Sperrin M (2018) A review of statistical updating methods for clinical prediction models. *Stat Methods Med Res* 27(1):185–197
7. Lorek KS (2014) Trends in statistically based quarterly cash-flow prediction models. In: *Accounting forum*, vol 38, no 2, pp 145–151. No longer published by Elsevier
8. Huang Q, Nouri H, Xu K, Chen Y, Sosina S, Dasgupta T (2014) Statistical predictive modeling and compensation of geometric deviations of three-dimensional printed products. *J Manuf Sci Eng* 136(6):061008
9. Hamidieh K (2018) A data-driven statistical model for predicting the critical temperature of a superconductor. *Comput Mater Sci* 154:346–354
10. Gourav, Rekhi JK, Nagrath P, Jain R (2020) Forecasting air quality of Delhi using ARIMA model. In: *Advances in data sciences, security and applications: proceedings of ICDSSA 2019*. Springer, Singapore, pp 315–325
11. Zhu S, Lian X, Liu H, Hu J, Wang Y, Che J (2017) Daily air quality index forecasting with hybrid models: a case in China. *Environ Pollut* 231:1232–1244
12. Kalapanidas E, Avouris N (2001) Short-term air quality prediction using a case-based classifier. *Environ Model Softw* 16(3):263–272
13. Kleine Deters J, Zalakeviciute R, Gonzalez M, Rybarczyk Y (2017) Modeling PM 2.5 urban pollution using machine learning and selected meteorological parameters. *J Electr Comput Eng*
14. Ni XY, Huang H, Du WP (2017) Relevance analysis and short-term prediction of PM2. 5 concentrations in Beijing based on multi-source data. *Atmos Environ* 150:146–161
15. Singh KP, Gupta S, Rai P (2013) Identifying pollution sources and predicting urban air quality using ensemble learning methods. *Atmos Environ* 80:426–437
16. Fu M, Wang W, Le Z, Khorram MS (2015) Prediction of particular matter concentrations by developed feed-forward neural network with rolling mechanism and gray model. *Neural Comput Appl* 26:1789–1797
17. Ma J, Cheng JC, Lin C, Tan Y, Zhang J (2019) Improving air quality prediction accuracy at larger temporal resolutions using deep learning and transfer learning techniques. *Atmos Environ* 214:116885
18. Zhang Z, Zeng Y, Yan K (2021) A hybrid deep learning technology for PM 2.5 air quality forecasting. *Environ Sci Pollut Res* 28:39409–39422
19. Kumar R, Peuch VH, Crawford JH, Brasseur G (2018) Five steps to improve air-quality forecasts

20. Du P, Wang J, Hao Y, Niu T, Yang W (2020) A novel hybrid model based on multi-objective Harris hawks optimization algorithm for daily PM2.5 and PM10 forecasting. *Appl Soft Comput* 96:106620
21. Tolstov GP (1976) Fourier series. Courier Corporation, Dover, New York
22. Hardy GH, Rogosinski W (1999) Fourier series, vol 1. Courier Corporation

# Criminal Liability and Artificial Intelligence: A Systematic Review of the Scientific Literature



Leslye Escalante-Huisacayna , Yasmina Riega-Virú ,  
Kiara Nilupú-Moreno , and Juan Luis Salas-Riega

**Abstract** The article presents a systematic review of the scientific literature on criminal liability in the context of artificial intelligence (AI), with the aim of the study to examine how AI is being addressed in terms of criminal liability in different areas, finding 40 relevant articles that explore the criminal liability of AI in fields such as medicine, robotics, autonomous vehicles, and the administration of justice. The results show the impact of AI on criminal law, concepts such as electronic personality, the determination and individualization of criminal responsibility, ethics and autonomy, traditional criminal law, and the permissible risk of AI are discussed. It proposes to consider AI as a subject of law and explores the legislative challenges of including “digital personality” in the criminal legal system.

**Keywords** Artificial intelligence · Criminal liability · Criminal law · Digital personality

## 1 Introduction

The intersection between artificial intelligence (AI) and criminal liability is an emerging field that raises fundamental questions about how electronic entities can fit within existing legal frameworks. As AI becomes increasingly integrated into various aspects of everyday life, from medicine to robotics to autonomous vehicles,

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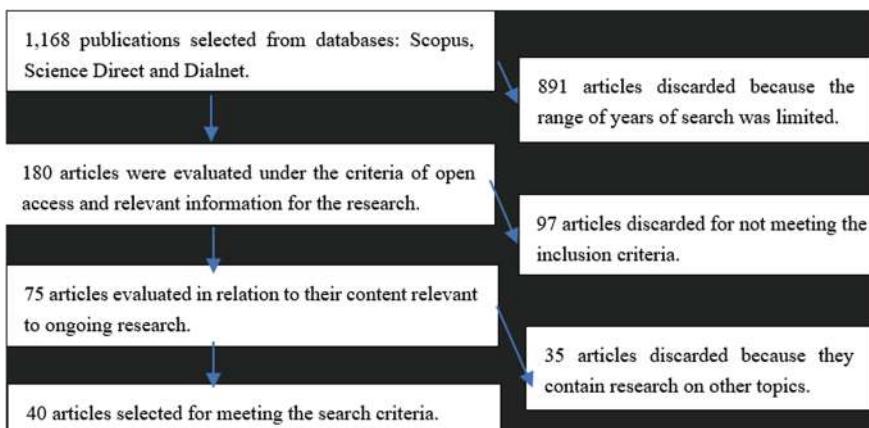
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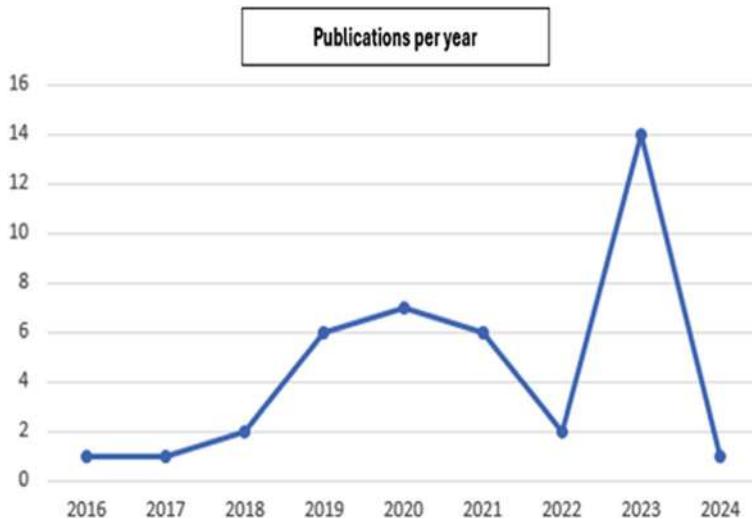
the need arises to reevaluate and possibly reform traditional notions of culpability and legal responsibility [1–3]. This paper discusses how AI challenges the principles of traditional criminal law, which is based on the capacity for understanding and will, and considers the possibility of attributing an “electronic personality” to AI entities, which would allow them to take legal responsibility for their actions, Through a systematic review of the scientific literature, the impact of AI on criminal law is analyzed and the proposed approaches to address the ethical and legal challenges presented by this disruptive technology are discussed [4].

## 2 Methodology

The methodology used was a systematic literature review [4], looking for articles related to artificial intelligence and criminal liability in international databases: Scopus, Science Direct, and Dialnet. The search terms were “artificial intelligence” and “criminal liability”. Scientific articles and systematic reviews published between 2016 and 2024, in English and Spanish, were included that addressed criminal liability for the use of AI, type of AI used, user area, and liability. Studies on software programming or computer engineering not related to law were excluded. “AND” and “OR” Boolean operators were used to identify relevant articles (Fig. 1).



**Fig. 1** Methodological sequence in the process of searching and selecting articles [5]



**Fig. 2** According to Fig. 2, in 2016 and 2017 there was one publication in each year. In 2018 and 2022, two annual publications were found, while in 2019 and 2021 there were six publications per year. In 2020, seven publications were made, in 2023 14 publications were found, and finally, in 2024 only one publication was found

### 3 Results

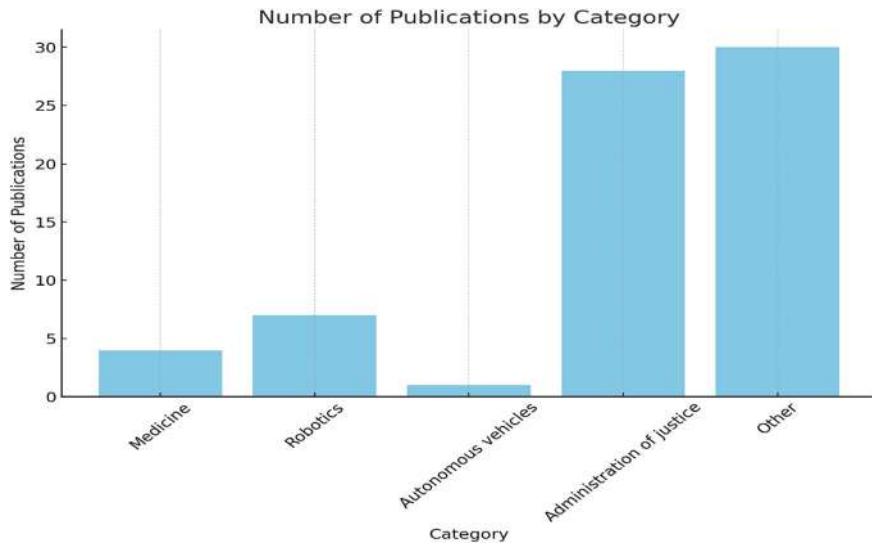
According to the results of a systematic review of 40 articles, Russia leads the list with eight published papers, followed by the United Kingdom with six and Spain with five. Italy ranks fourth with three publications. Egypt, China, and Germany share the fifth position with two articles each. Finally, the following countries have contributed one article each: United States, Turkey, Palestine, Netherlands, Mexico, North Macedonia, Indonesia, Finland, Croatia, Colombia, Chile, and Hungary.

Figure 3 presents a comprehensive overview of research on Criminal Responsibility and Artificial Intelligence across various fields. In the medical domain, Bartlett [6] and three other researchers [7–9] investigated AI's potential to enhance healthcare through advanced data analysis and decision-making, with a focus on improving accuracy and efficiency in patient care.

The field of Robotics saw contributions from five researchers [9–13], who explored AI applications that enable robots to perform tasks autonomously and intelligently, emphasizing their adaptive interactions with the environment.

In the realm of autonomous vehicles, four authors [10, 14–16] examined AI systems that facilitate self-driving capabilities and real-time decision-making without human intervention.

Bikeev et al. [2, 17] studied AI's role in justice administration, highlighting its potential to improve judicial efficiency and fairness while addressing crucial ethical concerns such as transparency and algorithmic accountability.



**Fig. 3** The systematic review covers various topics related to artificial intelligence (AI). Specifically, four articles address medicine, five deal with robotics, and four focus on autonomous vehicles. The administration of justice is the central theme of the two articles. Additionally, most of the studies, twenty-seven in total, explore AI applications in various other fields

A substantial group of 27 authors [1, 12, 16, 18–41] approaches the topic of AI's criminal responsibility from a broader perspective, examining its relationship with human behavior and its transformative impact on criminal law.

This diverse research landscape underscores the multifaceted nature of AI's influence on criminal responsibility across different sectors, reflecting the complexity and importance of this evolving field of study.

Table 1 on the impact of AI on criminal law shows: 14 publications address the creation of an electronic legal personality; 22 studies discuss the attribution of criminal responsibility to AI; 16 deal with ethical responsibility and autonomy; 17 analyze the impact of AI on traditional criminal law; and 12 identify the theory of permissible risk in AI.

### 3.1 *The Digital Personality*

The attribution of legal rights and responsibilities to AI marks a transition from traditional to digital criminal law [19, 35]. “Digital personality” poses legislative challenges by including AI in legal-criminal relations. There are opposing positions on AI responsibility. Some argue that personal responsibility cannot be attributed to AI due to its lack of legal personality, free will, intelligence, and consciousness [8, 23, 31].

**Table 1** Impact of artificial intelligence on criminal law

| N  | Authors                  | Digital personality | Determination and individualization | Responsibility from ethics and autonomy | Traditional criminal law | Permissible risk |
|----|--------------------------|---------------------|-------------------------------------|-----------------------------------------|--------------------------|------------------|
| 1  | Barlet [6]               |                     | 1                                   |                                         |                          |                  |
| 2  | Beck et al. [7]          |                     | 1                                   | 1                                       |                          |                  |
| 3  | Mia Swart [8]            | 1                   | 1                                   |                                         | 1                        |                  |
| 4  | Vuletic [9]              |                     |                                     |                                         | 1                        | 1                |
| 5  | Giannini et al. [10]     |                     | 1                                   |                                         | 1                        | 1                |
| 6  | Zuheir et al. [20]       |                     |                                     | 1                                       |                          |                  |
| 7  | Leyra et al. [1]         |                     |                                     | 1                                       |                          |                  |
| 8  | Yasser et al. [11]       | 1                   | 1                                   |                                         | 1                        |                  |
| 9  | Patrick [15]             |                     |                                     |                                         | 1                        | 1                |
| 10 | Russkevich et al. [21]   | 1                   |                                     |                                         |                          |                  |
| 11 | Straub [12]              |                     |                                     | 1                                       |                          |                  |
| 12 | Begishev [10]            |                     |                                     |                                         | 1                        |                  |
| 13 | Moneim et al. [42]       |                     | 1                                   |                                         | 1                        |                  |
| 14 | Bikeev et al. [2]        | 1                   | 1                                   |                                         | 1                        | 1                |
| 15 | Bokovnya et al. [22]     |                     |                                     | 1                                       |                          | 1                |
| 16 | Lagioia and sastor [23]  |                     | 1                                   |                                         |                          | 1                |
| 17 | Kirpichnikov et al. [24] | 1                   | 1                                   |                                         |                          | 1                |
| 18 | King et al. [25]         |                     | 1                                   |                                         |                          |                  |
| 19 | Uzman [26]               | 1                   |                                     |                                         |                          | 1                |
| 20 | Alexander et al. [27]    | 1                   | 1                                   |                                         | 1                        |                  |
| 21 | Rofi y Rizki [28]        |                     | 1                                   | 1                                       |                          |                  |
| 22 | Mosechkin [29]           | 1                   | 1                                   | 1                                       | 1                        | 1                |
| 23 | Andrea Perin [8]         |                     |                                     | 1                                       |                          |                  |

(continued)

**Table 1** (continued)

| N  | Authors               | Digital personality | Determination and individualization | Responsibility from ethics and autonomy | Traditional criminal law | Permissible risk |
|----|-----------------------|---------------------|-------------------------------------|-----------------------------------------|--------------------------|------------------|
| 24 | Khisamova et al. [30] | 1                   |                                     | 1                                       | 1                        | 1                |
| 25 | Shestak et al. [31]   |                     | 1                                   |                                         | 1                        |                  |
| 26 | Ugo Pagallo [13]      | 1                   |                                     |                                         |                          |                  |
| 27 | Robert van den [32]   | 1                   | 1                                   |                                         |                          |                  |
| 28 | Bartolini et al. [16] |                     | 1                                   |                                         | 1                        |                  |
| 29 | Beck, Susanne [4]     | 1                   |                                     |                                         | 1                        | 1                |
| 30 | Díaz et al. [33]      |                     |                                     | 1                                       |                          |                  |
| 31 | Ludvigsen et al. [9]  |                     | 1                                   |                                         |                          |                  |
| 32 | Rodrigues Rowena [34] |                     |                                     | 1                                       |                          |                  |
| 33 | Harbinja et al. [35]  |                     |                                     | 1                                       |                          |                  |
| 34 | Sari and Celik [36]   | 1                   | 1                                   | 1                                       |                          |                  |
| 35 | Alejandra Morán [37]  | 1                   |                                     | 1                                       |                          |                  |
| 36 | David Lorenzo [38]    |                     | 1                                   |                                         |                          |                  |
| 37 | Angelo Giraldi [39]   |                     | 1                                   |                                         |                          |                  |
| 38 | José Mateos [40]      |                     | 1                                   | 1                                       | 1                        |                  |
| 39 | Liced et al. [17]     |                     |                                     | 1                                       |                          |                  |
| 40 | Sun and Zhang [41]    |                     |                                     |                                         | 1                        | 1                |
|    |                       | 14                  | 21                                  | 16                                      | 17                       | 12               |

The doctrine proposes creating an “electronic personality” to group AI capabilities and responsibilities [3, 26, 28], allowing it to be subject to future legal relations with criminal responsibility [12]. Various proposals have been put forward: using legal fiction to treat AI personality [2, 28], granting it legal status like juridical persons [11], or considering it a subject of law with conscious decisions [24]. Digital personality could apply to advanced AI with independent decision-making [30]. Moran Espinoza [36] proposes recognizing AI as an active subject of crime, considering its capacity to commit cybercrimes, not just as a tool.

### ***3.2 Determination and Individualization of Liability***

The attribution of criminal responsibility to AI presents several models. Shestak [41] proposes three: commission through another, probable natural consequence, and direct liability of AI. Rahman et al. [25] offer similar perspectives on the responsibility of programmers or users. Some argue that AI does not meet the requirements for criminal liability [21, 22], and must fall on its creators [35, 37].

In medicine, AI could redefine “gross negligence” [6]. Autonomous vehicles and surgical robots pose new responsibility challenges [7, 13, 16]. There is debate about whether autonomous robots could be criminally responsible [31, 38]. Bustamante [39] distinguishes between weak and strong AI, suggesting that a “strong” AI could be responsible for autonomous value-based decisions.

To individualize the criminal liability of AI, the following are proposed: clear legal frameworks [4], strict liability [8], analysis of autonomy and human intervention [10, 26], and considering the responsibility of the programmer, user, and the AI itself [11]. It is also suggested to update the concept of “innocent harm” [24].

### ***3.3 Responsibility from Ethics and Autonomy***

A standardization and certification system for the creation and operation of AI is proposed as a measure to ensure ethical and responsible decisions. The implementation of clear and effective ethical frameworks is essential for the design, production, use, and modification of AI. It is crucial to develop ethical rules in software programs to prevent illicit acts and to develop mechanisms that restrict AI from acting outside of human control.

The use of AI algorithms in the administration of justice poses risks of perpetuating existing biases, which can result in unfair or overcrowded sentences. In addition, the authorship and identity of AI-generated texts raise concerns about projected truth. Therefore, it reflects on the ethics and autonomy of AI, especially in the context of strong AIs that could overcome human programming and act based on their “values”. Classifying AI into three categories—narrow AI, general AI, and superintelligent AI—provides insight into its level of autonomy and ethical implications.

Under this criterion, an AI's autonomy would be classified according to its ability to operate independently of human intervention and its ability to learn and adapt to different situations, which could lead to different degrees of legal liability. This classification of their autonomy is of utmost importance because it affects ethical considerations and the assignment of responsibility [1, 7, 8, 17, 18, 20, 22, 28–30, 34, 36, 40, 42].

### 3.4 Traditional Criminal Law

Traditional criminal law faces challenges in applying principles of personal responsibility to AI [11]. Kingston [18] exemplifies this with autonomous vehicles, questioning liability in accidents and highlighting the complexity due to AI's autonomy [18].

Hallevy [10] points out that machine learning and the unpredictability of AI challenge traditional legal foundations. Several authors [8, 20] suggest developing new regulations, while others [4, 7, 17, 39] propose creating special categories in criminal law that recognize the autonomy of AI. Espinoza [19] introduces “Penal Palingenesis”, advocating the transformation of criminal law for the digital world, considering “digital personality” and regulatory adaptation.

### 3.5 The Permissible Risk

The “permissible risk” in AI implies an acceptable level of risk with minimization measures [23], seeking to balance what is acceptable and unacceptable in new technologies [9]. Hallevy [10] proposes that AI could be a source of “unreasonable” harm, potentially exempting from liability in certain areas. Kingston [18] questions the social preparation to exempt the driver from responsibility in autonomous mode.

There is a debate about the ethical and legal limits of risks acceptable with AI [2, 4, 15] and the question of criminal liability arises when no one is directly guilty [21]. Regulatory gaps highlight the need for new legal models to prevent dangerous AI behaviors [12, 26]. Recognizing AI as a source of high risk implies strict liability, except for force majeure [28]. Assessment of permissible risk is crucial to determine liability and prevent technological disasters [3, 17].

## 4 Conclusions

Trustworthy AI can be achieved through ethical principles, regulations, and technical requirements that must be met throughout its lifecycle, philosophy and ethics influence AI regulation and are critical to ensuring ethical and responsible decisions [33,

35]. Such regulations will allow the use of AI not to transgress ethical principles and not incur in activities contrary to the norms, considering the principle of “meaningful human control” as a potential way to address these challenges.

It is proposed that AI with “limited personality” could be liable for damages and negative consequences, which would require a revision of key criminal law postulates and the creation of blank rules to regulate both human behavior and algorithms executed by technology [2, 7, 27].

The importance of establishing clear regulations that address the risks associated with AI, ensuring both user safety and technological innovation, is highlighted. Assessing the permissible risk is essential to determine the responsibility of AI and prevent possible negative consequences, thus ensuring responsible and ethical technological development. In conclusion, attributing criminal liability to AI will be given in relation to its autonomous nature and ability to act without human intervention. It is not feasible to attribute criminal liability to AI developers or users for acts committed by these autonomous entities, even more so if there is difficulty in establishing a direct causal relationship between the actions of the developer and those of the AI [2, 24].

## References

1. Leyra-Curiá S, Soler JP (2023) Lying in the age of artificial intelligence: A call to moral and legal responsibility. *Church Commun Cult* 8(2):135–153. <https://doi.org/10.1080/23753234.2023.2238001>
2. Bikeev I, Kabanov P, Begishev I, Khisamova Z (2019) Criminological risks and legal aspects of artificial intelligence implementation. In: Proceedings of the international conference on artificial intelligence, Information processing and cloud computing, New York, NY, USA: ACM, pp 1–7. <https://doi.org/10.1145/3371425.3371476>
3. Riega-Virú YB, Ninaquispe Soto ME, Salas JM, Natividad P, Salas-Riega JL, Nilupú-Moreno K (2023) Artificial intelligence and criminal justice: A systematic review of the scientific literature. In: Proceedings of the 21th LACCEI International Multi-Conference for Engineering, Education and Technology (LACCEI 2023), Latin American and Caribbean Consortium of Engineering Institutions. <https://doi.org/10.18687/LACCEI2023.1.1.1461>
4. Beck S (2016) Intelligent agents and criminal law—Negligence, diffusion of liability and electronic personhood. *Rob Auton Syst* 86:138–143. <https://doi.org/10.1016/j.robot.2016.08.028>
5. Gama ZADS, Gómez-Conesa A (2008) Factores de riesgo de caídas en ancianos: revisión sistemática. *Rev Saude Publica* 42:946–956. Accessed 20 Jun 2024. <https://www.scielosp.org/pdf/rsp/2008.v42n5/946-956/es>
6. Bartlett B (2023) The possibility of AI-induced medical manslaughter: Unexplainable decisions, epistemic vices, and a new dimension of moral luck. *Med Law Int* 23(3):241–270. <https://doi.org/10.1177/09685332231193944>
7. Beck S, Faber M, Gerndt S (2023) Legal aspects of the use of artificial intelligence and robotics in medicine and care | Rechtliche Aspekte des Einsatzes von KI und Robotik in Medizin und Pflege. *Ethik in der Medizin* 35(2):247–263. <https://doi.org/10.1007/s00481-023-00763-9>
8. Swart M (2023) Constructing ‘Electronic Liability’ for international crimes: transcending the individual in international criminal law. *Ger Law J* 24(3):589–602. <https://doi.org/10.1017/glj.2023.28>

9. Vuletic I (2023) Corporate criminal liability: An overview of the croatian model after 20 Years of practice. *Laws* 12(2):27. <https://doi.org/10.3390/laws12020027>
10. Giannini A, Kwik J (2023) Negligence failures and negligence fixes. A comparative analysis of criminal regulation of AI and autonomous vehicles. *Crim Law Forum* 34(1):43–85. <https://doi.org/10.1007/s10609-023-09451-1>
11. Ellamey Y, Elwakad A (2023) The criminal responsibility of artificial intelligence systems: A prospective analytical study. *Corp Law GovAnce Rev* 5(1):92–100. <https://doi.org/10.22495/clgrv5i1p8>
12. Lagioia F, Sartor G (2020) AI systems under criminal law: A legal analysis and a regulatory perspective. *Philos Technol* 33(3):433–465. <https://doi.org/10.1007/s13347-019-00362-x>
13. van GR, Van den Hoven (2018) Do We Need New Legal Personhood in the Age of Robots and AI?. In: Perspectives in Law, Business and Innovation, pp 15–55. [https://doi.org/10.1007/978-981-13-2874-9\\_2](https://doi.org/10.1007/978-981-13-2874-9_2)
14. Straub J (2021) Expert system gradient descent style training: Development of a defensible artificial intelligence technique. *Knowl Based Syst* 228. <https://doi.org/10.1016/j.knosys.2021.107275>
15. elsherif M. Salama (2021) Criminal responsibility for robots: A thorough and comparative study: الإنسانية,. *Arab J Forensic Sci Forensic Med* 3(1):140–159. [https://doi.org/10.26735/ECM\\_W8027](https://doi.org/10.26735/ECM_W8027).
16. Díaz-Rodríguez N, Del Ser J, Coeckelbergh M, López de Prado M, Herrera-Viedma E, Herrera F (2023) Connecting the dots in trustworthy Artificial Intelligence: From AI principles, ethics, and key requirements to responsible AI systems and regulation. *Information Fusion* 99:101896. <https://doi.org/10.1016/J.INFFUS.2023.101896>
17. Morales HL, Agudelo LS, Montoya RM, Montoya VAM (2021) Inteligencia artificial en el proceso penal: análisis a la luz del Fiscal Watson. *Pensamiento Jurídico* (54):147–164. Accessed: Jun. 20, 2024 [Online]. <https://revistas.unal.edu.co/index.php/peju/article/view/96091/82615>
18. Günsberg PS (2022) Automated vehicles—Is a dilution of human responsibility the answer? *New J Eur Crim Law* 13(4):439–451. <https://doi.org/10.1177/20322844221138049>
19. Russkevich ET, Dmitrenko TP, Kadnikov NG (2022) Crisis and palingenesis (rebirth) of criminal law in the context of digitalization. *Vestn St Petersburg Univ* 13(3):585–598. <https://doi.org/10.21638/spbu14.2022.301>
20. Begishev IR (2021) Limits of criminal law regulation of robotics. *Vestn St Petersburg Univ* 12(3):522–543. <https://doi.org/10.21638/spbu14.2021.303>
21. Yuryevna BA, Rustamovich BI, Ilduzovna KZ, Izmailovich BI, Leonidovna SE, Davletovna BD (2022) Pressing issues of unlawful application of artificial intelligence. *Int J Criminol Sociol* 9:1054–1057. <https://doi.org/10.6000/1929-4409.2020.09.119>
22. Kirpichnikov D, Pavlyuk A, Grebneva Y, Okagbue H (2020) Criminal liability of the artificial intelligence. *E3S Web Conf* 159:04025. <https://doi.org/10.1051/e3sconf/202015904025>
23. King TC, Aggarwal N, Taddeo M, Floridi L (2020) Artificial intelligence crime: An interdisciplinary analysis of foreseeable threats and solutions. *Sci Eng Ethics* 26(1):89–120. <https://doi.org/10.1007/s11948-018-00081-0>
24. Osman N (2020) The complexity of criminal liability of AI systems. *Masaryk Univ J Law Technol* 14(1):53–82. <https://doi.org/10.5817/MUJLT2020-1-3>
25. Sukhodolov AP, Bychkov AV, Bychkova AM (2020) Criminal policy for crimes committed using artificial intelligence technologies: State, problems, prospects. *J Sib Fed Univ HumIties Soc Sci* 13(1):116–122. <https://doi.org/10.17516/1997-1370-0542>
26. Rahman RA, Habibulah R (2019) The criminal liability of artificial intelligence: Is it plausible to hitherto Indonesian criminal system? Legality: *Jurnal Ilmiah Hukum* 27(2):147. <https://doi.org/10.22219/jih.v27i2.10153>
27. Mosechkin IN (2019) Artificial intelligence and criminal liability: problems of becoming a new type of crime subject. *Vestnik of Saint Petersburg University. Law* 10(3):461–476. <https://doi.org/10.21638/spbu14.2019.304>

28. Perin A (2019) Estandarización y automatización en medicina: El deber de cuidado del profesional entre la legítima confianza y la debida prudencia. *Revista Chilena de Derecho y Tecnología* 8(1):3. <https://doi.org/10.5354/0719-2584.2019.52560>
29. Khisamova Z, Begishev I (2019) Criminal liability and artificial intelligence: Theoretical and applied aspects. *Russ J Criminol* 13(4):564–574. [https://doi.org/10.17150/2500-4255.2019.13\(4\).564-574](https://doi.org/10.17150/2500-4255.2019.13(4).564-574)
30. Shestak V, Volevodz A, Alizade V (2019) On the possibility of doctrinal perception of artificial intelligence as the subject of crime in the system of common law: Using the example of the U.S. criminal legislation. *Russ J Criminol* 13(4):547–554. [https://doi.org/10.17150/2500-4255.2019.13\(4\).547-554](https://doi.org/10.17150/2500-4255.2019.13(4).547-554)
31. Pagallo U (2018) Apples, oranges, robots: four misunderstandings in today's debate on the legal status of AI systems. *Philos Trans R Soc A: Math, Phys Eng Sci* 376(2133):20180168. <https://doi.org/10.1098/rsta.2018.0168>
32. Bartolini C, Tettamanti T, Varga I (2017) Critical features of autonomous road transport from the perspective of technological regulation and law. *Transp Res Procedia* 27:791–798. <https://doi.org/10.1016/j.trpro.2017.12.002>
33. Ludvigsen KR, Nagaraja S (2020) Dissecting liabilities in adversarial surgical robot failures: A national (Danish) and European law perspective. *Comput Law Secur Rev* 44:105656. Accessed: Jan. 22, 2024 [Online]. <http://arxiv.org/abs/2008.07381>
34. Rodrigues R (2020) Legal and human rights issues of AI: Gaps, challenges and vulnerabilities. *J Responsible Technol* 4:100005. <https://doi.org/10.1016/j.jrt.2020.100005>
35. Harbinja E, Edwards L, McVey M (2023) Governing ghostbots. *Comput Law Secur Rev* 48:105791. <https://doi.org/10.1016/j.clsr.2023.105791>
36. Sari O, Celik S (2021) Legal evaluation of the attacks caused by artificial intelligence-based lethal weapon systems within the context of Rome statute. *Comput Law Secur Rev* 42:105564. <https://doi.org/10.1016/j.clsr.2021.105564>
37. Morán EA (2021) Responsabilidad penal de la Inteligencia Artificial (IA). ¿La próxima frontera? *REVISTA IUS* 15(48):2021. <https://doi.org/10.35487/rius.v15i48.2021.706>
38. Morillas FDL (2023) Implicaciones de la inteligencia artificial en el ámbito del Derecho Penal. In: *Derecho Penal, Inteligencia Artificial y Neurociencias*, Roma: Tre-Press, pp 59–89. Accessed: Jun. 20, 2024 [Online]. <https://romatrepres.uniroma3.it/wp-content/uploads/2023/02/diia-rima.pdf>
39. Giraldo A (2023) Deshumanizando la culpabilidad: los sistemas inanimados en la teoría del delito. In: *Derecho Penal, Inteligencia Artificial y Neurociencias*, Roma: Tre-Press, pp 119–158. Accessed: Jun. 20, 2024 [Online]. <https://romatrepres.uniroma3.it/wp-content/uploads/2023/02/diia-rima.pdf>
40. Bustamante JM (2023) De stockfish a skynet: cuestiones principales de la inteligencia artificial y el derecho penal. *Revista Electrónica de Estudios Penales y de la Seguridad*
41. Sun Y, Zhang P (2024) Study on the regulation of criminal procedure system in the age of artificial intelligence. *Appl Math Nonlinear Sci* 9(1). <https://doi.org/10.2478/amns-2024-0263>
42. Khlaif ZN et al (2023) The potential and concerns of using AI in scientific research: ChatGPT performance evaluation. *JMIR Med Educ* 9(1):e47049. <https://doi.org/10.2196/47049>

# Systematic Review of the Literature on Artificial Intelligence in Education



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and Gaetano Guevara-Bergna 

**Abstract** This study analyzes how AI improves learning processes through chatbots, virtual assistants, recommendation systems, and self-assessment platforms. However, significant challenges include technological integration, resistance to change, and data privacy concerns. The study provides recommendations to overcome these obstacles and maximize the benefits of AI in education, underscoring the importance of interdisciplinary collaboration and the development of appropriate educational policies.

**Keywords** Artificial intelligence · Machine learning · Chatbots · Education · Learning · Virtual tutoring

## 1 Introduction

In an era where the use of technology to accelerate processes and optimize resources is evident, Artificial Intelligence in the educational field is especially relevant since institutions must meet the needs of a connected student population that demands faster services [1]. Traditional digital channels, usually presented in platforms such as live chats, mobile applications, and social networks, have been useful in maintaining fluid communication between the institution and its students, but not in integrating learning processes [2]. Despite their advantages, digital channels face several

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challenges such as integration with existing platforms [3] and resistance to technological change by their educational community. Furthermore, information security and privacy are constant concerns, especially when there are specific laws [4] where sensitive student data must be rigorously protected [5]. In Latin America, the adoption of digital channels in universities has been uneven. While some institutions have made significant progress in implementing digital technologies, others face limitations due to budgetary and infrastructure constraints. The digital divide is a persistent problem that affects accessibility and equity in access to these services. The COVID-19 pandemic accelerated the need for digitalization in the educational sector, highlighting both the strengths and weaknesses of institutions and their systems [6].

Given these challenges, this systematic literature review aims to identify and recommend the most appropriate artificial intelligence systems for enhancing academic support for students.

## ***1.1 Automated Systems with Artificial Intelligence***

In efforts to enhance current processes within digital channels, numerous institutions have integrated advanced technologies as Artificial Intelligence (AI), to improve student experiences. The open-source nature and the diverse range of available AI models have facilitated their rapid adoption and implementation. The following sections delineate the most significant AI systems used in this context.

### **1.1.1 Chatbots**

AI-powered chatbots can interact with students in real-time, answering frequently asked questions about schedules, payment dates, enrollment shifts, and other administrative queries. These chatbots use natural language processing (NLP) to understand and respond accurately and consistently, reducing wait time and the workload of administrative staff [7].

### **1.1.2 Virtual Assistants**

Virtual assistants use AI (Artificial Intelligence) to offer more personalized attention, remembering preferences and the conversation history of each student. They can provide personalized reminders such as assignment submissions and suggest specific educational resources such as pending readings. They also integrate data from different university platforms, such as learning management systems (LMS) and student databases, to offer an integrated experience adapted to student's needs [8].

### 1.1.3 Query and Ticket Management Systems

To efficiently manage student queries and requests, many universities have adopted automated query and ticket management systems. These systems, powered by AI, can categorize, and prioritize requests, assign them to responsible staff, and provide automatic updates on the status of each case [9].

### 1.1.4 Automated Mentoring Platforms

Automated mentoring platforms connect students with mentors based on matching algorithms that consider factors such as area of study, career interests, and academic goals. These platforms use AI to facilitate progress tracking and continuous communication between mentors and students, thus optimizing the quality of support received [10].

## 2 Methodology

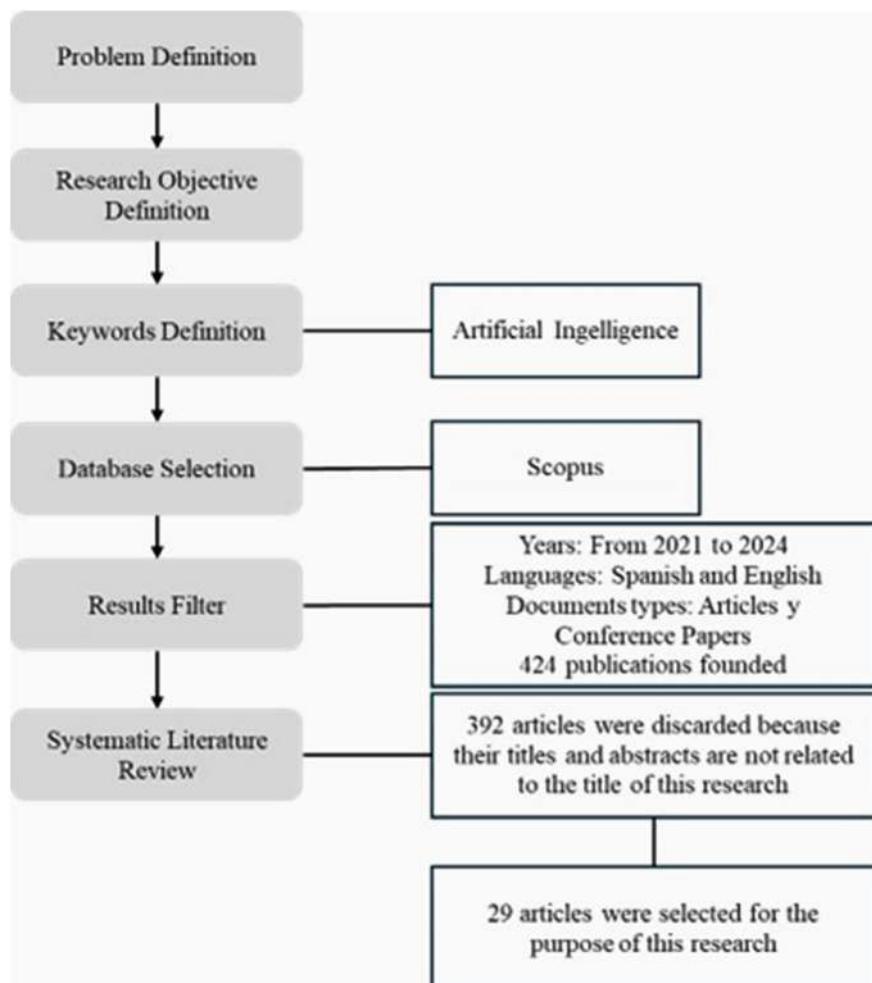
To develop this research, the systematic literature review methodology was used. “Intelligence,” “artificial,” “support,” and “academic” were defined as keywords for the search in the Scopus database. No additional keywords were included, and articles published between 2021 and 2024 were excluded. The search only included articles and conference papers in English and Spanish, categorized under social sciences, engineering, computer sciences, and arts.

After conducting this search, a systematic review matrix was generated, yielding a total of 424 publications corresponding to research in various fields, excluding those unrelated to education. The abstracts were then reviewed, and those not related to the objective of this study were excluded, leaving 130 articles, from which 29 were finally selected. The process followed in the methodology used in this research is shown in Fig. 1.

## 3 Results

The 29 articles selected for this systematic literature review were those detailed below.

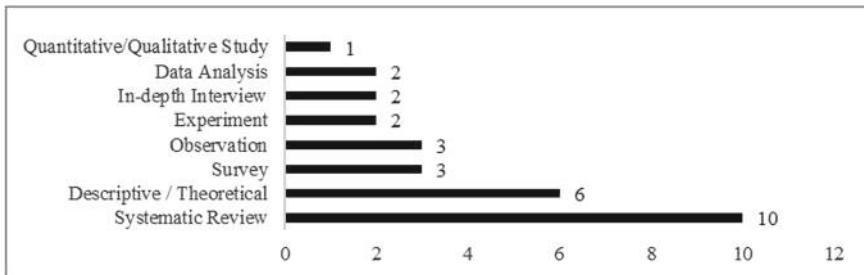
The results of the systematic analysis of the literature highlight that, of the 29 research articles reviewed, 10 use the systematic review methodology, six use descriptive/theoretical approaches, three are based on observation and three are based on surveys. In this way, when considering the sample of studies examined, it is concluded



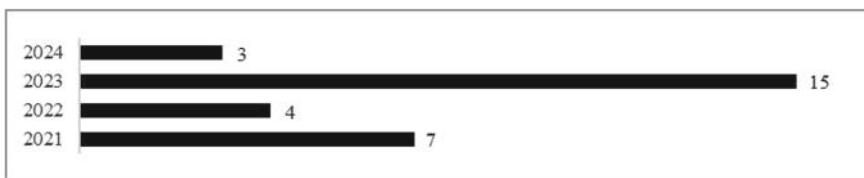
**Fig. 1** Process of the methodology used in the search and selection of articles

that the methodology most frequently applied in topics related to artificial intelligence is the systematic review of the literature, the same one that is used in this research (see Fig. 2).

During the year 2023, a notable increase was observed in research related to artificial intelligence (see graph 3), with 52% (15) of articles prepared on this topic. In these studies, AI was the main automation system used to improve learning processes. In contrast, in 2021, 7 articles were reviewed in which machine learning was the main automation system. The years 2022 and 2024 recorded the least amount of research, with 4 and 3 articles respectively (Fig. 3).



**Fig. 2** Methodologies used in the articles consulted

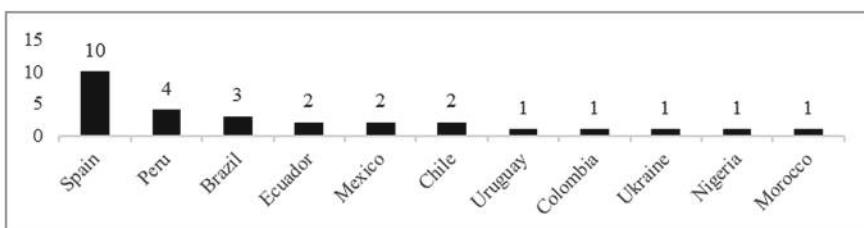


**Fig. 3** Years of publication of the articles consulted

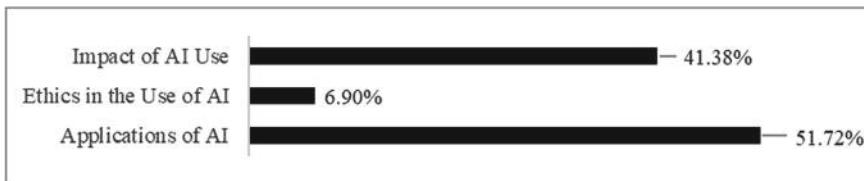
The increase in scientific articles in the field of artificial intelligence (AI) demonstrates the interest in several countries in America and Europe for it to be applied in the educational field. Examining the research landscape highlights fifteen relevant articles spread across seven countries in North and South America. See Fig. 4.

To analyze the problems addressed in the 29-research works considered in this systematic review, these problems have been classified into three main categories. 41% of the articles reviewed examine the impact of the use of artificial intelligence; 52% explore topics related to the applications or uses of artificial intelligence; and 7% focus on the ethics of using artificial intelligence (see Fig. 5).

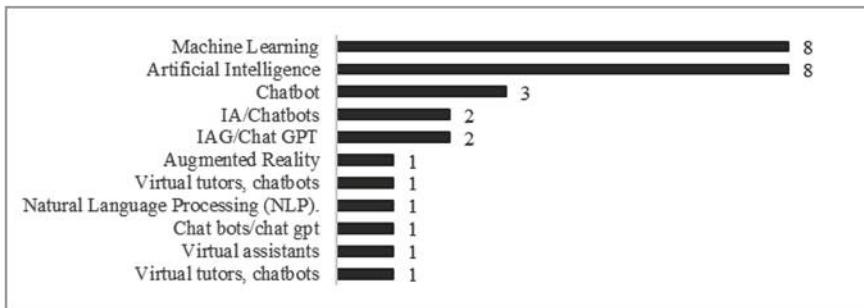
It is also highlighted that the automated systems most mentioned in the literature review are artificial intelligence and machine learning, with the main objective of defining the scope, processes, and benefits of their use (see Fig. 6).



**Fig. 4** Production of scientific articles by country



**Fig. 5** Problems addressed by scientific articles

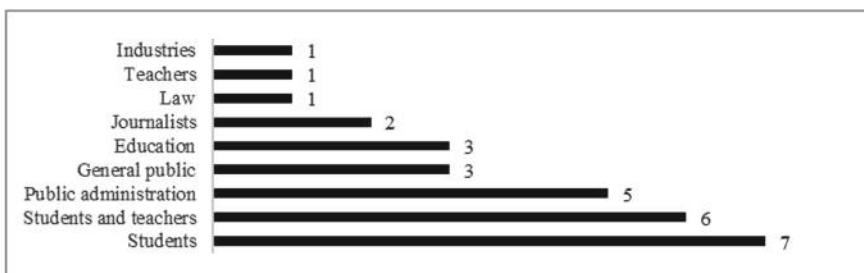


**Fig. 6** Artificial intelligence models most mentioned in the literature review

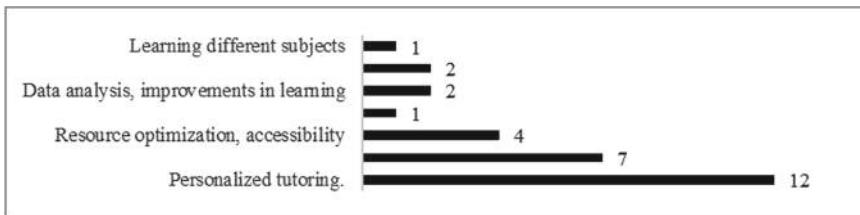
The review of scientific literature reveals that most articles highlight students as the main beneficiaries of AI (See Fig. 7).

This review demonstrates that AI is mainly used to offer personalized tutoring, that is, an approach that allows adapting the educational process to the individual needs of each student with detailed analysis of evaluations and monitoring of academic performance, [11] which facilitates the identification of areas of improvement and specific strengths.

Another important finding is that more than half of the articles reviewed in this systematic literature review highlight personalized tutoring and optimization of resources and operations as the main benefits provided by AI (see Fig. 8).



**Fig. 7** Main beneficiaries of the use of artificial intelligence

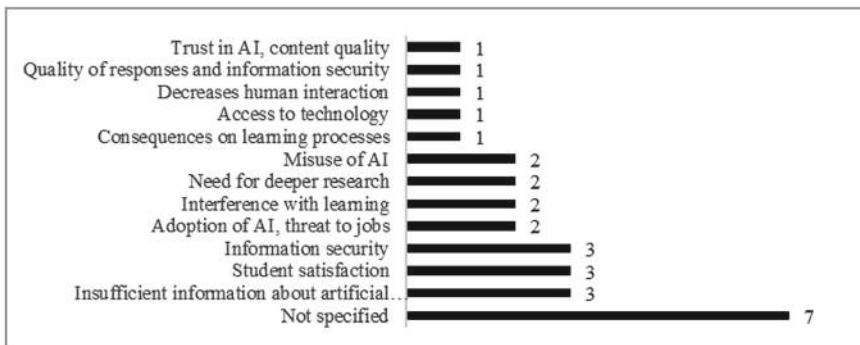


**Fig. 8** Main uses of artificial intelligence

In the field of personalized tutoring, artificial intelligence offers significant support to teachers in repetitive tasks, such as student evaluation. In addition, AI contributes significantly to the development of teaching materials for each class, integrating various sources of information and resources that it obtains from its reference sources.

An important fact to highlight is that many countries that rely on AI to optimize resources are those in development. This phenomenon can be easily explained by the interest in maximizing available resources to benefit the population, especially through the massification of existing services [12]. However, seven of the scientific articles reviewed do not specifically address the disadvantages of using AI; The documents that do analyze the drawbacks of its application identify three main issues: the limited information available about AI and its ability to automate existing tasks, the security of the information that AI must access, and student satisfaction in the process. Learning (see Fig. 9).

Regarding the last two points, it is important to highlight the little or non-existent legislation that exists to ensure that sensitive data used by AI is not used for purposes other than data processing [13]. Furthermore, the lack of trust in process automation is notable, especially in the case of academic tutoring, generating concern about the effectiveness of this technology in student learning.



**Fig. 9** Disadvantage of the use of artificial intelligence

Automated systems, such as chatbots and virtual assistants, provide quick and accurate responses to student queries, adapting to your individual needs. The introduction of virtual tutoring with artificial intelligence in the educational environment is proposed as a very effective solution to optimize available resources and expand the time dedicated to teachers to strengthen learning. Among the benefits identified, the accessibility and adaptability of teaching stand out, ensuring that students can receive a personalized service that understands their individual needs. The automation of administrative tasks reduces the workload of staff, allowing more efficient management of institutional resources [14].

The reliability of information provided by AI can be questionable, as algorithms can make mistakes without human supervision. This can lead to incorrect decisions or inaccurate information that negatively affects the learning process.

In relation to student satisfaction, although virtual tutoring can offer quick and personalized assistance, it is possible that some students prefer human interaction and feel less cared for with a model that is supported by artificial intelligence. Lack of understanding and possible misinterpretation of the student's messages can cause greater frustration with their use.

From the analysis carried out, it is considered that the model based on machine learning may be the most suitable for the implementation of a tutoring service, since the AI can learn from the student and adapt to its own learning pace. However, it is essential to implement this technology with adequate supervision, correct use of personal data, and complemented with human support when necessary.

## 4 Conclusions

Artificial intelligence (AI) possesses considerable potential to personalize and improve the educational experience by providing individualized tutoring and recommendations based on precise data analytics. These advancements primarily benefit students, facilitating enhanced learning outcomes. Nevertheless, the incorporation of AI into the educational sector faces significant challenges, including technological integration, resistance to change, and concerns related to data privacy and security. These challenges are exacerbated by the absence of comprehensive legislative frameworks.

Studies indicate that the primary application of AI in education is to enhance learning processes by providing personalization and support, which facilitates comprehension, retention, and active learning. This, in turn, improves the quality and accessibility of educational innovations. Additionally, AI is employed to optimize operations, enhancing process efficiency, and preventing service saturation. These applications support the automation of teaching interactions and advance the goal of personalized education.

A systematic review of the literature reveals that the most recommended AI system for academic support is based on machine learning. This model enables technology to learn from students and adapt to their individual learning paces. Its use should include

appropriate supervision, the correct use of personal data, and a human presence to foster connection and accompany students throughout their academic journey.

In conclusion, it is recommended to provide continuous training for teachers and students on the effective use of AI technologies; implement oversight and evaluation mechanisms to monitor AI's impact and adjust strategies as necessary; promote interdisciplinary collaboration within educational institutions; and ensure that AI solutions complement human support, maintaining human interaction and supervision to address students' emotional and contextual needs (Table 1).

**Table 1** Articles selected for the systematic literature review

| N  | Author(s)                                                                        | Title                                                                                                                                                                                      |
|----|----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1  | Moral-Sánchez S.N.; Rey F.J.R.; Cebrián-De-la-serna M                            | Analysis of artificial intelligence chatbots and satisfaction for learning in mathematics education                                                                                        |
| 2  | Frutos N.D., et al                                                               | Application of Artificial Intelligence (AI) in Education: Benefits and Limitations of AI as Perceived by Primary, Secondary, and Higher Education Teachers                                 |
| 3  | González Campos J.A.; López Núñez J.C.; Araya Pérez C.E                          | Higher education and artificial intelligence: challenges for the twenty-first century                                                                                                      |
| 4  | Forero-Corba W.; Bennasar F.N                                                    | Techniques and applications of Machine Learning and Artificial Intelligence in education: a systematic review                                                                              |
| 5  | Marín-Rodriguez W.J.; et al                                                      | Artificial Intelligence and Augmented Reality in Higher Education: a systematic review                                                                                                     |
| 6  | Toache E.A.; Rosales M.A                                                         | Ethical concerns in the use of artificial intelligence, transparency, and the right of access to information. The case of chatbots in the Mexican government, in the context of covid - 19 |
| 7  | Olusegun Oyetola S.; Oladokun B.D.; Ezinne Maxwell C.; Obotu Akor S              | Artificial intelligence in the library: gauging the potential application and implications for contemporary library services in Nigeria                                                    |
| 8  | Hind B.; Serhier Z.; Jallal M.; Bennani Othmani M                                | Chatbots for medical students exploring medical students' attitudes and concerns towards artificial intelligence and medical chatbots                                                      |
| 9  | Kronivets T.; Yakovenko O.; Tymoshenko Y.; Ilnytskyi M.; Iasechko S.; Iasechko M | The legal foundations for the use of artificial intelligence in educational processes                                                                                                      |
| 10 | Albarracín Vanoy R.J                                                             | Logistics 4.0: Exploring Artificial Intelligence Trends in Efficient Supply Chain Management                                                                                               |
| 11 | Mendiola M.S.; Degante E.C                                                       | La inteligencia artificial generativa y la educación universitaria ¿Salió el genio de la lámpara?                                                                                          |

(continued)

**Table 1** (continued)

| N  | Author(s)                                                                           | Title                                                                                                                        |
|----|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------|
| 12 | Martínez-Comesaña M, et al                                                          | Impact of artificial intelligence on assessment methods in primary and secondary education: Systematic literature review     |
| 13 | Lopezosa C.; Codina L.; Pont-Sorribes C.; Vállez M                                  | Use of generative artificial intelligence in the training of journalists: challenges, uses and training proposal             |
| 14 | Rama C                                                                              | New digital educational phase with artificial intelligence                                                                   |
| 15 | Flores-Vivar J.-M.; García-Peña F.-J                                                | Reflections on the ethics, potential, and challenges of artificial intelligence in the framework of quality education (SDG4) |
| 16 | Sanabria-Navarro J et al                                                            | Incidences of artificial intelligence in contemporary education                                                              |
| 17 | Flores Masias E.J.; Livia Segovia J.H.; Casique A.G.; Dávila Díaz M.E               | Sentiment analysis with artificial intelligence to improve the teaching–learning process in the virtual classroom            |
| 18 | Fieiras-Ceide C.; Vázquez M.; Túñez-López M                                         | Artificial intelligence strategies in European public broadcasters: Uses, forecasts and future challenges                    |
| 19 | Pabon J.F.; Aizaga M.; Recalde H.; Toasa R.M                                        | Review on the impact of artificial intelligence and its application in Ecuador                                               |
| 20 | Páez Chaljub P.M                                                                    | A Glance to the Speech of the Artificial Intelligence and the Author's Rights, Analyzed from the Theory of the Personality   |
| 21 | Alastruey C.F                                                                       | State of the Art in Artificial Intelligence and Learning Machines                                                            |
| 22 | Rocha I.F.; Kissimoto K.O                                                           | Artificial intelligence and Internet of Things adoption in operations management: Barriers and benefits                      |
| 23 | Maita-Cruz Y. et al                                                                 | Artificial intelligence in public management in times of Covid-19                                                            |
| 24 | Martín-Ramallal P.; Merchán-Murillo A.; Ruiz-Mondaza M                              | Virtual trainers with artificial intelligence: levels of acceptance among university students                                |
| 25 | Paz C.A                                                                             | Legal challenges for artificial intelligence in Chile                                                                        |
| 26 | Rodríguez J.A.; Santana M.G.; Perera M.V.A.; Pulido J.R                             | Embodied conversational agents: Artificial intelligence for autonomous learning                                              |
| 27 | Abar C.A.A.P.; Dos Santos Dos Santos J.M.; de Almeida M.V                           | Computational Thinking in Elementary School in the Age of Artificial Intelligence: Where is the Teacher?                     |
| 28 | Ocaña-Fernández Y.; Valenzuela-Fernández L.A.; Vera-Flores M.A.; Rengifo-Lozano R.A | Artificial intelligence (Ai) applied to public management                                                                    |
| 29 | Sichman J.S                                                                         | Inteligência Artificial e sociedade: avanços e riscos                                                                        |

## References

1. Ilk N, Shang G (2022) The impact of waiting on customer-instigated service time: field evidence from a live-chat contact center
2. Rasli A, Danjuma I (2011) Yew, LK, Igbal. Service quality, customer satisfaction in technology-based universities, MJ
3. Sitanggang N, Luthan P, Hamid A (2021) Relationship between total personal quality, service quality and student satisfaction on higher education system
4. Law No. 29733: Personal data protection law homepage. <https://www.leyes.congreso.gob.pe/Documentos/Leyes/29733.pdf>. Accessed 03 Jul 2011
5. Ke TT, Sudhir K (2023) Privacy rights and data security: GDPR and personal data markets
6. Deroncele-Acosta A, Palacios-Nunez M, Toribio-Lopez A (2023) Digital transformation and technological innovation on higher education post-COVID-19
7. Rahim N, Iahad N, Yusof A, Al-Sharafi M (2022) AI-based Chatbots adoption model for higher-education institutions: a hybrid PLS-SEM-neural network modeling approach
8. Essel H, Vlachopoulos D, Tachie-Menson A, Esi-Eduafua J, Papa-Kwame B (2022) The impact of a virtual teaching assistant (chatbot) on students learning in Ghanaian higher education
9. Quattrocchi G, Tamburri D, Van Den Heuvel W (2023) Making service continuity smarter with artificial intelligence: an approach and its evaluation
10. Terblanche N (2020) A design framework to create artificial intelligence coaches
11. Martín-Ramallal P, Merchán-Murillo A, Ruiz-Mondaza M (2023) Virtual trainers with artificial intelligence: degree of acceptance among university students
12. Ocaña-Fernández Y (2021) Valenzuela-Fernández, LA, Vera-Flores, MA, Rengifo-Lozano. Artificial intelligence (AI) applied to public management, RA
13. Paz CA (2021) Legal challenges for artificial intelligence in Chile
14. Flores E, Livia J, Casique A, Dávila Díaz ME (2023) Sentiment analysis with artificial intelligence to improve the teaching-learning process in the virtual classroom

# Expert Systems: The Case of Justo in the Digital Transformation of the Peruvian Justice System



Kiara Nilupú-Moreno , Yasmina Riega-Virú , Juan Luis Salas-Riega , José Miguel Salas-Riega , and Rocío Quiliano-Terreros

**Abstract** The study examines the impact of “Justo” AI on the digital transformation of the Peruvian justice system, comparing it to other expert systems. Accelerated by COVID-19 and aligned with the United Nations Sustainable Development Goals, the implementation of AI in justice has become crucial. The methodology involved a systematic review of the literature on expert justice systems and an analysis of the results of JUSTO 2022 using data from “El Peruano” and the Superior Court of Lima Norte. “Justo” correctly identified 71.68% of death orders, completing in 9 hours what would take a human 3 years. Despite being less advanced than other systems, “Justo” marks a significant step in Peruvian judicial automation by balancing efficiency and human oversight. To enhance its impact, “Justo” must expand its capabilities, develop an ethical framework, and integrate more advanced technologies appropriate to the Peruvian context, which will position it as a more robust system.

**Keywords** Expert systems · Digital transformation · Law · Justice · Technology

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## 1 Introduction

Artificial intelligence (AI) in judicial administration has gained global prominence, accelerated by the COVID-19 pandemic, and aligned with the United Nations Sustainable Development Goals on justice and innovation [1]. In Peru, digital transformation was regulated by Law No. 1412 (2018), followed by the implementation of the “Justo” Judicial Assistant Robot in 2022. However, despite these efforts, a substantial social impact has yet to be seen. This research aims to assess the role of “Justo” in Peru’s judicial system, its contribution to digital transformation, and how it compares to similar systems in Latin America. As an expert system designed to streamline order archiving, understanding the evolution and impact of “Justo” is crucial to improving its effectiveness. Previous studies in Peru have demonstrated the benefits of AI in judicial efficiency, decision-making, and cost reduction. However, challenges remain, including the need for proper regulation to ensure impartial, transparent, and accountable implementation [2, 3].

### 1.1 *Expert Systems*

Expert systems are a key application of artificial intelligence, designed to emulate human reasoning in specific domains [2, 3]. Based on rules and data provided by experts, they make autonomous recommendations, predictions, or decisions. In law, they can streamline processes and improve accuracy, sometimes exceeding human capabilities in specific tasks. These systems can analyze court precedents, interpret laws, and assess legal risks with unprecedented speed and consistency [4–8]. Their ability to process a large amount of information and apply expert logic makes them valuable for critical decision-making in complex environments [8, 9]. However, user acceptance and trust are crucial, especially in sensitive areas such as criminal law, where decisions have significant consequences. In Peru, “Justo” is positioned as a promising expert system in the legal field.

### 1.2 *“Justo” Robot Judicial Assistant in Perú and Digital Transformation*

The digital transformation of the judiciary began in the late twentieth century with computerized administrative and case management systems. This advanced towards the digitization of documents, improving the storage, search, and access to records. As technology advanced, courts implemented web portals, which offered online access to forms and case information. In recent years, emerging technologies such as AI, data analytics, and blockchain have been integrated into court systems, with

the goal of significantly increasing the efficiency, transparency, and accessibility of legal services [10–14].

The “Justo” software is an artificial intelligence robot developed to provide support in judicial offices by automating the generation of judicial orders and resolutions. Using technologies such as artificial intelligence, data science, and robotic process automation, “Justo” specializes in the intelligent and automated creation of court documents that are simple, repetitive, and amenable to automation. The objective of the research is to specify the use of JUSTO in the Peruvian judicial system; identifying its contribution to digital transformation based on the analysis of similarities and differences with respect to other expert systems implemented in Latin America [15].

## 2 Methodology

This basic research began with a systematic literature review to analyze previously published evidence on artificial intelligence, digital transformation, and justice systems. Specific search criteria included key terms such as “artificial,” “intelligence,” “justice,” “system,” and their Spanish equivalents. The Scopus and ProQuest databases were searched, and the grey literature of research repositories and official sources of the administration of justice was reviewed, from 2018 to the end of April 2024. The study analyzed the results of the nomination of “Justo—Auxiliar Judicial” using data from the Official Gazette “El Peruano” and documents from the transparency area of the Superior Court of Justice of Lima Norte [16]. An Excel table was used to analyze the results and Mendeley identified the duplicate items. The analysis and synthesis of the data was carried out with computer tools and systematic review techniques. The results were presented in a clear and concise manner, answering the research question, and comparing “Justo” with other systems experts in the administration of justice and digital transformation.

## 3 Results

See Table 1.

Table 1 provides a comparative overview of the implementation of artificial intelligence and data analytics technologies in the judicial and legal systems of different countries, highlighting the specific areas of application in each case.

“Justo” was tested with the Superior Court of Justice of Lima Norte from July to August 2022, focusing on cases of violence against women and family members. During this period, “Justo” successfully generated “Final Archival Orders” for the deceased parties. The results were very positive, demonstrating its potential to speed up judicial processes. Data on the deceased were collected from RENIEC (National Registry of Identification and Civil Status) and compared with SIJ (Integrated Judicial System) records to issue archiving orders [15]. The proof of concept showed that

**Table 1** Justice systems that use artificial intelligence

| No | Country       | Expert System and/or algorithm and/or mathematical model | Processes in the justice system | Police or judicial investigations | Legal Services |
|----|---------------|----------------------------------------------------------|---------------------------------|-----------------------------------|----------------|
| 1  | United States | <i>Compass</i>                                           | x                               |                                   |                |
| 2  |               | <i>PredPol</i>                                           |                                 | x                                 |                |
| 3  |               | <i>Voting-EL</i>                                         |                                 |                                   | x              |
| 4  |               | <i>Ross “Robot Lawyer”</i>                               |                                 | x                                 | x              |
| 5  |               | <i>ShotSpotter</i>                                       |                                 | x                                 |                |
| 6  | Argentina     | <i>Promethea</i>                                         | x                               |                                   |                |
| 7  | Colombia      | <i>Synapse</i>                                           | x                               |                                   |                |
| 8  |               | <i>Praetor -IA</i>                                       | x                               |                                   |                |
| 9  |               | <i>Fiscal Watson</i>                                     |                                 | x                                 |                |
| 10 | Brazil        | <i>Winner</i>                                            | x                               |                                   |                |
| 11 |               | <i>Socrates</i>                                          |                                 | x                                 |                |
| 12 | Spain         | <i>VioGén</i>                                            |                                 | x                                 |                |

**Table 2** Analysis of the death processes between “Justo—Judicial Auxiliary Robot” versus justice operators Proof of concept

| Activity                                                                                                                                   | Quantity | Percentage | Remarks                                                                                                                                                                                                                                                                                                                                             |
|--------------------------------------------------------------------------------------------------------------------------------------------|----------|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Death Warrants Filed by “Judicial Dispatch Assistant Robot: Just”                                                                          | 1741     | 100%       | Processing time spent: 09 h                                                                                                                                                                                                                                                                                                                         |
| Death sentences reviewed and downloaded to the SIJ, by the Judges of the Integrated Module on Violence against Women of the CSJ Lima Norte | 1248     | 71.68%     | Time spent on review and download: 40 h                                                                                                                                                                                                                                                                                                             |
| Cars that are observed and that allow opportunities for improvement and adjustments                                                        | 493      | 28.32%     | Case series:<br>(1) Deceased Persons Orders Developed Not Updated in the State: Execution; (2) Persons with a foreigner's card and not an identity card; (3) Duplication of orders proposed by citizens as victims and aggressors; (4) Duplication by non-cumulative processes; (5) Orders of deceased persons who have not had protection measures |

**Table 3** Human vs. “Justo” robot labor hours

|                     |                       |
|---------------------|-----------------------|
| Consultation period | 15/10/2018–22/06/2022 |
| Human               | 3 years               |
| “Justo” robot       | 8 h and 54 min        |

“Justo” correctly identified 71.68% of death orders. The remaining 28.32% was due to five specific cases, which could be integrated into Justo’s logic to enhance effectiveness.

Table 3 shows that “Justo” processes 1,741 file orders in about 9 h, compared to the 3 years it would take a human. This indicates that the implementation of “Justo” could significantly improve the efficiency of the Superior Court of Justice of Lima Norte.

### 3.1 Judicial Protection and Bias

Several authors express concerns about the impact of AI on fundamental rights [4, 5, 7–11, 17–26]. Kumar et al. [27] and Hipólito et al. [28] propose four key vectors for AI judicial systems: explainability, fairness, transparency, and auditability, which are absent in the information on “Justo”. Foulds et al. [29] suggest the theory of intersectionality for equity in crime control through machine learning, an approach that “Justo” lacks. Guimarães and Corvalán emphasize aligning AI systems with international ethical standards and human rights, while Dubišski [20] warns against the use of AI in critical decisions.

“Justos” lack of explicit adherence to these principles raises questions about its ability to protect fundamental rights. Cardoso and Von Hohendorff [1], together with Zimmerman and Lee-Stronach [18], underline the importance of the human aspect in new technologies. Although “Justo” involves human review, it is unclear how it integrates human legal reasoning into its design. Demertzis et al. [14] propose Blockchain for judicial protection, and Segura [17] emphasizes ethical legal reasoning in AI. The absence of these technologies in “Justo” could limit its robustness in judicial protection and bias prevention. Watkins et al. [19], Contini [23], and Noiret et al. [7] address the complexity of assessing AI’s impact on fairness and algorithmic biases. The lack of information on how “Justo” addresses these issues suggests a gap in its design, leading to an incomplete understanding of its judicial impact and bias mitigation.

### 3.2 Legal Advice with AI

Recent literature on AI in judicial systems highlights various perspectives [6, 10, 30, 31]. Quteishat et al. [6] and Covelo [10] emphasize research on judicial prediction and risk assessment tools. Segura [17] points to the efficiency potential of AI but warns

**Table 4** Use of artificial intelligence in justice systems

| N  | Titles                         | Judicial protection and bias | Legal advice with AI | Predictive Justice | AI to collect data |
|----|--------------------------------|------------------------------|----------------------|--------------------|--------------------|
| 1  | Long and Palmer 2024           |                              | 1                    |                    |                    |
| 2  | Quteishat et al. 2024          |                              | 1                    | 1                  |                    |
| 3  | Gravett 2024                   |                              | 1                    |                    |                    |
| 4  | Covelo de Abreu 2024           | 1                            |                      | 1                  |                    |
| 5  | Demertzis et al. 2023          | 1                            |                      |                    | 1                  |
| 6  | Segura 2023                    | 1                            |                      | 1                  |                    |
| 7  | Fernando et al. 2023           |                              | 1                    |                    | 1                  |
| 8  | Hernández and López 2022       |                              |                      |                    | 1                  |
| 9  | Hipólito et al. 2023           | 1                            |                      |                    |                    |
| 10 | Cardoso y Von Hohendorff 2022  | 1                            |                      |                    |                    |
| 11 | Caterini 2022                  |                              |                      | 1                  |                    |
| 12 | Zimmermann y Lee-Stronach 2022 | 1                            |                      | 1                  |                    |
| 13 | Watkins et al. 2021            | 1                            |                      |                    |                    |
| 14 | Dubišski 2021                  | 1                            |                      | 1                  |                    |
| 15 | Noiret et al. 2021             | 1                            |                      | 1                  |                    |
| 16 | Calderón-Valencia et al. 2021  |                              |                      | 1                  |                    |
| 17 | Sukanya y Priyadarshini 2021   |                              |                      | 1                  |                    |
| 18 | Mingtsung y Shuling 2020       |                              |                      | 1                  | 1                  |
| 19 | Kumar et al. 2020              | 1                            |                      |                    |                    |
| 20 | The End of the Game 2020       | 1                            |                      | 1                  |                    |
| 21 | Izquierdo 2020                 |                              |                      |                    | 1                  |
| 22 | Contini 2020                   | 1                            |                      | 1                  |                    |
| 23 | Calvo et al. 2020              | 1                            |                      |                    |                    |
| 24 | Foulds et al. 2020             | 1                            |                      | 1                  |                    |
| 25 | Guimarães 2019                 | 1                            |                      | 1                  |                    |
| 26 | Metsker et al. 2019            |                              |                      | 1                  |                    |
| 27 | Wongsinlatam y Buchitchon 2018 |                              |                      | 1                  | 1                  |
| 28 | Ruppert et al. 2018            |                              |                      |                    | 1                  |

(continued)

**Table 4** (continued)

| N            | Titles                      | Judicial protection and bias | Legal advice with AI | Predictive Justice | AI to collect data |
|--------------|-----------------------------|------------------------------|----------------------|--------------------|--------------------|
| 29           | Corvalán 2018               | 1                            |                      |                    |                    |
| 30           | Hauck et al. 2002           |                              |                      |                    | 1                  |
| 31           | Roa Avella et al. 2022      |                              |                      | 1                  |                    |
| 32           | Meijer y Wessels 2019       |                              |                      | 1                  |                    |
| 33           | Vargas 2021                 |                              |                      | 1                  |                    |
| 34           | Sánchez Pintado et al. 2023 |                              |                      | 1                  | 1                  |
| 35           | Roa Avella et al. 2023      |                              |                      | 1                  | 1                  |
| <b>Total</b> |                             | <b>16</b>                    | <b>4</b>             | <b>21</b>          | <b>11</b>          |

of threats to freedom and equality. Contini [23], Caterini [30], Zimmermann and Lee-Stronach [18] underline the importance of human analysis in judicial decisions.

Dubišski [20] explores the risks of AI replacing humans in legal decision-making, while Noiret et al. [7] and Calderón-Valencia et al. [8] discuss accountability in predictive justice. Sukanya and Priyadarshini [32], Mingtsung, and Shuling [21] discuss advances in deep learning models and “smart courts.” Zavrník [22] highlights the challenges of automated systems in ensuring fair trials.

The researchers propose several approaches: Foulds et al. [29] suggest Bayesian methods, while Wongsinlatam and Buchitchon [33] recommend mixed integer linear programming for fair case allocation. In contrast, Peru’s “Justo” is a limited AI system focused on generating file orders. It lacks predictive capabilities, advanced modeling, or broad ethical considerations typical of complex predictive justice systems. “Justo” does not address judicial resource allocation, risk assessment, or outcome prediction, positioning it as a specific administrative tool rather than a comprehensive predictive justice system.

### 3.3 Predictive Justice

It emphasizes the importance of judicial prediction and risk assessment [6, 10, 34–36]; and points to the potential of AI to improve judicial efficiency but warns of potential threats to freedom and equality [17]. Likewise, it is cautioned that judicial decisions should not be based solely on statistical predictions [18, 23, 30]. The risks of replacing humans with AI in legal decision-making should be explored [20].

The Debate on Accountability and the Impact of Predictive Justice Noiret et al. and Calderón-Valencia et al. [8] and the discussion on advances in deep learning models and “smart courts” continues [21, 32]. The challenges in access to justice with automated systems are highlighted by Završnik [22] and Bayesian approaches proposed by Foulds et al. [29] and Mixed Integer Linear Programming is recommended for fair case assignment [33].

The “Justo” system in Peru has a more limited scope compared to the advanced predictive justice systems discussed in the literature; its functionality is limited to generating archival orders, without incorporating sophisticated predictive capabilities, deep learning models, or general ethical considerations seen in other systems. “Justo” is positioned as a specific administrative tool, moving away from more complex functions such as the allocation of judicial resources or the prediction of legal outcomes.

### 3.4 *AI to Collect Data*

Demertzis et al. [14] describe programs such as Kira and CARA A.I., which use machine learning to evaluate legal cases from court documents. While Justo shares the basic principle of data extraction, he focuses more specifically on generating file orders using data from RENIEC and SIJ. This aligns with the global trend of AI automation in judicial tasks but represents a more specialized application. Fernando et al. [11] discuss systems such as the Robot Lawyer, capable of performing complex contract analysis and identifying legal problems. Justo’s capabilities are more limited in scope, focusing on identifying specific cases, such as deaths that require legal action.

This reflects a tailored approach to the implementation of AI in the Peruvian judicial system, prioritizing specific needs over broader analytical capabilities. The “Cruza.uy” project in Uruguay [12] demonstrates a similar application of machine learning to process historical archives. Justo’s approach to the generation of archiving orders represents a parallel development, adapted to the specific requirements of the Peruvian legal system. Mingtsung and Shuling’s [21] emphasis on data quality and integrity is particularly relevant to Justo’s effectiveness.

The fact that the system relies on data from RENIEC and SIJ underscores the critical importance of having accurate and complete databases in AI-powered court proceedings. While Izquierdo [37] analyzes facial recognition in justice systems, Justo employs a simpler approach using the ID card for identification. This highlights the pragmatic design of the system, leveraging existing identification systems rather than implementing more advanced, but potentially controversial, technologies. The metaheuristic techniques explored by Wongsinlatam and Buchitchon [33] for case assignment contrast with Justo’s simpler automated assignment based on deceased data.

This difference illustrates the different levels of algorithmic sophistication of AI judicial systems around the world. Ruppert et al. [13] discussion of NLP in

German court decisions provides an interesting comparison. While Justo's language processing capabilities seem more basic, his ability to generate file orders suggests some level of analysis and text generation. The Coplink [38] and VioGén [39] systems represent more advanced applications in criminal investigations and cases of gender-based violence, respectively. Justo's narrower scope to generate archival warrants for specific cases, including violence against women and family members, reflects an approach focused on addressing needs within the Peruvian justice system. In conclusion, while Justo may not incorporate the more advanced AI technologies that have been seen in some global judicial systems, he represents a pragmatic and specific application of AI in the Peruvian legal context. Its design and implementation reflect a balance between technological advancement and specific local needs, providing valuable insights into the adaptation of AI technologies in various judicial environments.

## 4 Conclusions

"Justo" represents a significant step towards modernization, demonstrating a practical and specific application of AI in the generation of file orders; its specialized approach allows for faster and more controlled implementation, effectively integrating with existing databases (RENIEC and SIJ) without requiring a complete restructuring of the data infrastructure. A crucial positive aspect is the maintenance of human judgment in the process; by requiring judges to review its proposals, "Justo" strikes a balance between AI efficiency and human oversight, mitigating some of the ethical risks associated with full automation.

This approach alleviates concerns about ethics and justice, recurring themes in the literature on AI and justice systems. However, "Justo" has significant limitations compared to more advanced AI systems; it lacks sophisticated capabilities such as advanced natural language processing, prediction of judicial outcomes, or analysis of complex cases, restricting its potential impact on global judicial efficiency, moreover, the absence of an explicit ethical framework and specific mechanisms to prevent bias or ensure fairness raises questions about its impact on justice. "Justo" represents an important advance in the digital transformation of the Peruvian judicial system, offering efficiency and automation in specific tasks.

To maximize its impact and ensure its alignment with global ethical and technological standards, it is necessary to expand its capabilities to include more complex analyses and a greater variety of court cases, develop and implement an explicit ethical framework, and explore the integration of advanced technologies such as natural language processing and prediction of judicial outcomes; these improvements could position JUSTO as a more robust and versatile AI court system.

## References

1. Cardoso J, Von R (2022) A utilização da inteligência artificial na tomada de decisão. *Revista Interdisciplinar de Ciência Aplicada* 6(10):17–30. <https://doi.org/10.18226/25253824.v6.n10.03>
2. Riega-Viru Y, Ninaquispe-Soto M, Salas-Riega J, Arizola J (2022) Expert systems and administration of justice in Peru and Brazil. In: 2022 IEEE engineering international research conference (EIRCON), pp 1–4. IEEE. <https://doi.org/10.1109/EIRCON56026.2022.9934806>
3. Riega-Viru Y, Ninaquispe-Soto M, Salas JM, Natividad P, Salas-Riega JL, Nilupú-Moreno K (2023) Artificial intelligence and criminal justice: a systematic review of the scientific literature. In: Proceedings of the LACCEI International Multi-conference for Engineering, Education and Technology
4. Roa-Avella M, Sanabria-Moyano J, Dinas-Hurtado K (2022) Uso del algoritmo COMPAS en el proceso penal y los riesgos a los derechos humanos. *Revista Brasileira de Direito Processual Penal* 8(1). <https://doi.org/10.22197/rbdpp.v8i1.615>
5. Meijer A, Wessels M (2019) Predictive policing: review of benefits and drawbacks. *Int J Public Adm* 42(12):1031–1039. <https://doi.org/10.1080/01900692.2019.1575664>
6. Quteishat E, Qtaishat A, Quteishat A (2024) Building a predictive model for legal studies through ensemble learning techniques. *Int J Relig* 5(2):90–101. <https://doi.org/10.61707/497t9n49>
7. Noiret S, Lumetzberger J, Kampel M (2021) Bias and fairness in computer vision applications of the criminal justice system. In: 2021 IEEE symposium series on computational intelligence, SSCI 2021—Proceedings. <https://doi.org/10.1109/SSCI50451.2021.9660177>
8. Calderon-Valencia F, Perez-Montoya J, De Morais F (2021) Sistemas de la en la Experiencia del Supremo Tribunal Federal Brasileño y la Corte Constitucional Colombiana. *Law, State Telecommun Rev* 13(1):143–169. <https://doi.org/10.26512/lstr.v13i1.35614>
9. Gravett W (2024) Judicial decision-making in the age of artificial intelligence 58. [https://doi.org/10.1007/978-3-031-41264-6\\_15](https://doi.org/10.1007/978-3-031-41264-6_15)
10. Covelo de Abreu J (2024) The artificial intelligence act proposal on European e-Justice Domains through the lens of user-focused, user-friendly and effective judicial protection principles, 58. [https://doi.org/10.1007/978-3-031-41264-6\\_21](https://doi.org/10.1007/978-3-031-41264-6_21)
11. Fernando Z, Kristanto K, Anditya A, Hartati S, Baskara A (2023) Bay M Robot lawyer in Indonesian criminal justice system: problems and challenges for future law enforcement. *Lex Sci Law Rev* 7(2):489–528. <https://doi.org/10.15294/lesrev.v7i2.69423>
12. Hernández-Muñiz F, López-Carrato M (2022) The social function in human rights archives through the Cruzar.uy Project | La función social en los archivos de derechos humanos a través del Proyecto Cruzar.uy. *Ibersid* 16(1):65–74. <https://doi.org/10.54886/IBERSID.V16I1.4836>
13. Ruppert E, Hartung D, Sittig P, Gschwander T, Rönneburg L, Killing T, Biemann C (2018) LawStats—Large-scale german court decision evaluation using web service classifiers, 11015 LNCS. [https://doi.org/10.1007/978-3-319-99740-7\\_14](https://doi.org/10.1007/978-3-319-99740-7_14)
14. Demertzis K, Rantos K, Magafas L, Skianis C, Iliadis L (2023) A Secure and Privacy-Preserving Blockchain-Based XAI-Justice System. *Inf (Switz)* 14(9). <https://doi.org/10.3390/info14090477F>
15. Poder Judicial Homepage, <https://busquedaselperuano.pe/dispositivo/NL/2089843-8>, last accessed 24/06/2024
16. Ministerio de Justicia y Derechos Humanos, <https://www.gob.pe/institucion/minjus/normas-legales/4923245-003979-2023-jus-ttaip-segunda-sala>, last accessed 14/04/2024
17. Segura R (2023) Inteligencia artificial y administración de justicia: desafíos derivados del contexto latinoamericano. *Rev Bioet Derecho* 58:45–72. <https://doi.org/10.1344/rbd2023.58.40601>
18. Zimmermann A, Lee-Stronach C (2022) Proceed with Caution. *Can. J Philos* 52(1):6–25. <https://doi.org/10.1017/can.2021.17>

19. Watkins E, Moss E, Metcalf J, Singh R, Elish M (2021) Governing Algorithmic Systems with Impact Assessments: Six Observations. In: AIES 2021—Conference on AI, Ethics, and Society, pp 1010–1021. <https://doi.org/10.1145/3461702.3462580>
20. Dubiński Ł (2021) Artificial Intelligence and Discretionary Decisions. The Triumph or Loss of Commander Pırı? Przegląd Prawniczy Uniwersytetu im. Adama Mickiewicza 13:199–213. <https://doi.org/10.14746/ppuam.2021.13.09>
21. Mingsung C, Shuling L (2020) Research on the application of artificial intelligence technology in the field of Justice. *J Phys: Conf Ser.* <https://doi.org/10.1088/1742-6596/1570/1/012047>
22. Završnik A (2020) Criminal justice, artificial intelligence systems, and human rights. *ERA Forum* 20(4):567–583. <https://doi.org/10.1007/s12027-020-00602-0>
23. Contini F (2020) Artificial intelligence and the transformation of humans, law and technology interactions in judicial proceedings. *Law, Technol HumS* 2(1):4–18. <https://doi.org/10.5204/lthj.v2i1.1478>
24. Guimarães R (2019) A Inteligência Artificial e a disputa por diferentes caminhos em sua utilização preditiva no processo penal. *Revista Brasileira de Direito Processual Penal* 5(3):1555–1588. <https://doi.org/10.22197/rbdpp.v5i3.260DS>
25. Corvalán J (2018) Inteligencia artificial: retos, desafíos y oportunidades – Prometea: la primera inteligencia artificial de Latinoamérica al servicio de la Justicia. *Revista de Investigaciones Constitucionales* 5(1):295. <https://doi.org/10.5380/rinc.v5i1.55334>
26. Calvo R, Peters D, Vold K, Ryan R (2020) Supporting Human Autonomy in AI Systems: A Framework for Ethical Enquiry. [https://doi.org/10.1007/978-3-030-50585-1\\_2](https://doi.org/10.1007/978-3-030-50585-1_2)
27. Kumar A, Braud T, Tarkoma S, Hui P (2020) Trustworthy AI in the age of pervasive computing and big data. In: 2020 IEEE International Conference on Pervasive Computing and Communications Workshops, PerCom Workshops 2020. <https://doi.org/10.1109/PerComWorkshops48775.2020.9156127>
28. Hipólito I, Winkle K, Lie M (2023) Enactive artificial intelligence: Subverting gender norms in human-robot interaction. *Front Neurorobot* 17. <https://doi.org/10.3389/fnbot.2023.1149303>
29. Foulds J, Islam R, Keya K, Pan S (2020) Bayesian modeling of intersectional fairness: The variance of bias. In: Proceedings of the 2020 SIAM International Conference on Data Mining, SDM 2020, pp 424–432. <https://doi.org/10.1137/1.9781611976236.48>
30. Caterini M (2022) El sistema penal en la encrucijada ante el reto de la inteligencia artificial. *IDP Revista de Internet Derecho y Política* 35:1–19. <https://doi.org/10.7238/idp.v0i35.392754>
31. Long B, Palmer A (2024) AI and access to justice: How AI legal advisors can reduce economic and shame-based barriers to justice. *TATuP—Zeitschrift für Technikfolgenabschätzung in Theorie und Praxis* 33(1):21–27. <https://doi.org/10.14512/tatup.33.1.21>
32. Sukanya G, Priyadarshini J (2021) A Meta Analysis of Attention Models on Legal Judgment Prediction System. *Int J Adv Comput Sci Appl* 12(2):531–538. [https://doi.org/10.14569/IJA\\_CSA.2021.0120266](https://doi.org/10.14569/IJA_CSA.2021.0120266)
33. Wongsinlatam W, Buchitchon S (2018) The Comparison between Dragonflies Algorithm and Fireflies Algorithm for Court Case Administration: A Mixed Integer Linear Programming. *J Phys: Conf Ser.* <https://doi.org/10.1088/1742-6596/1061/1/012005>
34. Metsker O, Trofimov E, Petrov M, Butakov N (2019) Russian court decisions data analysis using distributed computing and machine learning to improve lawmaking and law enforcement. In: Procedia Computer Science, pp 264–273. <https://doi.org/10.1016/j.procs.2019.08.202s>
35. Vargas O (2021) Juez inteligente. Sistema experto que asiste al Juez en la valoración de la Prueba Judicial. *Derecho & Soc* 57:1–24. <https://doi.org/10.18800/dys.202102.009>

36. Sanchez R, Villavicencio-Quinde M, Sánchez-Zambrano J (2023) Inteligencia Artificial como Herramienta Determinante para la Obtención de Prestaciones del Derecho de Alimentos. 593 Digital Publisher CEIT 8(6):5–22. <https://doi.org/10.33386/593dp.2023.6.2077>
37. Izquierdo Carrasco M (2020) La utilización policial de los sistemas de reconocimiento facial automático. IUS ET VERITAS 2020(60):86–103. <https://doi.org/10.18800/iusetveritas.202001.004>
38. Hauck R, Atabakhsh H, Ongvasith P, Gupta H, Chen H (2002) Using coplink to analyze criminal-justice data. Computer 35(3):30–37. <https://doi.org/10.1109/2.989927>
39. Roa M, Sanabria J, Peña A (2023) Los estándares internacionales de protección de la violencia basada en género de las mujeres aplicados a la inteligencia artificial predictiva. Justicia 28(43):43–56. <https://doi.org/10.17081/just.28.43.6161s>

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