Studies in Systems, Decision and Control 435

Jorge Luis García Alcaraz
Arturo Realyvásquez Vargas *Editors*

Algorithms and Computational Techniques Applied to Industry

Springer

Studies in Systems, Decision and Control

Volume 435

Series Editor

Janusz Kacprzyk, Systems Research Institute, Polish Academy of Sciences, Warsaw, Poland

The series "Studies in Systems, Decision and Control" (SSDC) covers both new developments and advances, as well as the state of the art, in the various areas of broadly perceived systems, decision making and control–quickly, up to date and with a high quality. The intent is to cover the theory, applications, and perspectives on the state of the art and future developments relevant to systems, decision making, control, complex processes and related areas, as embedded in the fields of engineering, computer science, physics, economics, social and life sciences, as well as the paradigms and methodologies behind them. The series contains monographs, textbooks, lecture notes and edited volumes in systems, decision making and control spanning the areas of Cyber-Physical Systems, Autonomous Systems, Sensor Networks, Control Systems, Energy Systems, Automotive Systems, Biological Systems, Vehicular Networking and Connected Vehicles, Aerospace Systems, Automation, Manufacturing, Smart Grids, Nonlinear Systems, Power Systems, Robotics, Social Systems, Economic Systems and other. Of particular value to both the contributors and the readership are the short publication timeframe and the world-wide distribution and exposure which enable both a wide and rapid dissemination of research output.

Indexed by SCOPUS, DBLP, WTI Frankfurt eG, zbMATH, SCImago.

All books published in the series are submitted for consideration in Web of Science.

More information about this series at https://link.springer.com/bookseries/13304

Jorge Luis García Alcaraz ·
Arturo Realyvásquez Vargas
Editors

Algorithms and Computational Techniques Applied to Industry

Springer

Editors
Jorge Luis García Alcaraz
Department of Industrial Engineering
Universidad Autónoma de Ciudad Juárez
Ciudad Juarez, Chihuahua, Mexico

Arturo Realyvásquez Vargas
Department of Industrial Engineering, I.T. Tijuana
Tecnológico Nacional de México
Tijuana, Baja California, Mexico

ISSN 2198-4182 ISSN 2198-4190 (electronic)
Studies in Systems, Decision and Control
ISBN 978-3-031-00855-9 ISBN 978-3-031-00856-6 (eBook)
https://doi.org/10.1007/978-3-031-00856-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Nowadays, engineers and managers who manage production systems in the industry use loT software and computational techniques to monitor, analyze, and make decisions quickly and in real time. Thus, product designers use specialized software to generate designs and prototypes according to customer specifications. Product and manufacturing planners use software to contact suppliers, estimate supply capacities, and fulfill delivery times, allowing them to generate their purchasing and acquisition plans. Product engineers simulate and test designs to see the product feasibility, manufacturability, and commercial suitability. Finally, supply chain managers use software to plan quick and on-time deliveries to distribution channels.

Some common software are SAP and ERP for materials management; AutoCAD, SOLIDWORKS, CATIA, OpenSCAD, Rhino3D, THINK3, and TRIZ for design; Minitab, ISO Quality Software, KAWAK, Its-BSC-Its solutions, QPR Metrics, and Vision Software for quality control into the production process, while other software are Umberto NXT, Simapro, BEES, and Gabi for environmental analysis, among others.

In the same way, in a production system, the software is used to control robots and autonomous vehicles that move from one place to another, carrying raw material and finished products. In addition, many sensors installed in machines obtain information from the production process and generate quality control graphics that allow monitoring it in real time. Also, in the finished product distribution process, many companies are using Ordoro, Cin7, Zoho Inventory, Fishbowl, inFlow Inventory, among others, to manage their inventories and practice e-commerce.

In conclusion, the software and computational techniques applications integrated into specialized software allow agile decision-making in production systems in industry and even more so. This book is aimed to collect algorithms and computational applications integrated into software that is being applied in the industry. That software streamlines the decision-making process, allowing real-time communication with suppliers, customers, and departments on the production lines, which increases productivity rates. Therefore, more competitive and efficient companies are in use and resources management.

This book is composed of a set of chapters, and all of them have been edited according to the norms and guidelines of Springer Verlag Editorial. Several calls for chapters were distributed among mailing lists of the field for researchers to submit their works to this issue. Thirty-one proposed chapters were received, subject to a screening and review process to ensure their clarity, authenticity, and relevancy to this book. These proposals came from several countries such as Colombia, Mexico, Spain, Peru, Ecuador, and India.

At least two pairs reviewed every chapter to ensure the relevance and quality of the documents. After this process, 19 chapters were finally accepted for publication once the corrections requested by reviewers and the editors were completed.

The book content is structured in three parts: (1) Supply Chain and Provisions, (2) Production Processes, and (3) Distribution and Commercialization. A brief description for every chapter is as follows:

Part One. Supply Chain and Provisions: This part contains six chapters.

First chapter entitled "Information Systems for Enterprise Resource Planning" indicates and presents a literature review on ERP systems' different perspectives and applications in the industrial sector in the last 20 years. As a result, most of the documented cases are related to implementing System Application and Product (SAP) and its different modules. A case study of the performance of CONTPAQi software in a small and medium-sized enterprise (SME) that relies on the ABC tool for inventory control is included.

Second chapter entitled "Geothermal Power Projects Valuation Model" indicates the importance of climate change and clean production processes. The authors use specialized software for risk analysis in a project from Colombia and conclude that geothermal energy generation has several uncertainties. Their conclusion is based on simulations for different scenarios using MATLAB.

Third chapter is entitled "Design and Implementation of a Desktop Application for Consultation Centers for Staff, Information Regarding Training, Job Promotion and Transportation Routes, in an Automotive Electrical Harness Company". In this chapter, the authors analyze the dissatisfaction of the workers of an electrical harness company. Due to a lack of timely information on the status of job promotions and transportation routes, it was resolved, with three consultation centers accessible 24 h a day. The project was programmed following the V development model and achieved a perception of equity, facilitating the personnel integration in the human resources management occupied on the production process.

Fourth chapter is entitled "Digital Evolution in Supply Chain Management with Industry 4.0", where authors identify some factors required for link supply chain and Industry 4.0 and indicate that synchronization is the most important in all networks. The authors conclude that software protocols are the most critical barrier to fully integrating both concepts.

Fifth chapter is entitled "Farm Based Discomfort and Perceived Mental Stress Among Farmers". In this chapter, the authors use specialized software to assess mental fatigue in farmers from India. They conclude that farmers feel tired, stressed, irritated, depressed, and alone, requiring specialized psychological interventions.

Sixth chapter is entitled "The Importance of Demand Management in the Just-in–Time Strategy for Mexican Maquiladora Companies". The authors report a structural equation model with three independent variables associated with demand management, Kanban, one-piece flow, and just in time as the dependent variables. Using WarpPLS software, authors indicate that a just-in-time procurement and production process requires forecast and close relationships with providers.

Part Two. Production Processes: This part contains seven chapters, and all of them are described briefly.

Seventh chapter is entitled "The Use of Quantum Computing with 3D Modeling in the Industrial Sector". This chapter represents the results obtained through the investigation about the computer problem solving of 3D tridimensional figures in the industrial sector. It defines the quantum computer paradigm, which defines the capacity storage of information in amplitude values based in cubits and not in bits as commonly used and known.

Eighth chapter is entitled "Unemployment in the Industry with the Arrival of Robotics in Mexico". In this research, the authors demonstrate the impact of robots on unemployment in industry and how the replacement of humans with machines has changed. In addition, due to the statistics found in the information collected throughout the investigation, a more precise idea will be given of the risk that some workers run that their employment is threatened by robotization.

Ninth chapter is entitled "Human Decision-Making Evaluation: From Classical Methods to Neurocomputational Models". In this chapter, the authors support that decision-making directly influences workers' performance and summarize computational methods that are being developed to deepen the understanding of decision-making. The authors declare that neurocomputational methods application in organizations will make it possible to predict workers' behavior in various situations, including critical accidents.

Tenth chapter is entitled "The Augmented Reality Technology. An Experimental Application in the Educational and Industrial Sector of Baja California, Mexico". The authors propose a solution to the lack of infrastructure or scarce information and communication technologies in rural and suburban areas of any world region. The scientific study aimed to apply a method comprised of designing a new educational model used in the industry without using ICT. The authors report a better uptake of knowledge when using ART both in the educational and industrial sectors, with real-life environments with graphics. They concluded that the use of ART could be vital for any activity.

Eleventh chapter is entitled "Lean Automation Case Study: Down-Time Reduction in a Paper Unwinding Machine". The authors use TIA software for programming a programmable logic controller in an unwinding machine that was automated. After the automation process, they report a waste reduction, increasing final product quality.

Twelfth chapter is entitled "Development, Testing, and Simulation of Antifungal Polyurethane Insoles for Footwear". The author reports the design, development, and simulation process for an insole using FreeCad and ANSYS software. They validate the efficiency in the insole and add an antifungal substance.

Thirteenth chapter is entitled "The Technological Adaptation of SMES Through Fuzzy Cognitive Maps". The author proposes fuzzy logic and neural networks to generate decision-making when information is vague to automate a production process. After the implementation, the author reports reduced waste, time invested in maintenance, and increased money saved.

Part Three. Distribution and Commercialization: This part is integrated by six chapters that are described briefly as follows.

Fourteenth chapter is entitled "A New Distribution Strategy for Psychotropic and Cold Chain Products in a Pharmaceutical Company". In this chapter, the authors analyze the pharmaceutical retail industry's psychotropic and cold chain products for proper handling and distribution operations. At the correct pharmacy, a correct amount under safety conditions and a minimal cost are requirements. The authors propose a methodology including a mathematical model that is solved using AMPL software; a good approach is obtained. The model is validated with real data from a distribution company case study, giving a suitable distribution schedule.

Fifteenth chapter is entitled "Inventory Management Optimization of a Container Glass Products Manufacturer". In this chapter, the authors are focused on inventory management in Peru's container glass products manufacturer. We analyzed its strategic situation aligned to its operational plan. The data existed in the SAP S/4HANA Cloud system, simplifying the project execution from the bottom to the up line. Due to the increasing influence of the information systems and their implementation for specific problems, we presented an MRP, S&OP, or IBP dilemma.

Sixteenth chapter is entitled "Distribution Network Optimization in the Peruvian Agro-Industrial Sector". The authors report a study concerning palm oil. They use specialized software to carry out the management process of materials and their purchase, the planning of the production process, sales, and distribution of the same.

Seventeenth chapter is entitled "Product and Content Management Through QR Codes as an Efficient Strategy in E-commerce". In this chapter, the authors report how the use of QR codes facilitates and increases the efficiency of e-commerce. The case study results indicate that these new technologies should be part of the strategy and competitiveness that companies wish to establish.

Eighteenth chapter is entitled "System Dynamics and Graphical Interface for the Supply Process: A Case Study in a Regional Food Packing Company in Mexico". In this chapter, the authors analyze the product distribution process using system dynamics and Stella software. The results indicate that it is possible to minimize warehouse losses by simulating different scenarios that may arise.

Nineteenth chapter is entitled "Analyzing Supply Quality Improvements in ETO Companies That Switch to Mass Customization via AI Techniques". The paper reports a model applied to mass customization using the CRIP-DM method for Engineering to Order (ETO). The authors conclude that advanced purchasing through Multidisciplinary Design Assessment Teams reduces defectiveness in supplies.

Finally, the editors would like to express their gratitude to reviewers who kindly agreed to contribute to the chapters' evaluation at all stages of the editing process.

Ciudad Juárez, Mexico Jorge Luis García Alcaraz
Tijuana, Mexico Arturo Realyvásquez Vargas
May 2022

Acknowledgments

The editors would like to thank each of the authors for their contributions, who trusted in our work and editorial project, even though this year 2021 was challenging due to the COVID-19 pandemic. Likewise, we appreciate the responses that all authors have made to the comments for improvement in the review process.

Likewise, we wish to thank also to all the anonymous reviewers who gave their assessment of the chapters initially proposed, without a doubt that, without their collaboration and wise judgment, this editorial project would not have the expected quality. Thanks to all of them for that invaluable collaboration.

Finally, the editors would like to thank their families for the support provided throughout this editorial project; since much of that time we invested in editing this book, we had to spend with them in harmony. Without a doubt, we are in debt with our families, and we look forward to enjoying more time with them very shortly.

Ciudad Juárez, Mexico — Jorge Luis García Alcaraz
Tijuana, Mexico — Arturo Realyvásquez Vargas
May 2022

Contents

Production Processes

Distribution and Commercialization

Editors and Contributors

About the Editors

Jorge Luis García Alcaraz is a full-time professor with adscription to Department of Industrial Engineering at the Autonomous University of Ciudad Juárez. He received a bachelor's degree and a M.Sc. in Industrial Engineering from the Instituto Tecnológico de Colima (Mexico), a Ph.D. in Industrial Engineering from Instituto Tecnológico de Ciudad Juárez (Mexico), a Ph.D. in Innovation in Product Engineering and Industrial Process from University of La Rioja (Spain), a Ph.D. in Engineering and Industrial Technologies, and a Postdoc in Manufacturing Process from University of La Rioja (Spain). His main research areas are related to multicriteria decision-making applied to lean manufacturing, production process modeling, and statistical inference. He is a founding member of the Mexican Society of Operation Research and an active member in the Mexican Academy of Industrial Engineering. Currently, he is a national researcher level III recognized by the National Council of Science and Technology of Mexico (CONACYT) and is working with research groups from Colombia, Spain, Chile, and Dominican Republic. He is an author/co-author of around 150 papers publisher in journals indexed in the Journal Citation Reports, more than 200 international conferences and congress around the world. He is the author of 12 books published by international publishers as Springer and IGI Global, all then related to lean manufacturing, the main tools, and techniques.

Scopus Author ID: 55616966800. e-mail: jorge.garcia@uacj.mx

Arturo Realyvásquez Vargas is a full-time professor from the Department of Industrial Engineering at Tecnológico Nacional de Mexico/Instituto Tecnológico de Tijuana in Mexico. He received a master's degree in Industrial Engineering and a Ph.D. in Engineering Sciences from the Autonomous University of Ciudad Juarez in Mexico, and a Ph.D. in Innovation in Product Engineering and Industrial Process at the University of La Rioja (Spain). Specifically, his main research areas are related to optimization of industrial processes, lean manufacturing, and ergonomics. Also, he is an active member of the Society of Ergonomists of Mexico Civil Association (Sociedad de Ergonomistas de México, SEMAC) and the Network of Optimization of Industrial Processes (Red de Optimización de Procesos Industriales, ROPRIN). Currently, he is a national researcher level I recognized by the National Council of Science and Technology of Mexico (CONACYT) as Candidate. He is an author/co-author in around 12 papers published in journals indexed in the Journal Citation Reports, and also, he has attended to international conferences and congress in Mexico as well as in the United States of America. Nowadays, he has supervised more than 20 bachelor's theses and five master theses. He is the author of one book published by the international publisher Springer, related to ergonomics. Also, he has edited two books in IGI Global, all of them related to ergonomics.

Scopus Author ID: 56167726800. e-mail: arturo.realyvazquez@tectijuana.edu.mx

Contributors

Alacreu-Crespo Adrián Departamento de Psicología y Sociología, Área de Personalidad Evaluación y Tratamiento Psicólogico, Universidad de Zaragoza-Campus de Teruel, Teruel, Spain

Arana-De-Las-Casas Nancy Ivette Graduate Studies and Research Division, Tecnológico Nacional de México, Cd. Cuauhtémoc, Chihuahua, México

Arredondo-Soto Karina Cecilia Facultad de Ciencias Químicas e Ingeniería, Universidad Autónoma de Baja California, Tijuana, México

Ávila-López Luis Alfredo Facultad de Contaduría y Administración, Universidad Autónoma de Baja California, Tijuana, México

Avilés-Sacoto Sonia Valeria Departamento de Ingeniería Industrial and Instituto de Innovación en Productividad, Logística CATENA-USFQ, Colegio de Ciencias e Ingeniería, Universidad San Francisco de Quito, USFQ, Diego de Robles s/n y Vía Interoceánica, Quito, Ecuador

Blanco Fernández Julio Department of Mechanical Engineering, University of La Rioja, Logroño, La Rioja, Spain

Castellanos Humberto García Division of Graduate Studies and Research, Tecnológico Nacional de México/IT Ciudad Juárez, Ciudad Juárez, Mexico

Castillo Jenniffer Deyanira Industrial Engineering Department, Tecnológico Nacional de México, Mexico City, Mexico

Chauhan Hullash KIIT Deemed to be University, Bhubaneswar, Odisha, India

Chong Mario Facultad de Ingeniería, Universidad del Pacífico, Lima, Perú

Domínguez-Domínguez Jorge Department of Probability and Statistics. Centro de Investigación en Matemáticas, Unidad Aguascalientes, Aguascalientes, Aguascalientes, México

Duque Diego Fernando Manotas Faculty of Engineering, School of Industrial Engineering, Universidad del Valle, Santiago de Cali, Colombia

Díaz-Reza José Roberto Department of Electrical Engineering and Computer Sciences, Autonomous University of Ciudad Juárez, Ciudad Juárez, Mexico

Esparza-Ramírez Beatriz Adriana Department of Industrial Engineering, Instituto Tecnológico José Mario Molina Pasquel y Henríquez, Lagos de Moreno, Jalisco, México

García Alcaraz Jorge Luis Department of Industrial and Manufacturing Engineering, Autonomous University of Ciudad Juarez, Ciudad Juárez, Chihuahua, México

González-Arredondo Carlos PONDERCEL S.A de C.V., Centro Agroindustrial S/N, Chihuahua, México

Hernández-Escobedo Guadalupe Departamento de Ingeniería Industrial, Tecnológico Nacional de México, Instituto Tecnológico de Tijuana, Tijuana, México

Hernández-Hernández Marisol UAEM Valle de Chalco University Center, Autonomous University of the State of Mexico, Valle de Chalco Solidaridad, Mexico, Mexico

Hernández-Ramos Daniela Department of Education Sciences, Baja California Center for University Studies, Rosarito, Baja California, Mexico

Jiménez Macías Emilio Department of Electrical Engineering, University of La Rioja, Logroño, La Rioja, Spain

Lagarda-Leyva Ernesto A. Department of Industrial Engineering, Instituto Tecnológico de Sonora, Sonora, Mexico

Lopez-Badilla Gustavo UNEA Universidad, AviaciónMexicali, Baja California, Mexico

Lopez-Rodríguez Rogelio Department of Sciences, San Quintin Faculty of Engineering and Business, Autonomous University of Baja California, San Quintin, Baja California, Mexico

Luna Ana Facultad de Ingeniería, Universidad del Pacífico, Lima, Perú

López-Hernández Juan Gabriel Department of Basic Sciences, Agricultural Technology Center School, Valle de San Quintín, Baja California, Mexico

Mares-Castro Armando Department of Industrial Engineering, Tecnológico Nacional de México / ITS de Purísima del Rincón, Guardarrayas, Purísima del Rincón, Guanajuato, México

Martínez Cámara Eduardo Department of Mechanical Engineering, University of La Rioja, Logroño, La Rioja, Spain

Martínez Ruiz Yessenia Faculty of Engineering, School of Industrial Engineering, Universidad del Valle, Santiago de Cali, Colombia

Medina Lucia Universidad del Pacífico, Lima, Peru

Miranda-Ackerman Marco Augusto Facultad de Ciencias Químicas e Ingeniería, Universidad Autónoma de Baja California, Tijuana, México

Molins Francisco Department of Psychobiology, University of Valencia, Valencia, Spain

Morales-García Adrián Salvador Department of Electrical Engineering and Computer Sciences, Autonomous University of Ciudad Juárez, Ciudad Juárez, Mexico

Mosquera-Recalde Galo Eduardo Departamento de Ingeniería Industrial and Instituto de Innovación en Productividad, Logística CATENA-USFQ, Colegio de Ciencias e Ingeniería, Universidad San Francisco de Quito, USFQ, Diego de Robles s/n y Vía Interoceánica, Quito, Ecuador

Márquez Bogart Yail Systems and Computing Department, Master's in Information Technology, Technologico Nacional de Mexico, Mexico City, Mexico;
Industrial Engineering Department, Technologic Nacional de Mexico, Mexico City, Mexico

Pallete Fernando Pacífico Business School, Universidad del Pacífico, Lima, Perú

Peña Manuel Universidad Nacional Mayor de San Marcos, Lima, Perú

Pérez-Naranjo Mercedes Estefanía Departamento de Ingeniería Industrial, Colegio de Ciencias e Ingeniería, Universidad San Francisco de Quito, USFQ, Diego de Robles s/n y Vía Interoceánica, Quito, Ecuador

Quiroz-Sánchez Juan Carlos Department of Sciences, Autonomous University of Baja California, Mexicali, Baja California, Mexico

Raaijen Berend Universidad del Pacífico, Lima, Peru

Ramírez de Esparza Francisco Javier Bermejo Department of Electrical Engineering, University of La Rioja, Logroño, La Rioja, Spain

Ramírez-Franco Omar Department of Basic Sciences, Agricultural Technology Center School, Valle de San Quintín, Baja California, Mexico

Ramírez Malule Howard Faculty of Engineering, School of Chemical Engineering, Universidad del Valle, Santiago de Cali, Colombia

Realyvásquez-Vargas Arturo Departamento de Ingeniería Industrial, Tecnológico Nacional de México, Instituto Tecnológico de Tijuana, Tijuana, México;
Industrial Engineering Department, Tecnológico Nacional de México, Mexico City, Mexico

Reyes Ruiz Gerardo Center for Higher Naval Studies (CESNAV), Naval University, Cd. de México, Cd. de México, México;
Calz de La Virgen, Coapa Ex-Ejido de San Pablo Tepetlapa, Coyoacán, Ciudad de México, México

Ricárdez-Rueda Fernando Department of Industrial Engineering, Instituto Tecnológico José Mario Molina Pasquel y Henríquez, Lagos de Moreno, Jalisco, México

Rivera Lucero Pacífico Business School, Universidad del Pacífico, Lima, Perú

Rodríguez-Medina Manuel Arnoldo Department of Industrial Engineering and Manufacturing, Autonomous University of Ciudad Juárez, Ciudad Juárez, Mexico

Sahoo A. K. KIIT Deemed to be University, Bhubaneswar, Odisha, India

Satapathy Suchismita KIIT Deemed to be University, Bhubaneswar, Odisha, India

Serrano Miguel Ángel Department of Psychobiology, University of Valencia, Valencia, Spain

Solís-Quinteros María Marcela Facultad de Contaduría y Administración, Universidad Autónoma de Baja California, Tijuana, México

Sáenz Diez-Muro Juan Carlos Department of Electrical Engineering, University of La Rioja, Logroño, La Rioja, Spain

Sáenz-Zamarrón David Graduate Studies and Research Division, Tecnológico Nacional de México, Cd. Cuauhtémoc, Chihuahua, México

Tacza Luis Pacífico Business School, Universidad del Pacífico, Lima, Perú

Valdes- Hernández Roberto Carlos Department of Technology, Faculty of Administrative Sciences, Autonomous University of Baja California, Mexicali, Baja California, Mexico

Veloz-Alcaraz Reyna Guadalupe Academic body in formation ITESLM-CA-2 “Quality, Productivity and Technological Innovation in Organizations”, Instituto Tecnológico José Mario Molina Pasquel y Henríquez, Lagos de Moreno, Jalisco, México

Wright-León Christine Nicole Departamento de Ingeniería Industrial and Instituto de Innovación en Productividad, Logística CATENA-USFQ, Colegio de Ciencias e Ingeniería, Universidad San Francisco de Quito, USFQ, Diego de Robles s/n y Vía Interoceánica, Quito, Ecuador

Zayas-Márquez Carolina Facultad de Contaduría y Administración, Universidad Autónoma de Baja California, Tijuana, México

List of Figures

The Augmented Reality Technology. An Experimental Application in the Educational and Industrial Sector of Baja California, Mexico

Lean Automation Case Study: Down-Time Reduction in a Paper Unwinding Machine

Development, Testing, and Simulation of Antifungal Polyurethane Insoles for Footwear

The Technological Adaptation of SMES Through Fuzzy Cognitive Maps

A New Distribution Strategy for Psychotropic and Cold Chain Products in a Pharmaceutical Company

List of Tables

The Importance of Demand Management in the Just-in-Time Strategy for Mexican Maquiladora Companies

The Use of Quantum Computing with 3D Modeling in the Industrial Sector

The Augmented Reality Technology. An Experimental Application in the Educational and Industrial Sector of Baja California, Mexico

Development, Testing, and Simulation of Antifungal Polyurethane Insoles for Footwear

The Technological Adaptation of SMES Through Fuzzy Cognitive Maps

A New Distribution Strategy for Psychotropic and Cold Chain Products in a Pharmaceutical Company

Inventory Management Optimization of a Container Glass Products Manufacturer

Distribution Network Optimization in the Peruvian Agro-Industrial Sector

Product and Content Management Through QR Codes as an Efficient Strategy in E-commerce

System Dynamics and Graphical Interface for the Supply Process: A Case Study in a Regional Food Packing Company in Mexico

Analyzing Supply Quality Improvements in ETO Companies That Switch to Mass Customization via AI Techniques

Supply Chain and Provisions

Information Systems for Enterprise Resource Planning

Karina Cecilia Arredondo-Soto, Guadalupe Hernández-Escobedo, Arturo Realyvásquez-Vargas, and Marco Augusto Miranda-Ackerman

Abstract Enterprise Resource Planning (ERP) refers to a specific type of software used by companies to manage day-to-day business activities, including but not limited to accounting, procurement, project management, compliance and risk management, and supply chain operations. This chapter presents a literature review on the different perspectives and applications of ERP systems in the industrial sector in the last 20 years. As a result, most of the documented cases are related to the implementation of System Application and Product (SAP) and its different modules. A case study of the performance of CONTPAQi software in a small and medium-sized enterprise (SME) that relies on the ABC tool for inventory control is included.

Keywords SAP · Industrial management · Supply chain · Computer software · ERP system · CONTPAQi®

1 Introduction

In the current era of digitization of processes, the automation of information management systems is an inevitable process. For at least the last twenty years, Enterprise

K. C. Arredondo-Soto (✉) · M. A. Miranda-Ackerman
Facultad de Ciencias Químicas e Ingeniería, Universidad Autónoma de Baja California, Calzada Universidad #14418, Parque Industrial Internacional, 22390 Tijuana, México
e-mail: karina.arredondo@uabc.edu.mx

M. A. Miranda-Ackerman
e-mail: miranda.marco@uabc.edu.mx

G. Hernández-Escobedo · A. Realyvásquez-Vargas
Departamento de Ingeniería Industrial, Tecnológico Nacional de México, Instituto Tecnológico de Tijuana, Calzada Tecnológico s/n, Fraccionamiento Tomás Aquino, 22414 Tijuana, México
e-mail: guadalupe.hernandez@tectijuana.edu.mx

A. Realyvásquez-Vargas
e-mail: arturo.realyvazquez@tectijuana.edu.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_1

Resource Planning (ERP) has been a par excellence pillar of the information automation process in companies (Bochek and Olson 2020). An ERP system is an enterprise multi-function system that integrates modules that support the standardization of processes in the organization; its functionality can be applied in various industrial sectors (Bjelland and Haddara 2018). The ERP system supports performing routine operations of the company by integrating data, decreasing, and even eliminating the costs of the old computer systems lacking integration, and creating interpretable information for management and decision making. The ERP software is a precursor of the industry 4.0 of the digital era by considering within the information management: geographic location, traceability of components, access to information in real-time and therefore it is possible to model and simulate the processes using the standard or centralized database of the enterprise information system. The use of ERP software benefits productivity, performance, and quality, as the user and the system interact in an integrated and natural way (Dewi et al. 2020).

There are different ERP software options. One of these options is System Application and Product (SAP), one of the complete systems. Other ERP software options are Oracle, which is the main competition of SAP, Netsuite (more appropriate for small and medium companies, as it can be adapted to their growth), Microsoft Dynamics GP (has a financial accounting focus but is easily adapted to cover functions of an ERP system), Epicor, J. D. Edwards, Baan, PeopleSoft, among others. ERP modules allow one or thousands of users in real-time (Tatnall 2012). The companies using ERP software are diverse, such as the automotive manufacturing industry, food industries, logistics services, transportation, construction, and services. The initial costs of implementing an ERP system for small and medium-sized companies alone are between US $20,000 and US $50,000. However, additional hidden costs include training and educating personnel on the new system, the migration process, hardware purchases, consulting services, subscription fees, and system maintenance. Even considering the costs involved, the application of ERP systems is increasing.

The amount of information generated by companies, their employees, and customers is increasing, so companies require better information management systems, including the analysis of information from manufacturing processes, employee safety, sales and customer service, accounting and financial operations and human talent management. Given the transcendence of ERP systems in the company and its scope in the most everyday processes, work is done to make the user experience with this system friendly, so it is common to measure user experience satisfaction, which ultimately ensures that the system can remain in the long term (Wong et al. 2016).

Given the importance of ERP systems in the industry, considering a systemic and corporate approach, analyzing the production that addresses ERP systems in the last twenty years is considered attractive. This analysis is carried out to determine the areas and approaches of study, including background, technological aspects, usability, benefits of its implementation, its incorporation as a tool in higher education institutions, case studies, and its approaches from the manufacturing and human factor perspective.

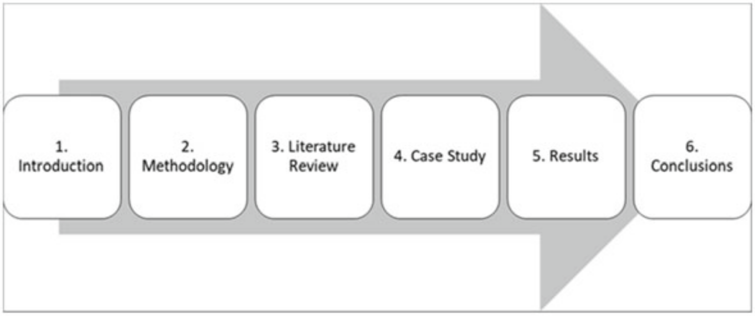


Fig. 1 Chapter organization

This chapter is organized as follows: the next section presents the methodology used for the literature review, then the literature review, followed by a particular case study in the implementation of an inventory system with CONTPAQi software, followed by an analysis of results, and finally the section of conclusions and general implications of the findings (see Fig. 1).

2 Methodology

The methodological process for the literature review consisted of using only the Scopus database as the primary search reference because there is institutional access. The keywords included in the search were SAP, software, ERP, computer software, ERP System, and Industrial Management, as shown in Fig. 2 (only journal articles were considered, omitting conference papers, books, and books chapters). This search yielded 65 papers. Of these 65 articles, it was only possible to access 57 because some are very old, and others are restricted to subscriptions, which is a limitation for accessing these documents.

When analyzing the main topics addressed in the documents resulting from the search, the topics that stand out refer to technological aspects, ERP in education, ERP in Small and medium-sized enterprises (SMEs), economic benefits, background, the usability of ERP systems, case studies of the application of ERP in different scenarios, also from the manufacturing and productivity approaches, as well as human factors. At least 31% of the research related to case studies and 19% related to manufacturing and productivity; therefore, these topics have had a relevance of 50% of the topics as

```
TITLE-ABS-KEY ( sap AND software AND erp ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( LIMIT-TO ( EXACTKEYWORD , "Computer Software" ) OR LIMIT-TO ( EXACTKEYWORD , "ERP" ) OR LIMIT-TO ( EXACTKEYWORD , "SAP" ) OR LIMIT-TO ( EXACTKEYWORD , "ERP System" ) OR LIMIT-TO ( EXACTKEYWORD , "Industrial Management" ) )
```

Fig. 2 Keywords for searching in Scopus

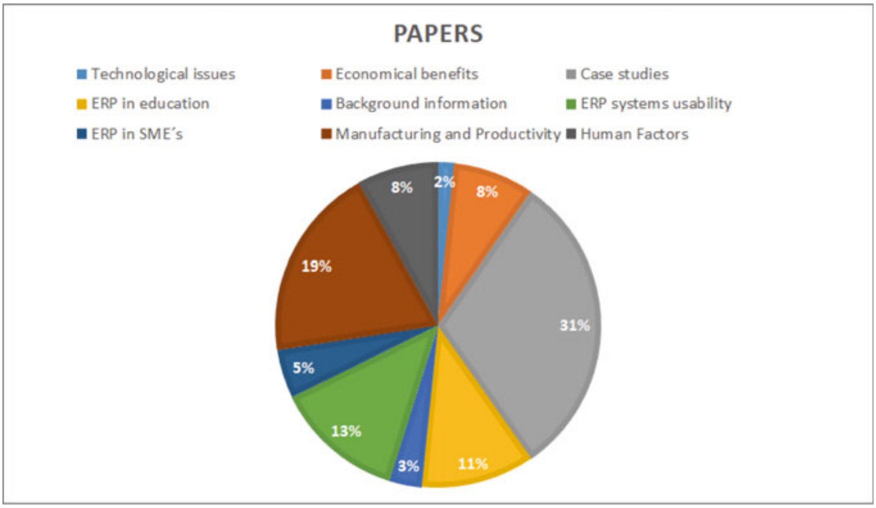


Fig. 3 Main ERP software topics documented in the last 20 years

research interest for academics and researchers (see Fig. 3). On the other hand, the usability of ERP systems and their implementation in higher education institutions and SMEs are topics that show consistent interest over time.

3 Literature Review

This section presents the literature review identified according to the methodology described in the previous section. For a better approach, ERP systems' background, technological issues, and generalities were considered. Also included are the economic benefits in their implementation, the usability aspects to be analyzed in ERP systems, and the different application contexts in SMEs, educational systems, manufacturing industry, and their association to productivity and the human factor. Table 1 presents the countries focusing on ERP systems topics. Table 2 includes the manuscripts per topic, author, and country.

3.1 Technological Issues and Background Information

Companies, as they grow, increase the amount of information they generate, so at some point, they must consider using an ERP system, where the transition processes can be very complex, costly, and in some ways can represent a risk for the organization (Kosalge and Ritz 2017). The system selection process can make a difference in the

Table 1 ERP topics

Country	Articles	Country	Articles	Country	Articles
Australia	1	Indonesia	1	Serbia	3
Bucharest	1	Ireland	1	Taiwan	2
Canada	3	Malaysia	1	Turkey	2
Croatia	2	Netherlands	3	United Kingdom	2
France	1	New Zealand	3	United States	21
Germany	6	Portugal	1		
Greece	1	Rusia	2		
India	1	Saudi Arabia	1		

Articles per country

implementation, and some of the variables considered in the selection process include primarily financial criteria.

However, it is essential to consider that non-financial criteria can indirectly affect the financial criteria. The benefits of a good selection span the operational, managerial, strategic, IT infrastructure, and organizational dimensions; the constraints involved in implementation include high costs and time consumption, inefficiencies during the implementation phase, the system customization and integration of data with the software (Findik et al. 2012).

Companies' main interest when applying ERP systems is optimization, flexibility to market demand, and the need to reduce the number of staff and increased workload for those who remain in their jobs. Therefore, the analysis of qualitative factors becomes viable, and philosophies as well-known as Six Sigma or Lean Manufacturing have been so successful by reducing manual and routine tasks, reducing waste and rework, reducing inventories, work in process, and having quick communication with customers. Integrating quality management in logistics processes is customary, incorporating SAP ERP even in the decision-making process (Klein and Fantes 2010).

The importance of ERP systems and their relationship with the system's quality, outwardly and inwardly, is then highlighted. Dewi et al. (2020) propose to evaluate the quality of ERP software systems and their capabilities; they performed quality testing of the One Gate Payment (OGP) system by applying the ISO 9126 quality standard that focuses on system functionality and efficiency. As a result, they recommend implementing SAP EDI, which can handle data format differences to send data manually and automatically by Host-to-Host (H2H) from the core SAP system to the non-SAP system to improve system interoperability of functionality and automatically improve quality in the OGP system.

Bouwers and Vis (2009) also focused on software quality measurement by proposing an alternative ERP system (Software Monitor) as an analysis tool and monitoring its quality during its development. They defined the requirements of the Software Monitor and explained why existing solutions do not meet all needs.

It is necessary to migrate to new software versions or integrate with other applications throughout the company in an implementation. On the other hand, among

Table 2 Manuscripts per topic, author, and country

Topic	Author	Country
Technological issues and background information	Dewi et al. (2020) Kosalge and Ritz (2017) Michelis (2015) Findik et al. (2012) Klein and Fantes (2010) Bouwers and Vis (2009) Stevens (2003)	Indonesia United States Germany Turkey Germany Netherlands United States
Economic benefits	Malinić and Todorović (2012) Lehrer and Behnam (2009) Chand et al. (2005) Ng et al. (2002)	Serbia United States United States Taiwan
ERP systems usability	Wong et al. (2016) Usmanij et al. (2013) Shkurskii and Sabel'nikova (2011)	Malaysia Australia Russia
ERP applied to SME's	Kosalge and Ritz (2017) Ruivo et al. (2015) Lee et al. (2009) Xie et al. (2007) Tinham (2006)	United States Portugal United States United Kingdom United Kingdom
ERP applied to education	Zhao et al. (2020) Barkhi and Kozlowski (2017) Chauhan and Jaiswal (2016) Chen et al. (2015) Mandal and Flosi (2012) Bandyopadhyay et al. (2011) Léger et al. (2011)	United States United States India United States United States United States Canada
Human factors and ERP integration	O'Connor et al. (2010) Janev et al. (2009) Le Loarne (2005) Reck and Barthel (2000)	Ireland Serbia France Germany
Manufacturing and productivity	Griend and Kusters (2012) Shkurskii and Sabel'nikova (2011) Bartels (2009) Catt et al. (2008) Surcel and Bologa (2008) Tchokogué et al. (2005) Chen et al. (2003) Ip and Chen (2002) Boykin (2001) Mullin (2001) Michel (1999) Strothman (1997)	Netherlands Russia United States New Zealand Bucharest Canada United States Canada United States United States United States United States

(continued)

Table 2 (continued)

Topic	Author	Country
Applications and case studies	Bochek and Olson (2020)	United States
	Rakovic et al. (2020)	Serbia
	Kaya and Aydin (2019)	Turkey
	Nađ and Vražić (2018)	Croatia
	Michelis (2015)	Germany
	Parveen and Maimani (2014)	Saudi Arabia
	Catt et al. (2008)	New Zealand
	Portougal (2005)	New Zealand
	Vuksic and Spremic (2005)	Croatia
	Gulledge and Sommer (2004)	United States
	Ioannou and Papadoyiannis (2004)	Greece
	Knoell et al. (2004)	Germany
	Haight (2003)	United States
	Mandal and Gunasekaran (2003)	United States
	Chang and Gable (2002)	Taiwan

the technical aspects that need to be considered when implementing is the heterogeneity of master data, which is often the main obstacle in implementing new ERP systems. Aspects such as data format, language(s) to be applied to the system, currency, and measurement units, among other variables that must be adapted to the new system. Often the data has to be reformatted, supplemented, and prepared for different applications (Michelis 2015).

Information systems and digital communication technologies are what make an ERP system possible. Today, companies spend time and energy on ERP processes and systems. Standards, ERP software, and middleware make up the ERP system, where each element is represented (human beings, resources, hardware and software, processes, organization, and society in general) and represents a seamless, secure, and reliable connection process for information management (Stevens 2003).

3.2 Economic Benefits

Malinić and Todorović (2012) discussed how accounting management changes with the implementation of ERP systems. They analyzed two studies where the economic benefits are not tangible in the first instance. The first case that included 54 companies concluded that there were no significant direct improvements in the results of the organizations considering the financial indicators; immediately during the period (three years) of ERP implementation, there was the only improvement in the costs of the final product. It is concluded that there is a time lag between implementing the ERP system and achieving the first positive effects.

The second case included 300 large industrial companies located in Finland. In this case, they concluded that ERP also did not significantly impact accounting management and that ERP did not stimulate the implementation of innovative techniques in the industry. Should we then question the viability of implementing an ERP system? Not necessarily. It takes time for ERP systems to reflect favorable results; changes are evolutionary and not revolutionary, promoting incremental changes. What is a fact is that financial management becomes simpler by automating processes through the ERP system and allows faster and more accurate decision-making.

In the specific SAP implementation case, Malinić and Todorović (2012) analyzed the Serbian industry. They concluded that the first phase of implementation focuses on the configuration of the basic modules and that the implementation process takes more than 18 months, leading to the simultaneous use of two systems in the company during this time.

The time lag to reach the full benefits of SAP's potential makes it a slow and painful implementation process from managers' perspective, who consider it complex and risky as it sometimes clashes with corporate culture, causing rigidity in information systems. The situation is made worse by choosing bad consultants who apply the wrong implementation strategy. However, SAP reduces the time required for traditional tasks and increases the time required for analysis and performance measurement needs.

Any information system requires maintenance and updating, including ERP systems. In many companies, information systems maintenance activities are allocated the largest departmental budgets. Ng et al. (2002) presented a case study of a large organization that implemented ERP (an SAP system) three years in advance. Some case study findings indicate that maintenance activities are related to the company, customers, and suppliers.

As in the internal software environment, enhancement is the primary maintenance activity in the ERP environment, comprising almost 64% of the total change request effort. ERP maintenance should be oriented to the benefits that best represent ERP maintenance activities, considering who is the source of the maintenance, why is it essential to address the request; and, what if the execution of the request has any impact on the installed modules?

Lehrer and Behnam (2009) analyzed product innovation through design strategies based on the functional aspect of products. Here, a historical case study on ERP-SAP software serves an internationally heterogeneous market. First, the principle of modularity and its relation to the standardization-adaptation dilemma is reviewed. Second, the lesser-known design principle of programmability is introduced. The study illustrates the interaction of these two principles; in essence, modularity helps to reduce some of the complexity and its associated costs by improving production scheduling.

An ERP system impacts the company's business objectives and creates a new framework for assessing the strategic impact of ERP systems. Chand et al. (2005) evaluated the organizational benefits of ERP systems using the balanced scorecard (BSC) approach, which can be a suitable technique for evaluating the performance of ERP systems. They used a successful SAP implementation of an international aircraft engine manufacturing and service organization as a case study.

3.3 ERP Systems Usability

Usability is a concept that relates to human–machine interaction and encompasses the ease or difficulty of learning to use it, efficiency, error tolerance, memorability, and the level of satisfaction generated. Usability is related to the quality of the system application, the degree of satisfaction, and the user experience considering the integrated system (people, tasks, activities, indicators). An information system can yield good indicators for the company in the financial area but be hated by the users and generate conflicts daily, which generates rejection and failure of the system, in the long run, impacting negatively on the initial investment for its implementation. Thus, companies that offer information systems design them with increasingly friendly features, improving usability.

Wong et al. (2016) analyzed problems related to SAP system usability, taking as a case study a textile company located in Bangladesh, where the usability of ERP systems, especially in the textile sector, had been scarcely addressed. They were asked about the characteristics that encouraged or discourage users from using the SAP system and identified new usability features that could make the system more flexible, more efficient, and less disruptive, considering employees' motivation and time. Three criteria were used as a basis:

- operability (associated with the user's operations and operations control effort applicable in their SAP usability testing)
- training (associated with the effort required to teach the use of software to the user)
- communicativeness (associated with the effectiveness of the software to communicate to the user the purpose for which it has been developed and the method of using it).

Usmanij et al. (2013) studied SAP-ERP systems with a human-centered approach and user satisfaction; they explored the relationship between human-centered dimensions (process, syntactic, semantic, social, and pragmatic) and user satisfaction SAP-ERP system. They answered the questions: what human-centered model can provide a systematic and detailed analysis of user satisfaction? Moreover, what methodology can validate this model, and how can it be applied to assess user satisfaction? They addressed the need for the human-centered approach as a basis for ERP system design and defined a systematic human-centered model for measuring user satisfaction. The essential features of the SAP ERP system are application integration, modular structures, shared data storage, open access, international acceptance, and manageability, including data storage, open access, international acceptance, and applicability for any branch of industry (Shkurskii and Sabel'nikova 2011).

3.4 ERP Applied to SME's

When analyzing enterprise resource planning (ERP) software, it can be said that there is a contrast between the corporate environment and the small business environment. ERP information systems also have their application in SMEs, and as they grow, they need to adopt new tools, systems, and software to plan their resources. As previously discussed, these changes can result in high costs and considerable risks, so it is of interest that before implementing a total change, they evaluate the possibility of making incremental changes within the systems they already use (Kosalge and Ritz 2017).

Some companies have explored the value variations of ERP planning in SMEs using different commercial packages such as Microsoft NAV, SAP All-in-one, ORACLE JDE, and SAGE X3. Specifically, the study by Ruivo et al. (2015) evaluated the use of ERP, collaboration, and analytics to explain the value of ERP on individual productivity, management control, and customer satisfaction; 883 European SME's participated in this study. As part of the results, it was identified that for Dynamics and ORACLE, the most critical factor is the capacity of the analytics system. For SAP and SAGE, it is the greater capacity of the collaboration system. In addition, for SAP and ORACLE, the increased use of ERP is an essential factor, but not for Dynamics and SAGE. Finally, collaboration and analytics capabilities are the most significant differentiators of ERP value. This study can support acting in software development.

Xie et al. (2007) identified ERP customer expectations and ERP vendor value propositions as a mutually compatible process for achieving ERP software performance. They contrasted the delivery of prominent ERP vendors that market systems such as SAP concerning the offerings of smaller ERP vendors when framed within a value proposition that they claim to be comparable or distinctive. For the high end of the market, enterprise systems are dominated by SAP, and Oracle focuses on large organizations. SMEs cannot afford the high software costs of these types of ERP systems. Open-source software is available as an alternative to enterprise systems, and Service-Oriented Architecture (SOA) can be an alternative for SMEs. They can use SOA to customize or improve their systems using web 2.0 to develop better business processes collaboratively. Lee et al. (2009) recommend working with SOA through Web 2.0 before implementing systems external to the company.

There are several contexts in which information technology has been used as an ERP in SMEs, such as the case presented by Tinham (2006) of the company Yorkshire Water, call center system, middleware, and mobile PCs. The company replaced all its financial, purchasing, human resources, and payroll services to redesign all operational and customer and operational processes and end-to-end integration from call centers to engineers and contractors. Calls are logged in SAP as jobs to be performed; then, overnight, SAP offloads all work to Advantex, where field technicians are scheduled to access priority jobs.

Griffiths et al. (2013) present the case study of a UK SME using SAP® Business One. They considered the actual costs (representing double the initial costs, including additional costs) of its implementation and the inconveniences during the process. Finally, Fleisch et al. (2004) identified the strategy to reduce ERP implementation times (which generally require about 18 months) to about 5–6 months in the case of SMEs. They analyzed four SMEs that implemented SAP R/3 using Accelerated SAP (ASAP), SAP's rapid implementation process, allowing the customization of processes.

3.5 ERP Applied to Education

It is a challenge for business students or employees to understand business processes and software without participating in real-world practices. That is why it is being incorporated into university curricula (Mandal and Flosi 2012). Given the importance of ERP systems concerning increasing and improving business indicators to achieve high performance, educational institutions (universities) have incorporated these topics in their curricula to improve the graduate profile of their students and achieve better job positions for graduates. That is why studies such as the one by Zhao et al. (2020) on constructivist learning theory have been conducted to determine whether students will promote its use and application in the long term and their level of satisfaction and perceived learning outcomes. They focused specifically on SAP software and included students from four mid-sized U.S. state universities as informants, with 373 informants. The main factors of importance identified for achieving student satisfaction were student motivation, instructor support, and ERP system quality. Their continued use will depend only on student motivation and ERP system quality.

It is claimed that the knowledge of software such as ERP improves the students' employability, but like everything else, it requires the stakeholders' acceptance. Chauhan and Jaiswal (2016) studied the determinants of acceptance of ERP SAP software training by Indian business school students and the role of gender differences and experience differences. It included the participation of 324 students from business study programs. Results revealed that online access, information technology innovativeness, performance, and effort expectancy positively influence students' intention to use. Gender moderates the effects of online access and effort expectancy on intention to use, with stronger relationships for females. Experience moderates the effect of effort expectancy on intention to use, and unexpectedly negatively moderates the effects of facilitating conditions on user behavior.

Another study related to SAP teaching in universities is presented by Barkhi and Kozlowski (2017). They pilot the implementation of the SAP ERP system in the classroom by proposing three step-by-step practical exercises that introduce some of the functional aspects of the software. In such a way, students can learn how to verify internal system controls and identify system weaknesses to expose students to real-world business practices. Chen et al. (2015) empirically examined ERPsim, an enterprise resource planning (ERP) teaching–learning tool for students in business education programs to learn real SAP and enterprise processes. The study provided empirical evidence that the primary constructs' enjoyment and cognitive appraisal of the use of information systems play an essential role in students' training and the effectiveness of using simulation to learn business processes and software.

Léger et al. (2011) also analyzed the implementation of ERPsim from a business simulation training approach developed at the interface between participants and the real-life business system (SAP), recreating a realistic environment for learners to develop the competencies and skills needed in the business world. They further addressed the challenges teachers face in adapting to this training approach, where learning needs to be fun and meaningful and where the learning paradigm used proven to be efficient is problem-based learning. Still and with the great need to increase the number of expert practitioners of ERP systems, Bandyopadhyay et al. (2011) identified the problem of declining enrollment of management information systems (MIS) in the United States. So, they suggested an enterprise resource planning (ERP) curriculum to reverse the trend in enrollment by facilitating ERP topics in the curriculum of business programs applying ERP software in different sectors.

3.6 Manufacturing and Productivity

ERP systems have also been investigated from manufacturing systems and increased productivity. Software process providers look at real-time event integration on the shop and factory floors to enterprise planning environments. Industry-specific, real-time integration scenarios are geared toward benefits such as cost reduction, latency, waste, or improved asset performance. SAP is an example by focusing on ERP/enterprise business planning and execution functions, where potential benefits and manufacturing philosophies such as lean, JIT, and Six Sigma are considered (Surcel and Bologa 2008). Bartels (2009) proposed a case study example focused on software services to prevent failures by applying predictive maintenance to a power generation company. As part of the information system, they used Microsoft SharePoint with a hierarchical database structured on the same basis as SAP.

Catt et al. (2008) described and applied a market-oriented method of measuring forecast performance (cost of forecast error—CFE) and compared the results with commonly adopted statistical measures of forecast accuracy in an ERP environment. It is a cost evaluation of SAP's forecasting models. The study results supported the adoption of CFE as a more relevant business decision-making measure than commonly applied statistical forecast measures.

Another case study is presented by Boykin (2001), focusing on material returns due to the negative impacts it has on resource loss and customer service quality. Material returns are a process that is related to functional areas such as materials, accounting, manufacturing, sales, and service, thus requiring an integrated information system solution. ERP systems were the solution by designing a material return authorization process linked to the ERP information system to support this process.

On the other hand, it is common to find studies involving the SAP R/3 system (Strothman 1997; Michel 1999; Mullin 2001; Ip and Chen 2002; Chen et al. 2003;

Shkurskii and Sabel'nikova 2011). Chen et al. (2003) present a prototype system for logistics flows and information extraction between customers and suppliers using World Wide Web, XML with SAP R/3 programming technology (ABAP/4 language). The objective was to support the improvement of business processes for customer services, logistics, planning, and manufacturing through the XML data interface integrated into the software solutions and provide a reliable and scalable IT infrastructure that meets the requirements of data transparency and consistency.

Ip and Chen (2002) investigated the organizational structure in an ERP system following its functional requirements. For this, they used SAP R/3. The authors proposed using enterprise modeling to analyze the gap between (1) the organizational structure of the enterprise and (2) the virtual enterprise in the system design and implementation. Enterprise modeling provided them with the essential tools and methods needed for (a) business process reengineering, (b)continuous improvement (c)customizing the ERP software, and (d) avoiding the complete reconstruction of the entire enterprise structure. Shkurskii and Sabel'nikova (2011) studied production automation processes in Russian enterprises applying OAO NLMK, also based on SAP ERP R/3 software, which integrates all economic processes of the group.

Mullin (2001) focused on the chemical industry, applying SAP R/3 ERP systems customer relationship management (CRM) and product life cycle management. He proposed the Scala Business Solutions Global series as a client/server-based ERP software package consisting of fully integrated modules for business processes, IBM's Axapta business management solution, and SAP UK Automotive Solution, based on the SAP R/3 system. Michel (1999) also focused on SAP R/3 but proposed an Accelerated SAP (ASAP) methodology that confirms excellent performance to enhance the benefits of SAP R/3. Strothman (1997) used SAP R/3 in inventory management and warehouse management, identifying its weaknesses in meeting the requirements of plant functions. He used a batch control system as an interface between SAP and the plant to remedy this shortcoming. Griend and Kusters (2012) proposed an experimental approach to defining an integration testing effort metric based on ERP system logs. They proposed a change flow reconstruction process based on SAP R/3 system logs to show how effort can be distilled from the changing flow.

Finally, Tchokogué et al. (2005) point out some strategic, tactical, and operational considerations inherent to implementing an ERP are prerequisites for the effective organizational transformation required by implementing a system such as SAP R/3. They concluded that success is conditioned by adequate management of the complex context of an ERP implementation. The human factor was given prominence. They considered managers' leadership to provide all the necessary resources and manage them through performance indicators.

3.7 Human Factors and ERP Integration

The information systems with the ERP approach have modules that are useful to the human resources department because it generates a database with all the information of the employees. It is even possible that employees can access their information in a self-service type and generate reports, work records, payroll receipts, the validity of social services rights, among others. Implementing SAP HR software cannot and should not be limited to the mere replacement of the existing payroll system. Different approaches to self-service have been developed, including solutions offered by SAP, Sage Software, and IBM®. O'Connor et al. (2010) examined the approach taken by IBM Lotus® Workforce Management, a self-service solution for IBM WebSphere® Portal. Lotus Workforce Management provides three key features that allow organizations more choice and control over the implementation of a self-service solution:

1. Extensibility (which allows users to add or remove components and functionality and determine the communication structure between portal resources)
2. Customization (design a solution tailored to their needs)
3. Ease of integration (uses existing components for SAP ERP systems).

The realization of HR strategy with the support of software inevitably leads to a redesign of existing HR processes (Reck and Barthel 2000).

Expert data integration of systems can present challenges. Janev et al. (2009) discussed expert data integration and expert search challenges in organizations. In presenting the case study, they presented how the latest semantic technologies (ontologies, web services, semantic wiki) could be used on top of commercial ERP software (SAP®) and open source ECM (Enterprise Content Management) software (Alfresco) to ensure expert knowledge search and retrieval for internal users. Janev et al. (2009) made a brief analysis of the structure and functionality of ERP systems and Supply Chain Management—ERP and Customer Relationship Management—ERP relationships, highlighting the possibilities of improving the performance of logistics systems. He emphasizes that integration is possible through available ERP software modules such as SAP, Oracle, and MS Dynamic Nav. systems.

The extractive and processing industry also has applications for ERP systems. In this regard, Le Loarne (2005) documented a case in which he analyzed the social and power-sharing effects of software implementation associated with work procedures. They emphasize that the ERP system brings about fundamental changes in the way personnel organize themselves and strengthens their control over their work. Another finding is that managers violate the system to achieve objectives, with system specialists being the main actors.

3.8 Applications and Case Studies

Taking advantage of their centralized information system, companies network to get as much information as possible and keep processes flowing to increase their sales and thus their profits (Rakovic et al. 2020). According to Parveen and Maimani (2014), SAP and Oracle are now more viable for small and medium-sized companies, while Microsoft Dynamics is now more viable for medium to large companies. They also identified that Oracle is more frequently selected than SAP or Microsoft Dynamics to meet various needs, priorities, and competitive advantages. The SAP ERP system contains robust forecasting methods (exponential smoothing). However, it could be enhanced by incorporating simultaneous forecast comparisons, prediction intervals, seasonal and autocorrelation charts, linear regression lines for trend analysis, and event management based on structured judgmental forecasting or intervention analysis—practical implications (Catt et al. 2008).

Data heterogeneity is the main obstacle when implementing new ERP systems, the migration process to new software versions, or integrating with other applications in the company (Michelis 2015). As with all new projects, it has been found that ERP system implementation depends on top management commitment, business process re-engineering, project management practices, and user training/education (Bochek and Olson 2020). With the support of their managers, companies in e-commerce, pharmaceutical industry, electrical machine factories, food industry, among others, have performed successful implementations of ERP systems. Mandal and Gunasekaran (2003) described the experience of ERP system implementation in a water company. The case reveals the difficulties that can occur during the planning and implementation stages and offers some suggestions. Haight (2003) took as a case study the Delphi company focused on communication with suppliers by taking advantage of digitalization processes. So that they could be integrated with the Kanban system, allowing suppliers to use standard web browsers to receive schedules, forecasts, and recall signals sent to the Delphi plant. Delphi has also replaced its (ERP) systems with SAP software to improve communication.

With the rise of digitalization of processes, e-commerce has also increased and prospered over the Internet. This mode of purchasing has advantages for companies and generates the need to incorporate ERP information systems, and many of them operate using SAP. Kaya and Aydin (2019) addressed the critical aspects of e-commerce and proposed a solution for ERP integration into an e-commerce system. Nađ and Vražić (2018) presented the possibility of using software (ERP) for an alternative analysis of electrical machines (all types, taking induction machine as an example) with SAP ERP without including any additional programming. Vuksic and Spremic (2005) presented the impacts of information technologies and ERP systems on business process renewal. They took the reengineering of business processes and implemented SAP software solutions in the pharmaceutical industry. Portougal (2005) documented implementing an SAP module in a food industry considering abrupt changes in demand, including inventory stocks and not only sales on order.

Knoell et al. (2004) evaluated the best-known life cycle models concerning their suitability for SAP software implementation from the process approach. Most companies have not taken advantage of all their virtues, giving a convenient approach.

Gulledge and Sommer (2004) identified that the implementation of SAP software is substantially different between the public and private sectors. In the public sector, split instances are expected, implying that the implementing organization does not own all the business processes in its domain. They recommended considering this when proposing SAP implementation methodologies.

For their part, Ioannou and Papadoyiannis (2004) approached a manufacturer of packaging products and equipment as a case study. They identified the reasons for ERP systems' long implementation times and organizational drawbacks, with code development in ERP systems being one of the leading causes (due to the key and unique requirements required in the business environment). Also, a second cause is the localization and reporting needs that companies require. They relied on the Theory of Constraints to solve the issues by implementing SAP R/3. Mandal and Gunasekaran (2003) describe how SAP R/3 software was an appropriate tool for inventory management in a company with global operations. They evaluated the system requirements, the configuration of SAP R/3 to meet those requirements, the difficulties of implementing the system, and the benefits obtained. Chang and Gable (2002) presented a case study focused on the government finance department, a public company where SAP Financials was implemented. The study results determine the need to make a more detailed division of data to get the maximum potential of ERP systems.

4 Case Study

This chapter has dealt extensively with ERP systems and different applications and software modules, mainly SAP. This section will present as a case study the implementation of a perpetual inventory control system in a warehouse in a security company and audio accessories for motor vehicles using CONTPAQi software. CONTPAQi integrates sales, invoicing, purchasing, inventory, accounts receivable, and accounts payable; it focuses on growing sales and tax compliance. The case study company is in downtown Tijuana, Mexico. It consists of a warehouse of products delivered to its customers through two distribution channels: over-the-counter sales or delivery by motorcycle throughout the city. One of the company's goals is to meet immediate customer satisfaction by delivering products when required. This project consisted of creating and implementing an inventory control system using the ABC analysis tool, supported by CONTPAQi; it should be noted that there was no information management system in the warehouse at the beginning of the project. It should be noted that the company's approval at the start of the project was essential to demonstrate the importance of information management since poor management of it, especially in inventories, can cause significant waste, and a substantial impact on profits goes unnoticed.

Inventory knowledge is purely empirical based on sales and observation. The input process (purchases) is not recorded or documented as inventory, and the output (sales) of merchandise is done through a Point of Sale (POS) system that only records the number of pieces sold, their price, and the name of the customer. By not having control over its inventory, the company suffers two significant situations over time: constant loss of sales due to not having the products for their realization and an excessive inventory of certain products, which after a specific time is left behind or is sold, as a way of capital recovery, at cost price. The project's objective was to establish a perpetual inventory control system with the support of the ABC inventory technique, where the inventory can be visualized in real-time, allowing a preventive inventory control where the correct amount of products to be ordered can be obtained.

Specifically, the goal was to:

- reduce unrealized transactions due to lack of inventory,
- reduce excess inventory,
- install a CCTV monitoring system to provide evidence of physical product entries and exits in the event of an eventuality, and
- Create a warehouse inventory database that is available at all times and updated in real-time.

Having an inventory control system is vital for any company or organization. In the case of Wade Security, inventory is information that must be treated as accurate and real as possible since our financial transactions depend on it. The availability or non-availability of a product can result in the success or failure of a sale or in the erroneous order of a product that is already in stock, resulting in over inventory. The project presented directly benefits the company by raising its level of reliability in its inventory through the implementation of computer software, CONTPAQi Commercial. To keep track of the inputs and outputs in the warehouse and thus, in the future, know what product and in what quantities products should be purchased, establish demand forecasts, techniques of maximum and minimum, among others. All this is summarized in having a robust and efficient inventory control, which can be consulted at any time. Where there is no information bias and serves as a support for other departments' decision-making leads organizations to obtain what they all seek: the generation of profits.

The project's central area was developed in the warehouse, where the products are distributed in racks. The size of the boxes and the type of products are different and include components for audio and vehicle safety. This is where the products are extracted for delivery to the customer to the counter or home delivery. The main problem is that there is no precise control of incoming and outgoing goods. There is no specific person in charge of the warehouse and its control. Using an inventory control system would make it easier to be aware of the warehouse at all times without having to repeatedly check to see if there are any pieces of a particular item left. Purchasing to maintain inventory was done purely on an empirical basis and based on seasonal sales spikes, not specific items. One of the biggest problems was the dissatisfaction of customers when their orders were not fulfilled (not satisfying a demand), and the organization incurred losses. This concept of when an unfulfilled sale generates losses was the deciding factor for the project to be carried out.

At the start of the project, sales receipts were made manually without any stamp or letterhead. All this, for the simple purpose of generating a sum that matched the amount of money at the end of the day. The situation was a source of alarm due to the lack of control of the items when using this method since when the accounts were settled, the accounting day was approved without knowing which items were sold. After conducting a thorough physical count, it was found that most of the items that should have been in the warehouse were no longer there because the list that was kept was from a long time ago when many items were still being handled or had in stock. Figure 4 shows the initial state of the warehouse.

With the items physically accounted for, we proceeded to use the ABC inventory technique using the Excel software of Microsoft Office. The first column contains

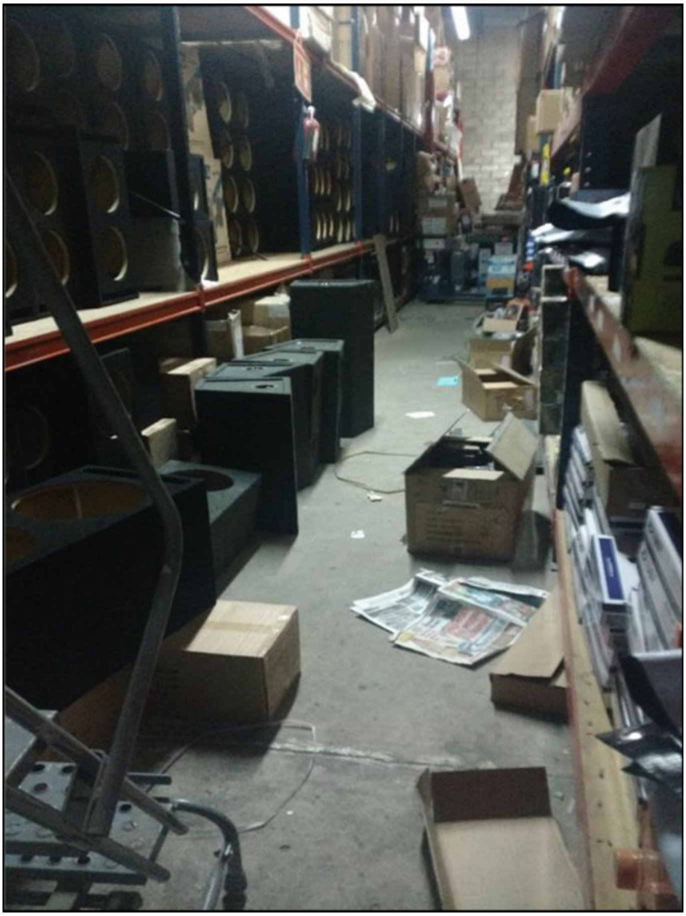


Fig. 4 Aisle without control or records of items

Table 3 Example of column arrangement for ABC inventory

#	Name	Unit cost	# Units	Total cost
1	ARGON LAZER	$12.96	272	$3525.93
2	COBRA	$12.96	17	$220.37
3	FIRE LAZER	$12.96	89	$1153.70
4	FUSION	$12.70	65	$825.74
5	LETHAL	$12.70	30	$381.11
6	USA17	$12.22	22	$268.89
7	VENOM	$13.15	235	$3089.81
8	BANDIDO SILVER	$12.59	31	$390.37
9	ALARMA ALFA	$14.81	139	$2059.26
10	KIT DE VIDRIOS (2)	$43.63	3	$130.89
11	KIT DE VIDRIOS (4)	$85.93	10	$859.26
12	ACTUADORES	$1.22	800	$977.78
13	KIT C/4 ACTUAD Y MODULO	$7.04	5	$35.19
14	BVW2	$2.22	31	$68.89
15	BVW5	$2.63	35	$92.04
16	FDFV2-250	$1.81	65	$117.96
17	RV2-5	$2.00	42	$84.00

the item number. The second column contains a brief description of the item, and the third column contains the unit cost, followed by a fourth column with the number of existing items as shown in Table 3.

Once all the items have been arranged in this way, the necessary formulas are applied to the columns to obtain the required data.

- Total Cost: It is the multiplication of the units by the cost of the item.
- Range: The order or range from lowest to highest in terms of inventory cost.
- Accumulated Units: Once we know the range of each item, we then need to calculate how many total units are needed for the items classified as less than or equal to.
- Percentage of Accumulated Units.

Finally, the formula for the classified A, B, or C with a formula in Excel with the "IF" command. We proceed to perform the ABC inventory calculations, which are based on the Pareto principle as shown in Fig. 5.

The graph is elaborated with the values obtained in Fig. 5, considering the accumulated quantities and the error values to obtain the ABC classification as shown in Fig. 6.

According to the inventory analysis by the ABC method, we proceed to the relocation of the items according to their importance, as shown in Fig. 7.

ABC Class	Number of items	Items	% of Total cost	H-	H+	V-	V+
A	10%	760	23%	759.9	1,519.8	23%	23%
B	20%	2,280	47%	1,519.8	5,319.3	23%	53%
C	70%	7,599	100%	5,319.3	-	53%	0%

Summary for the chart			
A Class	760 items	23.2% total cost ($14k)	A Class760 items23.2% total cost ($14k)
B Class	1,520 items	23.3% total cost ($15k)	B Class1,520 items23.3% total cost ($15k)
C Class	5,319 items	53.5% total cost ($33k)	C Class5,319 items53.5% total cost ($33k)

Fig. 5 ABC classifications and their values

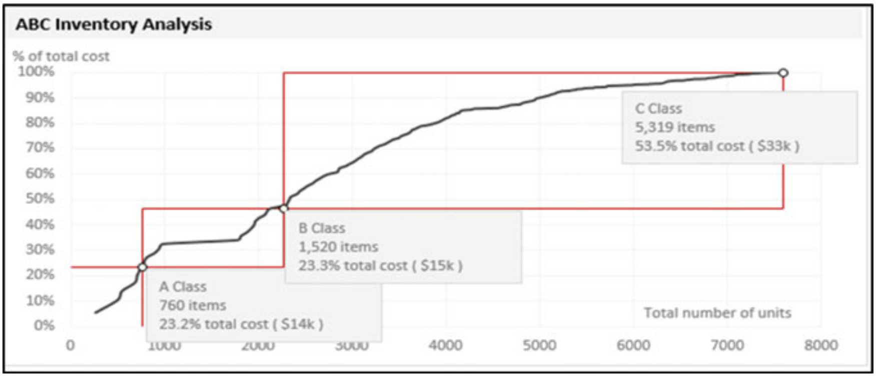


Fig. 6 ABC analysis and classification

Subsequently, CONTPAQi software was acquired in its “Commercial Pro” version. The installation required a PC with at least 2 Gb RAM for the program’s exclusive use and at least 2 h for the software installation. The installation was carried out on two computers, one that would function as the main box and the other as the information monitoring station. The training was for the cashier in charge of sales and the entry/exit of items, a fundamental part of inventory control. It is worth mentioning that this was the right person because the software covered collateral needs such as the migration to electronic invoicing. Once the program was installed on the computer, we started updating the database at the same time that we were downloading the information to the software. The updating process ran, and the real challenge was to perform a count without closing transactions in the company. This objective was achieved by doing a quick count by families, closing these for transactions at that moment, and continuing from family to family.

The software had a very user-friendly interface, as shown in Fig. 8. Customer information was collected along with their tax information. New items were added as they were added throughout the previous count, and this one—all this information to make the system as reliable as possible. With the ABC price matching that was done previously, this task was performed efficiently. It is worth mentioning that during the months of the project, customers were offered a list of overstocked products at cost prices to eliminate the excess inventory. This promotion was offered regularly

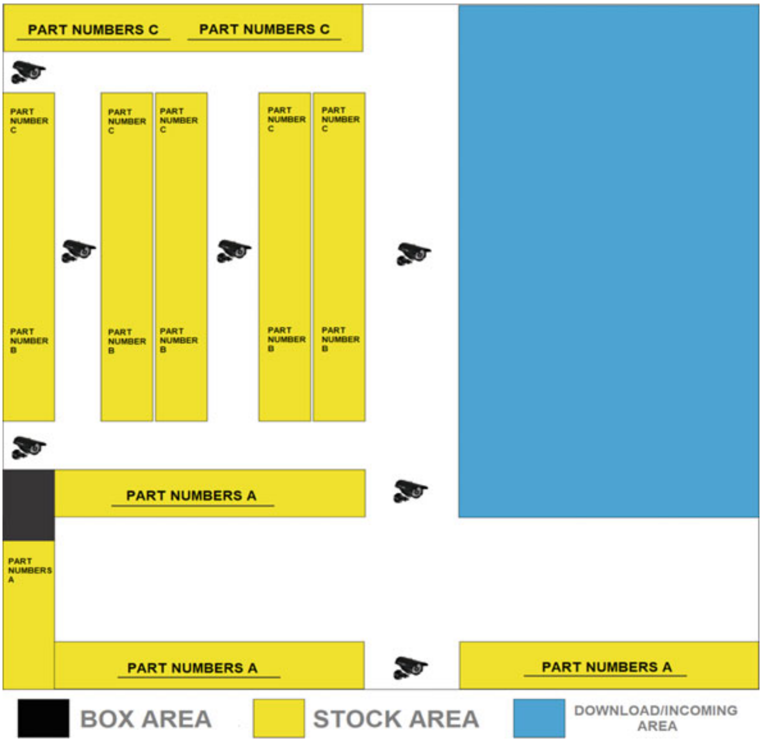


Fig. 7 Layout based on the results of the ABC technique analysis of inventory and position of the surveillance cameras

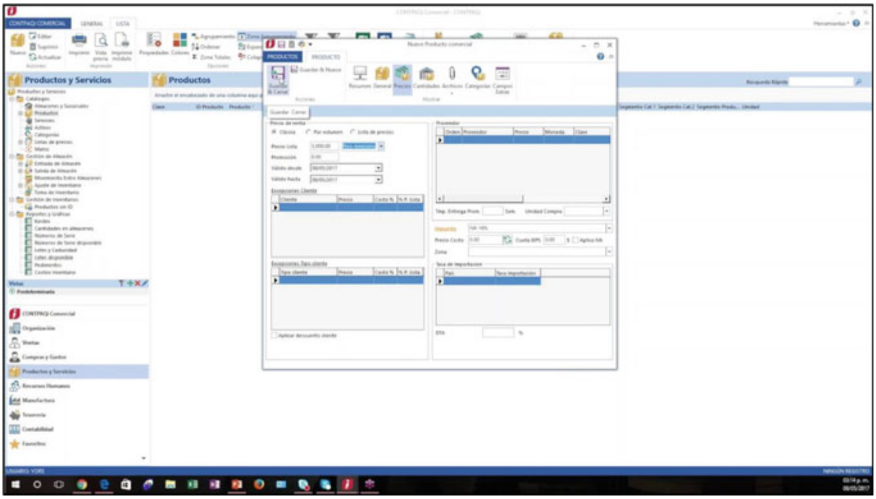


Fig. 8 CONTPAQi Commercial Pro system graphical user interface

Fig. 9 Before and after the implementation of ABC method

when the customer came to make purchases, and they were even called to offer the products. With the implementation of the software, it was possible to increase sales, covering 15% of sales not covered due to lack of stock and an additional 10% increase, generating an overall increase of 25% in sales due to the implementation of the inventory system and the software. The use of the software also had a positive impact on the amount of inventory, which was reduced by 27%. Figure 9 presents the before and after the implementation of the ABC method.

5 Results

The literature review presents a perspective demonstrating the evolution of the application of ERP information systems. Twenty years ago, their incorporation in large companies was considered a novelty and very complicated for small and medium-sized companies. This has changed with the development of more user-friendly packages and their update systems based on usability, increasing the implementation's success rates and reducing the implementation times to periods as short as five months.

These agile features incentivize their performance, use, and maintenance in organizations. It can be said that, with the current boom in the digitization of processes, it is no longer considered a novelty. It is viewed as a necessity and requirement of the supply chain. While before, it was commented on global scales, now it is applied to local and regional scales. The costs of implementation, training, maintenance, and upgrades continue to be a constraint for more excellent coverage in its adoption by a more significant number of companies. Measuring the quality of the performance of ERP systems and the different software in the market has been necessary for system upgrades. Another finding is related to the economic benefits, wherein in the early 2000s, the profits generated by implementing ERP systems were not quickly reflected by companies. Instead, it caused much dissatisfaction in organizations from managers' perspective due to the need to work simultaneously with two or more information systems during the migration process. This situation has been reduced by creating compatible systems that allow information import more efficiently.

6 Conclusions

Any organization providing services has different interrelated departments that can lead to success if they are managed correctly or to failure if they are neglected in their entirety. The excellent management of resources of any origin, whether commercial, economic, and human, is key to the optimal functioning of any company. For this reason, ERP systems are critical in any business unit to have accurate and reliable information, which can be helpful in decision making. The owner or manager of a company or organization cannot be everywhere, and companies' information increases. According to the analysis carried out, it is highlighted that historically ERP systems have been considered expensive and therefore difficult to access, mainly because their use was for business models of large companies and in the case of small and medium-sized companies. Its application was often unfeasible. With the rise of the digital age, large companies act as a link between producers and customers globally, managing sales and absorbing the costs of the systems due to more efficient use of them. With the COVID-19 pandemic, global sales increased. An opportunity arose for people to test the success or failure of business information systems. The balance has been quite positive, generating real expectations for growth and new areas of business opportunity for ERP systems in the world.

References

Bandyopadhyay, K., Barnes, C., Ajendla, B.: ERP integration in the college of business curriculum. IJBIS **8**, 146 (2011). https://doi.org/10.1504/IJBIS.2011.041789

Barkhi, R., Kozlowski, S.: ERP in the classroom: three SAP exercises focused on internal controls. J. Emerg. Technol. Account. **14**, 77–83 (2017). https://doi.org/10.2308/jeta-51701

Bartels, N.: Machines have their say. Control (chicago, Ill) **22**, 28–34 (2009)

Bjelland, E., Haddara, M.: Evolution of ERP systems in the cloud: a study on system updates. Systems **6**, 22 (2018). https://doi.org/10.3390/systems6020022

Bochek, Z., Olson, D.L.: Case study of SAP implementation in a corporation network plant. Int. J. Serv. Oper. Manage. **35**, 189–206 (2020). https://doi.org/10.1504/IJSOM.2020.105270

Bouwers, E., Vis, R.: Multidimensional software monitoring applied to ERP. Electron. Notes Theoret. Comput. Sci. **233**, 161–173 (2009). https://doi.org/10.1016/j.entcs.2009.02.067

Boykin, R.F.: Enterprise resource planning software: a solution to the return material authorization problem. Comput. Ind. **45**, 99–109 (2001). https://doi.org/10.1016/S0166-3615(01)00083-5

Catt, P.M., Barbour, R.H., Robb, D.J.: Assessing forecast model performance in an ERP environment. Ind. Manage. Data Syst. **108**, 677–697 (2008). https://doi.org/10.1108/02635570810876796

Chand, D., Hachey, G., Hunton, J., et al.: A balanced scorecard based framework for assessing the strategic impacts of ERP systems. Comput. Ind. **56**, 558–572 (2005). https://doi.org/10.1016/j.compind.2005.02.011

Chang, S.-I., Gable, G.G.: A comparative analysis of major ERP life cycle implementation, management and support issues in Queensland government. J. Glob. Inf. Manag. **10**, 36–54 (2002). https://doi.org/10.4018/jgim.2002070103

Chauhan, S., Jaiswal, M.: Determinants of acceptance of ERP software training in business schools: empirical investigation using UTAUT model. Int. J. Manag. Educ. **14**, 248–262 (2016). https://doi.org/10.1016/j.ijme.2016.05.005

Chen, L., Keys, A., Gaber, D.: How does ERPsim influence students' perceived learning outcomes in an information systems course? An empirical study. J. Inf. Syst. Educ. **26**, 135–146 (2015)

Chen, R.-S., Wang, H.-C., Wang, C.-M.: A Web-based data extraction system for supply chain management using SAP R/3. Int. J. Comput. Appl. Technol. **16**, 33–38 (2003). https://doi.org/10.1504/IJCAT.2003.000308

Dewi, N.D.K., Saputra, M., Wahjoe Witjaksono, R., et al.: Functionality and efficiency measurement of corporate payable ERP system development as one gate payment to vendor. Int. J. Sci. Technol. Res. **9**, 300–305 (2020)

Findik, S., Kusakci, A., Findik, F., Kusakci, S.: Selection and Implementation of ERP systems: a comparison of SAP implementation between BIH and Turkey. South East Eur. J. Econ. Bus. **7**, 19–28 (2012). https://doi.org/10.2478/v10033-012-0002-x

Fleisch, E., Öesterle, H., Powell, S.: Rapid implementation of enterprise resource planning systems. J. Organ. Comput. Electron. Commer. **14**, 107–126 (2004). https://doi.org/10.1207/s15327744joce1402_02

Griffiths, M., Heinze, A., Ofoegbu, A.: The real SAP® business one cost: a case study of ERP adoption in an SME. IJMP **6**, 199 (2013). https://doi.org/10.1504/IJMP.2013.055831

Gulledge, T.R., Sommer, R.A.: Splitting the SAP instance: lessons on scope and business processes. J. Comput. Inf. Syst. **44**, 109–115 (2004)

Haight, B.: Delphi is expanding its use of web based tools to manage its more than 5000 suppliers. Automot. Ind. AI **183** (2003)

Ioannou, G., Papadoyiannis, C.: Theory of constraints-based methodology for effective ERP implementations. Int. J. Prod. Res. **42**, 4927–4954 (2004). https://doi.org/10.1080/00207540410001721718

Ip, W.-H., Chen, B.: Organisation structure and enterprise modelling in ERP realisation. Int. J. Network. Virtual Organ. **1**, 170–183 (2002). https://doi.org/10.1504/IJNVO.2002.002544

Janev, V., Dudukovic, J., Vraneš, S.: Semantic web based integration of knowledge resources for expertise finding. Int. J. Enterp. Inf. Syst. (IJEIS) **5**, 53–70 (2009). https://doi.org/10.4018/jeis.2009090204
Kaya, A., Aydin, Ö.: E-commerce in Turkey and sap integrated e-commerce system. Int. J. eBusiness eGovernment Stud. **11**, 207–225 (2019). https://doi.org/10.34111/ijebeg.20191128
Klein, G., Fantes, K.: Increased efficiency by integration of quality management into the logistical processes solutions with and without SAP®ERP. World Metall. ERZMETALL **63**, 77–84 (2010)
Knoell, H.-D., Kuehl, L.W.H., Kuehl, R.W.A., Moreton, R.: Evaluation of standard ERP software implementation approaches in terms of their capability for business process optimization. J. Comput. Inf. Sci. Eng. **4**, 271–277 (2004). https://doi.org/10.1115/1.1710865
Kosalge, P.U., Ritz, E.: Identifying the antecedents to ERP adoption. Int. J. Bus. Innov. Res. **13**, 344–362 (2017). https://doi.org/10.1504/IJBIR.2017.10005069
Le Loarne, S.: Working with ERP systems—is big brother back? Comput. Ind. **56**, 523–528 (2005). https://doi.org/10.1016/j.compind.2005.02.010
Lee, S.M., Olson, D.L., Lee, S.-H.: Open process and open-source enterprise systems. Enterp. Inf. Syst. **3**, 201–209 (2009). https://doi.org/10.1080/17517570902777624
Léger, P.-M., Charland, P., Feldstein, H.D., et al.: Business simulation training in information technology education: guidelines for new approaches in IT training. J. Inf. Technol. Educ. Res. **10**, 039–053 (2011)
Lehrer, M., Behnam, M.: Modularity vs programmability in design of international products: Beyond the standardization–adaptation tradeoff? Eur. Manag. J. **27**, 281–292 (2009). https://doi.org/10.1016/j.emj.2009.01.003
Malinić, S., Todorović, M.: How does management accounting change under the influence of ERP? Econ. Res.-Ekonomska Istraživanja **25**, 722–751 (2012). https://doi.org/10.1080/1331677X.2012.11517531
Mandal, P., Flosi, A.: Horizontal integration of courses through SAP: implementation in a business school. IJBIS **9**, 343 (2012). https://doi.org/10.1504/IJBIS.2012.045722
Mandal, P., Gunasekaran, A.: Issues in implementing ERP: a case study. Eur. J. Oper. Res. **146**, 274–283 (2003). https://doi.org/10.1016/S0377-2217(02)00549-0
Michel, R.: New speed limits. Manuf. Syst. **17**, 90–92, 94, 96 (1999)
Michelis, A.: Master data optimization before ERP migration. ZWF Z. Fuer Wirtschaftlichen Fabrikbetrieb **110**, 311–313 (2015). https://doi.org/10.3139/104.111330
Mullin, R.: Taking IT to the next level. Chem. Week **163**, 1–3 (2001)
Nađ, J., Vražić, M.: Analytical model of electrical machines in business software. Tehnicki Vjesn. **25**, 582–586 (2018). https://doi.org/10.17559/TV-20160626125528
Ng, C.S.P., Gable, G.G., Chan, T.: An ERP-client benefit-oriented maintenance taxonomy. J. Syst. Softw. **64**, 87–109 (2002). https://doi.org/10.1016/S0164-1212(02)00029-8
O'Connor, J., Dalton, R., Naro, D.: Lotus workforce management. Int. J. Web Portals (IJWP) **2**, 22–36 (2010). https://doi.org/10.4018/jwp.2010010103
Parveen, M., Maimani, K.: A comparative study between the different sectors using the ERP software in Jeddah region- KSA. Life Sci. J. **11**, 40–45 (2014)
Portougal, V.: ERP implementation for production planning at EA cakes Ltd. J. Cases Inf. Technol. **7**, 98–109 (2005). https://doi.org/10.4018/jcit.2005070106
Rakovic, L., Duc, T.A., Vukovic, V.: Shadow it and ERP: multiple case study in German and Serbian companies. J. East Eur. Manag. Stud. **25**, 730–752 (2020). https://doi.org/10.5771/0949-6181-2020-4-730
Reck, J., Barthel, E.: Increasing the contribution of human resources to the company's value by implementing a human resources system. Wirtschaftsinformatik **42**, S107–S113 (2000). https://doi.org/10.1007/bf03250704
Ruivo, P., Oliveira, T., Neto, M.: Using resource-based view theory to assess the value of ERP commercial-packages in SMEs. Comput. Ind. **73**, 105–116 (2015). https://doi.org/10.1016/j.compind.2015.06.001

Shkurskii, S.A., Sabel'nikova, E.A.: Resource-control system based on the SAP ERP system. Coke Chem **54**, 426–427 (2011). https://doi.org/10.3103/S1068364X1111010X

Stevens, C.P.: Enterprise resource planning: a trio of resources. Inf. Syst. Manag. **20**, 61–67 (2003). https://doi.org/10.1201/1078/43205.20.3.20030601/43074.7

Strothman, J.: Where ERP meets process control, S88 can help. INTECH **44**, 49–50 (1997)

Surcel, T., Bologa, R.: The ERP capabilities for enhancing the logistic system integration. Amfiteatru Econ. **10**, 84–93 (2008)

Tatnall, A. (ed.): Reflections on the History of Computing. Springer, Berlin (2012)

Tchokogué, A., Bareil, C., Duguay, C.R.: Key lessons from the implementation of an ERP at Pratt & Whitney Canada. Int. J. Prod. Econ. **95**, 151–163 (2005). https://doi.org/10.1016/j.ijpe.2003.11.013

Tinham, B.: IT keys to mouth. Manuf. Comput. Solutions **12**, 36–37 (2006)

Usmanij, P.A., Khosla, R., Chu, M.-T.: Successful product or successful system? User satisfaction measurement of ERP software. J. Intell. Manuf. **24**, 1131–1144 (2013). https://doi.org/10.1007/s10845-012-0645-6

van de Griend, P.A., Kusters, R.J.: Integration test effort in sap R/3 systems. J. Softw. Evolut. Process **24**, 421–435 (2012). https://doi.org/10.1002/smr.546

Vuksic, V.B., Spremic, M.: ERP system implementation and business process change: case study of a pharmaceutical company. J. Comput. Inf. Technol. **13**, 11–24 (2005). https://doi.org/10.2498/cit.2005.01.02

Wong, W.-P., Veneziano, V., Mahmud, I.: Usability of enterprise resource planning software systems: an evaluative analysis of the use of SAP in the textile industry in Bangladesh. Inf. Dev. **32**, 1027–1041 (2016). https://doi.org/10.1177/0266666915585364

Xie, Y., Hickman, S., Zhou, L.: A critical evaluation of enterprise resource planning (ERP) software sourcing and provision using theoretical constructs. IJISM **3**, 327 (2007). https://doi.org/10.1504/IJISM.2007.013367

Zhao, Y., Bandyopadhyay, K., Barnes, C.: Predictive maintenance information systems: the underlying conditions and technological aspects. Int. J. Enterp. Inf. Syst. **16**, 54–72 (2020). https://doi.org/10.4018/IJEIS.2020040104

Geothermal Power Projects Valuation Model

Yessenia Martínez Ruiz, Diego Fernando Manotas Duque, and Howard Ramírez Malule

Abstract Interest in geothermal energy has increased lately due to climate change, dependence on fossil fuels, and clean energy production. However, the development of this kind of energy project is affected by great risks and uncertainties, mainly associated with its investment phases and geothermal resources. Therefore, considering its nature of assuming certainty in the key variables and projected cash flows, conventional valuation is not adequate to assess the financial feasibility of this type of investment. This study was based on a probability approach through Monte Carlo simulation to know the economic valuation of geothermal energy projects in Colombia. This study also included the analysis of Colombian government instruments, mainly tax and accounting incentives, developed in the framework of non-conventional renewable sources to promote and encourage investments in this type of energy. Different scenarios with and without these regulatory policies were then carried out to evaluate the governmental support to the financial viability of renewable energy projects, especially geothermal ones. For this purpose, the valuation was performed by applying two classic methods known as NPV and LCOE. Considering geothermal energy projects have high risks and uncertainties, the decision criteria of these approaches were evaluated using the VaR and CVaR risk measures for different confidence levels and using MATLAB ® for the modeling of different scenarios.

Keywords Geothermal energy · Financial valuation · Risk assessment · Value at risk · Conditional value at risk

Y. Martínez Ruiz (✉) · D. F. M. Duque
Faculty of Engineering, School of Industrial Engineering, Universidad del Valle, Calle 13, no. 100-00, Santiago de Cali, Colombia
e-mail: yessenia.martinez@correounivalle.edu.co

D. F. M. Duque
e-mail: diego.manotas@correounivalle.edu.co

H. Ramírez Malule
Faculty of Engineering, School of Chemical Engineering, Universidad del Valle, Calle 13, no. 100-00, Santiago de Cali, Colombia
e-mail: howard.ramirez@correounivalle.edu.co

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_2

1 Introduction

The global goal of reducing the dependence and the environmental effects of using fossil fuels for energy production has led to an increase in the use of renewable sources, such as geothermal (Ehyaei et al. 2020). However, the availability of this non-conventional resource is associated with geologic factors where the most relevant are found within the well-known "Pacific Ring of Fire" which crosses countries such as Indonesia, the United States, Mexico, Bolivia, Chile, and Colombia (Tecnología y Recursos de la Tierra et al. 2011; Pambudi 2018). In Indonesia, geothermal energy currently supplies 5% of the energy generated in this country, and its installed capacity by 2025 is estimated to be around 6000 MW (Bertani 2016). On the other hand, Iceland is recognized as one of the countries whose energy production is totally renewable, being supplied mainly by hydropower and geothermal energy, the latter, with a 27% share in the electricity generation matrix.

In the case of Colombia, it is estimated that the country has a geothermal energy potential of 2200 MW (ISAGEN 2014), which establishes it as a focus of interest for the development of clean energies (UPME 2015). However, geothermal energy has not been developed in Colombia. In fact, energy generation with non-conventional renewable sources does not exceed 220 MW of installed capacity in the country. This only represents a participation of 1.26% in the Colombia electricity matrix (XM 2020). This situation has led the national government to establish a new regulatory framework, mainly represented by Law 1715 (Congreso de Colombia 2014), to encourage investment in this clean energy project employing policy stimulus and promotion measures.

Compared to other kinds of renewable energy such as solar and wind, geothermal energy is considered the technology with the greatest technical potential since its capacity factor is in the range of 70–90% (Bazmi and Zahedi 2011). In addition, the risk associated with the features of the geothermal resource, which are subject to the project site (Lesmana et al. 2020), means that the development of this technology faces major obstacles. Thus, ensuring the economic viability of projects of this nature from the outset would lead to a mistake (Van Erdeweghe et al. 2018). In other words, uncertainties affecting the operating environment are typical of projects where drilling is necessary to obtain relevant resource data. This feature differs from other renewable technologies, where valuable information is obtained for project development without large capital requirements (Pollack and Mukerji 2019).

From the financial point of view, this study aims to evaluate the feasibility of geothermal energy projects in Colombia, using NVP and LCOE under a risk perspective based on Value at Risk (VaR) and Conditional Value at Risk (CVaR) measures. The analyses carried out included Monte Carlo simulation to model the behavior of technical and financial variables, according to the main uncertainties associated with geothermal resources and the Colombian energy market. This analysis also includes the economic effect of the Colombian regulatory framework on the decision criteria of each indicator applied. The probability distribution and descriptive statistics for each valuation approach were also analyzed.

The remainder of this chapter is as follows. Section 2 presents a literature review with the main valuation methods for evaluating renewable energy projects. Section 3 describes the methodology developed for the valuation analyses of the case study. Section 4 contains the results obtained from the model. Finally, the main conclusions of this research are presented in Sect. 5.

2 Literature Review

The financial valuation of geothermal energy projects has been carried out through several applications of discounted cash flow methods such as Net Present Value (NPV), Expected Net Present Value (ENPV), and Levelized Cost of Energy (LCOE). Van Erdeweghe et al. (2018) used the NPV approach to assess the impact of drilling cost in low-temperature geothermal plants. Also, Córdova Geirdal et al. (2015) calculated the NPV to compare in economic terms a traditional installation of a geothermal plant and a wellhead method, which allows energy production from the beginning of the project. Bilqist et al. (2018) evaluated the financial feasibility of geothermal energy projects under the technique known as ENPV. The authors found that the volatility of these projects can be reduced while obtaining more robust results for decision-making.

However, uncertainties associated with renewable resources and climatic variables directly influence the risk of this type of investment, which is characterized by being developed in an uncertain horizon and harbors huge uncertainties (Loncar et al. 2017). Thus, energy generation from renewable sources can vary significantly from one place to another if factors such as geographical location, variability of the resource, and even season of the year, are considered. Hence, authors such as Kim et al. (2017) and Martínez-Ruiz et al. (2021a) argue that applying static approaches to energy project valuation does not adequately capture variables' risks, exposures, and uncertainties assuming certainty in the cash flows. For example, despite the LCOE is often applied in the framework of renewable energy projects, many authors have questioned its application as a valuation metric, due to does not consider important cost in the lifespan of a project, variation in energy production, and presents many shortcomings regarding risk and uncertainty analysis (Harvey 2020; Shen et al. 2020; Aquila et al. 2021b). Studies such as the one by Lukawski et al. (2016) performed stochastics analyses to characterize the uncertainty associated with the drilling costs of geothermal wells as a function of their depth. This study was based on the probabilistic assignment of the variables that affect such costs, finding that project costs have a considerable increase as the depth is greater.

On the other hand, the large capital amount required to develop investment in renewable energy projects makes the government's support necessary to incentivize and improve the economic viability of these projects (Tang et al. 2012). In the case of geothermal projects, some authors such as Nasruddin et al. (2016) and Compernolle et al. (2019) agree that one of the barriers to the large-scale use of geothermal energy is related to the financing of these projects, which require significant investments to undertake them.

More sophisticated analyses based on the Real Options Approach (ROA) (Zhang et al. 2019), Decouple Net Present Value (DNPV) (Espinoza and Rojo 2015), and probabilistic approaches as Monte Carlo Simulation (Tran and Smith 2018), have been carried out by different researchers. Other methodologies, such as the one developed in Aquila et al. (2021a), performed risk analyses based on "CVaR (Conditional Value at Risk)-LCOE" to compare the ranking of 20 Brazilian cities against a deterministic LCOE, for a photovoltaic installation. Besides that, Díaz-Trujillo et al. (2020) implemented the CVaR to assess the uncertainty associated with biomass availability. An environmental and economic analyses was carried out in this study through a multi-scenario with this risk approach.

3 Methodology

This section describes the case study on which the financial feasibility analyses were performed. The characteristics of this case and the modeling variables established are detailed. The risk measures applied to this analysis are also part of the development of this section.

3.1 Case Description

This research design is based on Martínez-Ruiz et al. (2021b) to evaluate the economic feasibility of geothermal projects according to a case study located in Colombia. The analyses were carried out using risk measures known in the literature, namely Value at Risk (VaR) and Conditional Value at Risk (CVaR) for 3 confidence levels, and applied to two traditional valuation methods. These results were compared with those obtained by applying the deterministic Net Present Value (NPV) and the Levelized Cost of Energy (LCOE).

3.1.1 Investment and Operating Phases

Located in a Colombian municipality, the horizon of this project is considered a total of 27 years which are composed as follows: first eight years (from year 0 to year 7), the investment phases are developed. The project starts its operating phase with a useful life of 20 years. The first investment stage of geothermal energy projects is the *exploration phase*. This phase aims to obtain important information about the technical characteristics of the site where the project will be located, including the energy potential forecast. If the geoscientific exploration developed indicates a positive result of the potential resource, then the drilling of deep exploratory wells

Table 1 Project capital investment

Phase	Activities	Investment in MM COP	%
Exploration 3 years	Access roads	$2.901	
	Field preparation	$3.917	
	Piping systems	$4.352	
	Engineering and supervision	$1.458	
	Hiring and contingencies	$4.250	
	Drilling exploration wells	$20.737	
	Total exploration phase	$37.614	15
Drilling 2 years	Drilling production wells	$18.145	
	Drilling of reinjection wells	$9.073	
	Steam piping systems	$16.319	
	Reinjection system	$2.539	
	Total drilling phase	$46.075	19
Development 3 years	Plant construction	$104.960	
	Engineering and hiring	$48.675	
	Licenses	$10.524	
	Total development phase	$164.159	66
	Total investment	$247.848	100

Source Own research

is carried out. Production and reinjection wells are also drilled in the *drilling phase*. In this study, the number of successful wells for exploration and energy production was assumed equal to 1 with a success rate of 50% for each.

Technical information obtained from the previous stage is crucial for carrying out the *development phase*, due to these factors are closely related to the geothermal plant design. For this case, the type of power plant was defined as Single-Flash Power Plant, considering the characteristics of the production well, such as its temperature and flow rate.

The duration, activities, and capital required to develop the investment phases of this case study are listed in Table 1.

The amount of electricity to be generated by the geothermal project during its *operating phase* was estimated mainly based on the features of the geothermal sources, which determine the thermal power of the successful production well. These characteristics are represented by well temperature (T_i) and flow rate (Q), two technical variables that harbor great uncertainties and whose estimates depend on the geothermal properties of each site. The efficiency of geothermal plants for energy production was also evaluated by incorporating the capacity factor (cf) in the analysis. These technical variables, along with other parameters, were used to estimate the annual net energy production of the project (EN_n) from Eq. (1):

$$EN_n = \big((\rho_F \cdot c_p \cdot Q \cdot (T_i - T_o)) \cdot cf \cdot Ha\big) \cdot (1 - Dg)^{(n-8)}/1000; \forall_{n>7} \qquad (1)$$

EN_n: Net energy production of year n (kWh)
ρ_F: Density of water (1000 kg m^{-3})
c_p: Specific heat capacity of water (4180 J kg^{-1} K^{-1})
Q: Flow rate (m^3 s^{-1})
T_i: Well temperature (K)
T_O: Reinjection temperature (373.15 K)
cf*:* Capacity factor (%)
Ha: Hours per year (8760)
Dg: Annual decrease in energy production (3%)

As can be noted in Eq. (1), from year 2 of operation onwards (n > 8), an annual decrease in energy production was considered, which is related to the degradation of geothermal resources over the life of the project.

3.1.2 Input Variables

The input variables of the case study were defined considering those technical and financial variables that do not have a certain behavior and whose values can have many implications on the financial feasibility of the geothermal project. To address this, such input variables were modeled through a probabilistic function according to the historical information available and modelling criterial considered by other studies. In the technical variables case, it was determined a probabilistic approach given the significant level of uncertainty in geothermal projects, especially, in the early years when exploration and production wells are drilled. Alike, the behavior of financial variables was simulated with stochastic approaches due to the volatilities of the spot and financial markets. Table 2 summarizes the uncertain technical and financial variables, their probability distribution, and the corresponding input arguments. The input arguments of capacity factor were established according to NREL (National Renewable Energy Laboratory 2020).

Table 2 Input variables of the model, where normal N (μ; σ) and triangular T (min; mode; max)

Type	Variable	Notation	Units	Input arguments
Technical	Temperature	T_i	K	N (473.1; 29.3)
Technical	Flow rate	Q	m^3/s	T (0.029; 0.038; 0.042)
Technical	Capacity factor	cf	%	T (75.0; 90.0; 94.3%)
Financial	Bilateral contracts price	$P_{contracts}$	COP$/kWh	N (203.0; 19.7)
Financial	Spot price	P_{spot}	COP$/kWh	N (309.73; 117.01)
Financial	Producer price index	PPI	%	N (3.8; 2.3%)
Financial	Consumer price index	CPI	%	N (4.4; 1.7%)
Financial	Fixed operating and maintenance costs	OM	COP$/kW	T (202,967; 225,519; 257,091)
Financial	Investment year 0	Inv_0	MM COP$	T (9905; 11,034; 12,538)
Financial	Investment year 1	Inv_1	MM COP$	T (9905; 11,034; 12,538)
Financial	Investment year 2	Inv_2	MM COP$	T (9905; 11,034; 12,538)
Financial	Investment year 3	Inv_3	MM COP$	T (15,652; 17,435; 19,812)
Financial	Investment year 4	Inv_4	MM COP$	T (20,748; 23,111; 26,263)
Financial	Investment year 5	Inv_5	MM COP$	T (38,906; 43,338; 49,248)
Financial	Investment year 6	Inv_6	MM COP$	T (50,577; 56,339; 64,022)
Financial	Investment year 7	Inv_7	MM COP$	T (40,202; 44,782; 50,889)

Source Own research

3.2 Financial Assessment

Utilizing the Free Cash Flow (FCF) construction, the financial assessment of this project was carried out. The revenues of this generation project are made up from the sale of electricity either by (i) the bilateral contracts or (ii) by the Spot Market, according to the Wholesale Energy Market (MEM, for its acronym in Spanish).

Bilateral contracts are characterized by contemplating long-term contracts, where transactions between the agents are carried out to reduce the volatility characteristic of market prices. In this way, an energy-generating agent will seek that the percentage of participation that the long-term contracts will have over the total income of the project is as close to 100%, to ensure most of its income and hedge against the inherent eventualities of the stock exchange market. Revenues from this concept will be represented by the percentage of energy traded through long-term contracts and by the average price at which each kWh traded through these contracts will be paid. For this study, the amount of electrical energy traded under bilateral contracts was defined as 80% of the total energy production, and its average price ($P_{contracts}$) was modeled with a normal distribution and was annually adjusted based on the Producer Price Index (*PPI*) from year 2 of operation onwards (n > 8).

The difference between the total energy produced and the amount of energy committed to the bilateral market (i.e., 20% of the total energy production in this case study) will be traded through the spot market. Unlike to bilateral market, transactions in the spot market are carried out with a short term (less than one day), and its price (P_{spot}) is characterized by high volatility due to its dependence on the climate variability of the country. For this geothermal energy project, the behavior of this financial variable was defined as a normal distribution from its historical data. Annual revenues (I_n) for the case study were estimated from Eq. (2):

$$I_n = EN_n \cdot \left(\left(0.8 \cdot P_{contracts} \cdot (1 + PPI)^{(n-8)}\right) + \left(0.2 \cdot P_{spot}\right)\right); \quad \forall_{n>7} \tag{2}$$

Fixed operating and maintenance costs (*OM*) represent the project's expenses for each kW of the plant capacity (*PC*). This value was annualized based on the duration of the operating phase (20 years) and applying a discount rate (i) of 7.52% according to the capital structure assumed. Following Eq. (3), the total operating and maintenance costs of the project (*Total OM*) were obtained:

$$Total\ OM = OM \cdot \left[\frac{i \cdot (1+i)^{20}}{(1+i)^{20} - 1}\right] \cdot PC \tag{3}$$

After, the result was annually adjusted based on the Consumer Price Index (CPI), as shown in Eq. (4):

$$Total\ OM_n = Total\ OM \cdot (1 + CPI)^{(n-8)}; \quad \forall_{n>7} \tag{4}$$

The working capital (*WC*) policy in this project was established as one month over OM. The investment in working capital ($InvWC_n$) is the capital required to develop the daily operations of the plant and corresponds to the variation of WC between the current and previous year. These values were calculated from Eqs. (5) and (6), respectively.

$$WC_n = OM_n/12; \quad \forall_n \tag{5}$$

$$InvWC_n = WC_n - WC_{n-1}; \quad \forall_{n\geq 1} \tag{6}$$

The FCF for each year of the project were estimated from Eq. (7):

$$FCF_n = NOPAT_n + Dep_n - Inv_n - InvWC_n; \quad \forall_n \tag{7}$$

FCF_n: Free Cash Flow of year n (MM COP\$)
$NOPAT_n$: Net Operating Profit After Tax of year n (MM COP\$)
Dep_n: Depreciation of year n (MM COP\$)
Inv_n : Investment of year n (MM COP\$)
$InvWC_n$: Investment in working capital of year n (MM COP\$) Where $NOPAT_n$ is estimated following Eq. (8):

$$NOPAT_n = (I_n - TotalOM_n - Dep_n) \cdot (1 - \tau); \quad \forall_n \tag{8}$$

τ : Tax rate (32%)

3.2.1 Regulatory Framework

The Colombian government has established new laws and regulations in the last years to encourage and promote the development and use of non-conventional energy sources (especially those from renewable sources), allowing diversified sources generation of the country. This new regulatory framework is mainly represented by Law 1715 enacted in 2014 (Unconventional Renewable Energies Law), which establishes tax, tariff, and accounting incentives for these projects (Congreso de Colombia 2014). These are:

- Value Added Tax (VAT) and import duties exemption.
- Accelerated depreciation of assets, within 5 year (20% annual).
- Income tax deduction of up to 50% for investors, for a period no longer than 15 years.

As mentioned before, the financial feasibility of the case study developed in this work was carried out considering scenarios with and without these incentives, to quantify the effect of government policies on the financial sustainability of geothermal energy projects.

3.3 Decision Criteria and Risk Analysis

3.3.1 Net Present Value (NPV)

The NPV approach was one of the traditional methods applied in this work to determine the economic feasibility of the geothermal energy project. This tool is widely used in the framework of project valuation and consists of discounting future cash flows to the present and subtracting the present value of the investment. The decision criteria associated with this method classifies the project as financially viable if its NPV is positive (NPV > 0). This entails that the revenues of the project must exceed its expenses for it to be attractive, otherwise it is rejected. Future cash flows are discounted to the present using an interest rate that considers the time value of money and the risk associated with such investment. The NPV of the case study were calculated using Eq. (9).

$$NPV = \sum_{n=0}^{27} \frac{FCF_n}{(1+i)^n} \tag{9}$$

NPV: Net Present Value of the project (MM COP$)
FCF_n : Free Cash Flow of year n (MM COP$)
i: Discount rate (7.52%)

Levelized Cost of Energy (LCOE)

Furthermore, the LCOE was calculated as another decision criteria to know the economic viability from the point of view of cost. To determine the result of this indicator, the lifecycle cost was calculated considering the investments and the fixed OM of the project. The tax shield resulting from depreciation and project expenses was also considered. Equation (10) shows the basic definition of the LCOE, where the lifetime energy production was obtained from the sum of the discounted annual electricity generated.

$$LCOE = \frac{\sum_{n=0}^{27} \frac{Inv_n + Total\ OM_n - TS_n - Income\ tax_n}{(1+i)^n}}{\sum_{n=0}^{27} \frac{EN_n}{(1+i)^n}} \tag{10}$$

LCOE: Levelized Cost of Energy of the project (COP$/kWh)
Inv_n : Investment of year n (COP$)
$Total OM_n$: Total operating and maintenance costs of year n (COP$)
TS_n: Tax Shield (COP$)
$Incometax_n$*:* Income tax deduction of Law 1715 of year n (COP$)
EN_n: Net energy production of year n (kWh)
i: Discount rate (7.52%)

where TS_n is estimated following Eq. (11) and τ is the tax rate equal to 32%:

$$TS_n = \tau \cdot (Total\ OM_n + Dep_n) \tag{11}$$

For the case of the scenario with tax incentives, income tax deduction was considered as negative flows for the calculation of the LCOE, since it represents a reduction in the result of this indicator.

3.3.2 Value at Risk and Conditional Value at Risk Estimation

VaR is a risk measure used to quantify the market risk of a portfolio of assets. It is defined as the maximum expected loss given a confidence level (α) in a specific period (Mosquera-López et al. 2017). CVaR is a more pessimistic measure than VaR, as it focuses on losses found in the tails of the distributions, i.e., it is estimated as

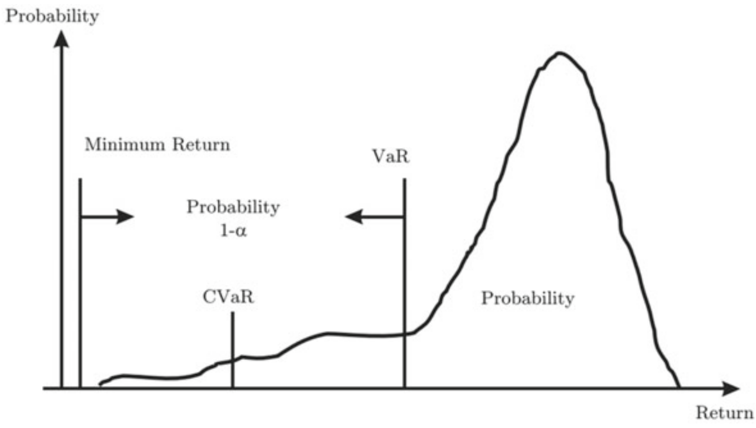


Fig. 1 VaR and CVaR (Sawik 2010, Open access)

the average of the values that exceed VaR (Aquila et al. 2021a). The application of this statistic indicates the maximum loss if an unexpected event occurs. Figure 1 represents the definition of VaR and CVaR graphically.

The estimation of these risk measures can be extended to the field of project valuation. In this study, in addition to calculating the NPV and LCOE of the project, VaR and CVaR estimation were also carried out. Due to the nature of the NPV approach, risk measurement was assessed at 90, 95, and 99% of confidence levels since the unfavorable scenarios are on the left-hand side of the distribution. Unlike this, the LCOE method has a cost distribution, then, the important analyses for its risk evaluation were performed at 10, 5, and 1% of confidence levels.

4 Results

Following the methodology of Sect. 2 and using MATLAB ® software, 10,000 different scenarios based on Monte Carlo Simulation were simulated for the economic feasibility and risk analyses.

4.1 NPV Analysis

From the NPV simulation, a financial comparison was obtained between the result of this indicator without considering government support and the economic effect of these policy measures. For the two cases, the descriptive statistics and different pieces of information such as skewness, kurtosis, and range (maximum and minimum) of

Table 3 Descriptive statistics of the NPV

Descriptive statistics	NPV without incentives (MM COP$)	NPV with incentives (MM COP$)
Mean	−28,028.58	−15,287.83
Median	−30,677.68	−17,956.24
Standard deviation	34,789.67	34,770.19
Skewness	0.53	0.53
Kurtosis	3.50	3.50
Maximum	158,384.68	170,936.81
Minimum	−125,485.52	−112,546.05
Deterministic result	−18,540.42	−5944.53

the scenarios computed for the NPV are detailed in Table 3. The deterministic result for each case is also shown.

In the scenario without incentives, the simulation mean was equal to −28,028.58 MM COP$, 151.17% higher than the loss calculated with the deterministic approach. Similar behavior was obtained for the scenario with incentives. However, the simulation mean was 2.57-fold higher than the deterministic value in this case. Although the descriptive statistics of both scenarios classified the project as not feasible, the results of this decision criteria pointed out that the effect of the regulatory framework reduced the loss in 12,740.75 MM COP. In addition, it was registered that the NPV of this case study can take positive values, even without incentives, which cannot be perceived by applying only the static method.

The probability histograms for the two NPV cases were bell-shaped with kurtosis of 3.50 and positive skewness. Figure 2 shows the probability distribution obtained from the simulation for the scenario with government support.

The results obtained by applying the risk measures, namely VaR and CVaR, to NPV indicator are shown in Table 4, for the two scenarios evaluated.

From Table 4 it was observed that, for the different confidence levels, the VaR of the NVP indicated that the project is not financially viable. For example, with a confidence level of 95%, the investors might lose 67,172 MM COP$ in this investment project, but this loss can reach up to 79,948 MM COP$ without regulatory support.

According to the CVaR at a 90% of confidence level, the maximum expected loss of this project is equal to $69,311 MM COP in a scenario with tax and accounting benefits, which entails that the project's capital should be sufficient to cover losses of this nature. However, and as expected, without policy measures, the losses of this project require capital to support that exceeds 100.000 MM COP$ with a confidence level of 99%.

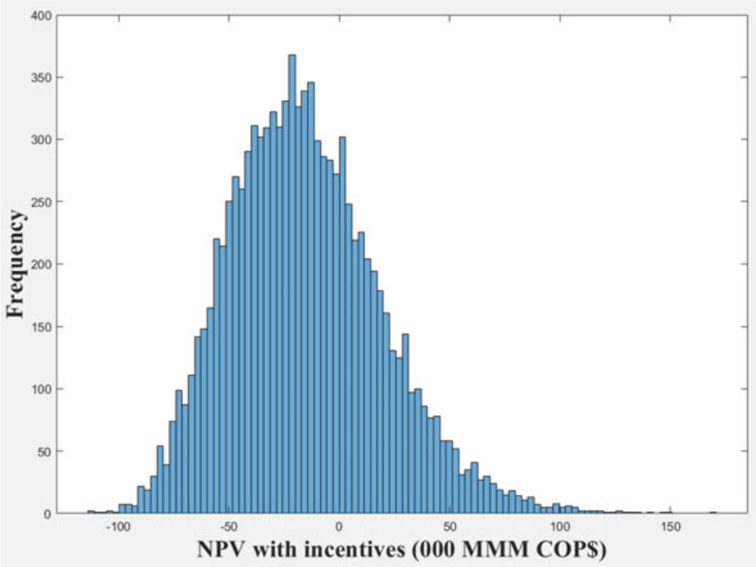


Fig. 2 Probability histogram of the NPV

Table 4 VaR and CVaR risk measures of the NPV

Confidence level (%)	VaR of NPV without incentives (MM COP$)	VaR of NPV with incentives (MM COP$)
90	−70,084.82	−57,286.46
95	−79,948.14	−67,172.81
99	−95,240.33	−82,438.30
Confidence level (%)	CVaR of NPV without incentives (MM COP$)	CVaR of NPV with incentives (MM COP$)
90	−82,100.11	−69,311.65
95	−89,588.56	−76,793.70
99	−102.595.40	−89,748.75

4.2 LCOE Analysis

For the LCOE indicator, the deterministic result was 30.11 COP$/kWh less than the mean of the computed scenarios with regulatory incentives, as shown in Table 5. Hence, by assuming the total certainty of the variables, the static approach ignores possible scenarios in which the variables involved in the financial analysis can take different values that affect the result of the decision criteria. In addition, without policies that encourage investment in this type of project, the minimum value of the

Table 5 Descriptive statistics of the LCOE

Descriptive statistics	LCOE without incentives (COP$/kWh)	LCOE with incentives (COP$/kWh)
Mean	252.42	194.62
Median	237.68	183.28
Standard deviation	76.78	58.94
Skewness	3.01	3.01
Kurtosis	33.40	33.36
Maximum	1762.37	1353.28
Minimum	111.69	86.59
Deterministic result	213.23	164.51

simulated scenarios for the LCOE was 111.96 COP$/kWh, against 86.59 COP$/kWh obtained from the with-incentives scenario.

Figure 3 shows the probability distribution obtained by simulating the LCOE indicator considering government support in the analysis.

The skewness of the probability distribution of LCOE was equal to 3.01 in both scenarios (without and with incentives). That is, the values farthest from the mean are located on the right side of the distribution, where the LCOE takes the highest

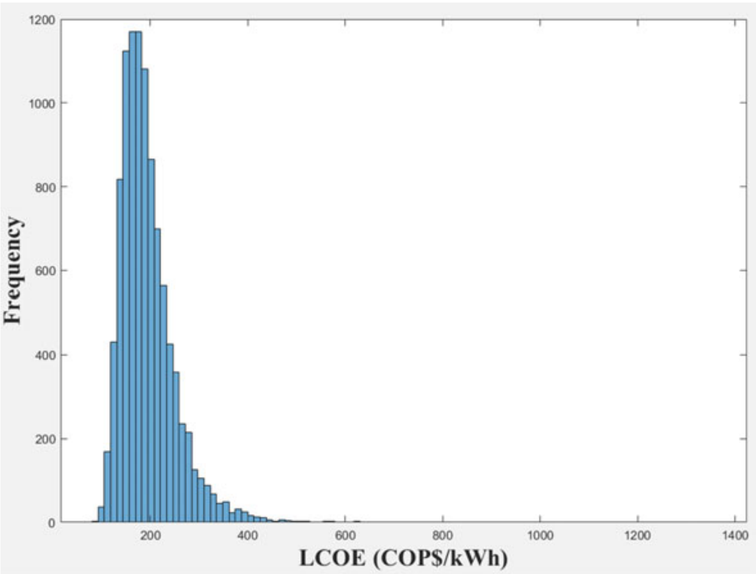


Fig. 3 Probability histogram of the LCOE

Table 6 VaR and CVaR risk measures of the LCOE

Confidence level (%)	VaR of LCOE without incentives (COP/kWh)	VaR of LCOE with incentives (COP/kWh)
10	342.34	263.77
5	388.89	299.25
1	507.06	390.14
Confidence level (%)	CVaR of LCOE without incentives (COP/kWh)	CVaR of LCOE with incentives (COP/kWh)
10	415.21	319.60
5	468.52	360.53
1	618.29	475.51

values and makes risk analyses become important. To address this, VaR and CVaR measures were calculated for the LCOE, which are detailed in Table 6.

As can be noted in Fig. 3, the probability histogram of the LCOE presented a leptokurtic shape with a kurtosis equal to 33.36 (see Table 5) and heavy tails. Thus, the risk assessment with the VaR measure showed that, with a 5% confidence level, the maximum LCOE of this project was $299.25 for each kWh generated from a scenario with policy stimulus. At the same confidence level, the VaR increase to 89.64 COP$/kWh when incentives of Law 1715 are not considered.

Focusing on the extreme values of the right side of the distribution (which exceed the VaR), a LCOE equal to 618.29 COP/kWh was the most catastrophic scenario with 1% confidence and without incentives to support these investments. A comparison of the CVaR measures between the two cases analyzed shows that the maximum expected LCOE of the project without incentives is 1.3-fold the worst scenario of the case with incentives, at each confidence level.

5 Conclusions

The objective of this research was to determine the financial feasibility of geothermal energy projects in Colombia through the application of a case study. As a contribution to the traditional methodology, this work introduced a stochastic approach to evaluate different scenarios, considering the uncertainty of technical and financial variables typical of generation projects with geothermal sources and the effect of policy instruments on the feasibility of these types of investments. Additionally, the analysis and evaluation of risk measures for two commonly used valuation indicators were carried out to know the possible risk scenarios that an investor would face, given different confidence levels. The main findings of this work indicated that employing a deterministic analysis, the possible losses of this project were being underestimated by 257% when comparing the static NPV results against the mean of the simulations obtained for this same indicator. Similarly, the maximum LCOE resulting from the simulations is 8.22-fold higher than the classical valuation methodology, where the calculations are made assuming total certainty of the elements incorporated in the analysis. In addition, the results obtained from the two decision criteria analyzed pointed out that the inclusion of tax and accounting benefits has a high influence not only on the economic viability but also on the level of risk of these investments, as policy incentives are incorporated into the analysis.

The application of VaR and CVaR in the financial valuation made it possible to know the worst scenario for each feasibility indicator involved in this study, which was computed through Monte Carlo Simulation. This analysis was especially important for evaluating risk scenarios in the LCOE, whose probability histogram indicated a leptokurtic shape, where the tails of the distribution harbor a large amount of data that must be considered when performing the financial valuation analysis, and which are generally ignored with the application of traditional discounted cash flow techniques. This assessment provides an overview of the investment risk for this kind of energy, considering the lack of data for geothermal projects during their investment phases and that geological resources databases in countries such as Colombia are still negligible. Thus, the uncertainties inherent to energy projects require a more detailed feasibility analysis focused on the behavior of its variables, the risk associated with the type of investment and the energy environment where the project is developed.

References

Aquila, G., de Coelho, E.O.P., Bonatto, B.D., et al.: Perspective of uncertainty and risk from the CVaR-LCOE approach: an analysis of the case of PV microgeneration in Minas Gerais, Brazil. Energy **226**, 120327 (2021a). https://doi.org/10.1016/j.energy.2021a.120327

Aquila, G., Nakamura, W.T., Junior, P.R., et al.: Perspectives under uncertainties and risk in wind farms investments based on Omega-LCOE approach: an analysis in São Paulo state. Brazil. Renew. Sustain. Energy Rev. **141**, 110805 (2021b). https://doi.org/10.1016/j.rser.2021.110805

Bazmi, A.A., Zahedi, G.: Sustainable energy systems: Role of optimization modeling techniques in power generation and supply—a review. Renew. Sustain. Energy Rev. **15**, 3480–3500 (2011). https://doi.org/10.1016/j.rser.2011.05.003

Bertani, R.: Geothermal power generation in the world 2010–2014 update report. Geothermics **60**, 31–43 (2016). https://doi.org/10.1016/j.geothermics.2015.11.003

Bilqist, R.A., Dachyar, M., Farizal, F.: Project valuation in the geothermal power plant project: a comparison of expected net present value and static net present value approaches. SSRN Electron J. (2018). https://doi.org/10.2139/ssrn.3248120

Compernolle, T., Welkenhuysen, K., Petitclerc, E., et al.: The impact of policy measures on profitability and risk in geothermal energy investments. Energy Econ. **84**, 104524 (2019). https://doi.org/10.1016/j.eneco.2019.104524

Congreso de Colombia.: Ley 1715 de 2014. Por medio de la cual se regula la integración de las energías renovables no convencionales al Sistema Energético Nacional. Colombia (2014)

Córdova Geirdal, C.A., Gudjonsdottir, M.S., Jensson, P.: Economic comparison of a wellhead geothermal power plant and a traditional one. Geothermics **53**, 1–13 (2015). https://doi.org/10.1016/j.geothermics.2014.04.003

Díaz-Trujillo, L.A., Fuentes-Cortés, L.F., Nápoles-Rivera, F.: Economic and environmental optimization for a biogas supply chain: a CVaR approach applied to uncertainty of biomass and

biogas demand. Comput. Chem. Eng. **141**, 107018 (2020). https://doi.org/10.1016/j.compchemeng.2020.107018
Ehyaei, M.A., Ahmadi, A., Rosen, M.A., Davarpanah, A.: Thermodynamic optimization of a geothermal power plant with a genetic algorithm in two stages. Processes **8**, 1–16 (2020). https://doi.org/10.3390/pr8101277
Espinoza, R.D., Rojo, J.: Using DNPV for valuing investments in the energy sector: a solar project case study. Renew Energy **75**, 44–49 (2015). https://doi.org/10.1016/j.renene.2014.09.011
Harvey, L.D.D.: Clarifications of and improvements to the equations used to calculate the levelized cost of electricity (LCOE), and comments on the weighted average cost of capital (WACC). Energy **207**, 118340 (2020). https://doi.org/10.1016/j.energy.2020.118340
ISAGEN.: Geotermia en Colombia. Serv. Geológico Colomb. 15 (2014)
Kim, K., Park, H., Kim, H.: Real options analysis for renewable energy investment decisions in developing countries. Renew. Sustain. Energy Rev. **75**, 918–926 (2017). https://doi.org/10.1016/j.rser.2016.11.073
Lesmana, A., Winofa, N.C., Pratama, H.B., et al.: Preliminary financial modelling with probabilistic approach for geothermal development project in Indonesia. IOP Conf. Ser. Earth Environ. Sci. **417** (2020). https://doi.org/10.1088/1755-1315/417/1/012024
Loncar, D., Milovanovic, I., Rakic, B., Radjenovic, T.: Compound real options valuation of renewable energy projects: the case of a wind farm in Serbia. Renew. Sustain. Energy Rev. **75**, 354–367 (2017). https://doi.org/10.1016/j.rser.2016.11.001
Lukawski, M.Z., Silverman, R.L., Tester, J.W.: Uncertainty analysis of geothermal well drilling and completion costs. Geothermics **64**, 382–391 (2016). https://doi.org/10.1016/j.geothermics.2016.06.017
Martínez-Ruiz, Y., Manotas-Duque, D.F., Ramírez-Malule, H.: Evaluation of investment projects in photovoltaic solar energy using the DNPV methodology. Int. J. Energy Econ. Policy **11**, 180–185 (2021a). https://doi.org/10.32479/ijeep.10577
Martínez-Ruiz, Y., Manotas-Duque, D.F., Ramírez-Malule, H.: Análisis de opciones reales para la valoración financiera de proyectos de energía geotérmica en Colombia. Rev CEA **7**, 1944 (2021b). https://doi.org/10.22430/24223182.1944
Mosquera-López, S., Manotas-Duque, D.F., Uribe, J.M.: Risk asymmetries in hydrothermal power generation markets. Electr. Power Syst. Res. **147**, 154–164 (2017). https://doi.org/10.1016/j.epsr.2017.02.032
Nasruddin, Idrus, M.A., Daud, Y., et al.: Potential of geothermal energy for electricity generation in Indonesia: a review. Renew. Sustain. Energy Rev. **53**, 733–740 (2016). https://doi.org/10.1016/j.rser.2015.09.032
National Renewable Energy Laboratory.: Utility-Scale Energy Technology Capacity Factors (2020). https://www.nrel.gov/analysis/tech-cap-factor.html
Pambudi, N.A.: Geothermal power generation in Indonesia, a country within the ring of fire: current status, future development and policy. Renew. Sustain. Energy Rev. **81**, 2893–2901 (2018). https://doi.org/10.1016/j.rser.2017.06.096
Pollack, A., Mukerji, T.: Accounting for subsurface uncertainty in enhanced geothermal systems to make more robust techno-economic decisions. Appl. Energy **254**, 113666 (2019). https://doi.org/10.1016/j.apenergy.2019.113666
Sawik, B.: A bi-objective portfolio optimization with conditional value-at-risk. Decis. Mak. Manuf. Serv. **4**, 47–69 (2010). https://doi.org/10.7494/dmms.2010.4.2.47
Shen, W., Chen, X., Qiu, J., et al.: A comprehensive review of variable renewable energy levelized cost of electricity. Renew. Sustain. Energy Rev. **133**, 110301 (2020). https://doi.org/10.1016/j.rser.2020.110301
Tang, A., Chiara, N., Taylor, J.E.: Financing renewable energy infrastructure: formulation, pricing and impact of a carbon revenue bond. Energy Policy **45**, 691–703 (2012). https://doi.org/10.1016/j.enpol.2012.03.022
Tecnología y Recursos de la Tierra, S.A, Sanchez Guzmán, J., Sanz López, L.: Evaluación del Potencial de Energía Geotérmica (2011)

Tran, T.T.D., Smith, A.D.: Incorporating performance-based global sensitivity and uncertainty analysis into LCOE calculations for emerging renewable energy technologies. Appl. Energy **216**, 157–171 (2018). https://doi.org/10.1016/j.apenergy.2018.02.024

UPME.: Integración de las energías renovables no convencionales en Colombia Integración de las energías en Colombia (2015)

Van Erdeweghe, S., Van Bael, J., Laenen, B., D'haeseleer, W.: Feasibility study of a low-temperature geothermal power plant for multiple economic scenarios. Energy **155**, 1004–1012 (2018). https://doi.org/10.1016/j.energy.2018.05.028

XM.: Reporte integral de sostenibilidad, operación y mercado 2020 (2020). https://informeanual.xm.com.co/2020/informe/pages/xm/24-capacidad-efectiva-neta.html

Zhang, Q., Chen, S., Tan, Z., et al.: Investment strategy of hydrothermal geothermal heating in China under policy, technology and geology uncertainties. J. Clean Prod. **207**, 17–29 (2019). https://doi.org/10.1016/j.jclepro.2018.09.240

Design and Implementation of a Desktop Application for Consultation Centers for Staff, Information Regarding Training, Job Promotion and Transportation Routes, in an Automotive Electrical Harness Company

Fernando Ricárdez-Rueda, Beatriz Adriana Esparza-Ramírez, and Reyna Guadalupe Veloz-Alcaraz

Abstract The use of Information and Communication Technologies (ICT) within the organizational context has revolutionized management and administrative thought, this is evidenced through various aspects, one is how human talent is managed (Riascos and Aguilera in Herramientas TIC como apoyo a la gestión del talento humano Cuadernos de Administración. Universidad del Valle Cali, Colombia, pp 141–154, 2011). The dissatisfaction of the workers of an electrical harness company located in Lagos de Moreno, Jalisco. For lack of timely information about their training, status of job promotions and transportation routes, was solved with the implementation of consultation centers (Kiosks) accessible 24 h a day, the relevance of developing an information system that will be linked to Kiosks, was identified, it was made with the V-Shaped Software Development Model. The updated information was generated a perception of equity, facilitating the integration of human resources in the management of the production process, due to the decrease in turnover, and a more satisfied and committed staff. A kiosk has been installed in each of the

R. G Veloz Alcaraz: Academic body in formation ITESLM-CA-2 "Quality, Productivity and Technological Innovation in Organizations"

F. Ricárdez-Rueda (✉) · B. A. Esparza-Ramírez
Department of Industrial Engineering, Instituto Tecnológico José Mario Molina Pasquel y Henríquez, Campus Lagos de Moreno, Libramiento Tecnológico 5000. Col. Portugalejo de los Romanes, Lagos de Moreno, Jalisco, México
e-mail: fernando.ricardez@lagos.tecmm.edu.mx

B. A. Esparza-Ramírez
e-mail: beatriz.esparza@lagos.tecmm.edu.mx

R. G. Veloz-Alcaraz
Academic body in formation ITESLM-CA-2 "Quality, Productivity and Technological Innovation in Organizations", Instituto Tecnológico José Mario Molina Pasquel y Henríquez, Campus Lagos de Moreno, Libramiento Tecnológico 5000. Col. Portugalejo de los Romanes, Lagos de Moreno, Jalisco, México

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_3

three locations of the company for its three thousand workers who have access to the module, regardless of the shift. They increased the perception of fairness by giving the areas involved updated information, thus avoiding employee discontent throughout the company.

Keywords Consultation centers · Staff integration · Talent development · “4 + 1” view model of software architecture · V-shaped software development model

1 Introduction

The design of an application with Microsoft Access to consultation centers for staff in a manufacturing facility with three main lotions was the framework for collaboration between the company’s human resources area and the research group, due to the need for documented communication, official and with immediate access for the staff with reference to the status of job promotion processes (“posting”), training and pertinent information to the staff of the other procedures in their work stay, with the possibility of direct and independent consultation to the work shift, and with the security of including safeguards for the worker’s sensitive information, setting individual accessibility requirements.

In the initial phase of the needs assessment, the company sets the restriction on the use of Microsoft Access, per corporate information technology policy. The implementation of this project has the physical aspect of the equipment and the location of the hardware, the programming language, and the interfaces for the supply of information and in consultation with it to increase the integration of the personnel.

The Application software are programs that make computers useful. The programming languages provide the mechanisms for the management of the databases and the hierarchy and process algorithms to transform the databases into accessible information in a safe and easy way for the user.

Implementation was accomplished by establishing a consultation center in each of the three main locations of the company.

2 Literature Review and Hypotheses Statement

Information technology (IT) can accomplish Human Resources (HR) record keeping, HR transactions, and many other administrative tasks quickly, efficiently, and accurately. It can analyze data in ways that can guide and support evidence-driven HR practices and policies. It can also facilitate change efforts by assessing the capabilities of the workforce and providing information and training that support change. Finally, it can support the development and implementation of business strategy by providing important information about the capabilities and core competencies of the organization, as well as creating transparency with respect to organizational performance. Our study examines the extent to which the design and activities of the HR function are changing by analyzing survey (U.S. and Global Responses) data from 1995, 1998, 2001, 2004, 2007, 2010, 2013, and 2016. (Lawler 2018), Implementations such as "Human Resources Portal Project, experience in implementation at the University of Buenos Aires" report that the digitization of the process in human resources increases the integration of personnel and gives speed and quality to the administrative processes (Aybar et al. 2017).

HR departments play a crucial role in helping the digital transformation of a company. They face a double challenge: on the one hand, that of transforming the activities of the department itself and, on the other, that of transforming the workforce, by adopting new technologies, they will have a strong impact on the results of the company and on the experience of your employees (Volini et al. 2017).

In the phase of diagnosing the needs of the company, the research group proposed the use of MySQL, which is free software under licensing, and SQL Server 2008, which is licensed, both provide protection in terms of computer security, greater Database capacity and greater flexibility to consult information compared to Microsoft Access, which is a database management system included in Microsoft Office, which contains an office suite of applications. Features of the options are presented below.

Microsoft SQL Server: It is a database among the most used, its easy-to-configure architecture has an administration system with fast compaction speed, stability, and ease of deployment (Cordova and Cuzco 2013). Advantages: It is useful for handling and obtaining data from the network, and compatibility with most of the administrative tasks of SQL SERVER. Working on a social network allows you to add other SQL SERVER servers, and you can view other databases. Disadvantages: Use a lot of RAM (Random Access Memory) for the installations and use of the software, and the consequence is that the computer slows down.

MySQL: It has transaction support, scalability, stability, and security, it also includes a powerful graphical administration environment. It allows working in client–server mode, where the information and data are housed on the server and the terminals or clients of the network only access the information. Advantages: It is easy to install, configure, use, and administer, it has extensive database functionality, its security is robust, it has transaction and stored procedure support. Disadvantages: A large percentage of MySQL utilities are not documented. It is not intuitive, like Microsoft Access.

Access: Macros are a simplified programming language that is written generating a list of actions to be performed (Feddema 2008). Advantages: Macros allow you to add functionality to forms, reports, and controls without writing code in a Visual Basic for Applications (VBA) module. Disadvantages: Its search processing is limited, therefore, in very complex corporate sectors, other programs will be required.

By policies of the management of Information Technology of the company, this determined to use Microsoft Access, which allows managing the information gathering in an effective and efficient way, avoiding redundant information problems and data isolation in the business management process (Cortes 2020).

2.1 Access 2007

Access 2007 is the version used by the company. In this section, important elements are discussed for a better understanding.

- Databases. It is defined as the collection of logically interrelated data and a description of this data, designed to meet the information needs of an organization. Chopra (2010) and the set of programs that allow managing this data is what is called Database Management System. Access 2007 databases have the ACCBD extension so that the computer recognizes them as such. Almost all modern database management systems store and process information using the relational database management model. In a relational database system, the data is organized in tables.
- Data tables. A database table is similar in appearance to a spreadsheet in that the data is stored in rows and columns. Hence, it is quite easy to import a spreadsheet into a database table. The main difference between storing your data in a spreadsheet and storing it in a database is the way the data is organized. Each row in a table is called a record. Information is stored in the records. Each record consists of one or more fields. The fields are equivalent to the columns in the table.
- Queries. Queries can perform various functions on a database. The most common function is to retrieve specific data from tables. The data that you want to see is generally spread across multiple tables, and queries allow you to view it on a single data sheet. Also, because you often don't want to see all the records at once, queries allow you to add criteria to "filter" the data and get only the records you want. There are several types of queries to select, update, delete data, but in principle they are used for extracting, data from tables that meet certain conditions. In this project, only certain data is extracted from each employee, and they are not modifiable, they are only used for visualization.
- Forms. Forms allow you to create a user interface in which you can enter and modify data. Forms often contain command buttons and other controls that perform different tasks. You can create a database without using forms by simply modifying the data in the table's data sheets. However, most database users prefer to use forms to view, write, and modify data in tables. You can program command buttons to determine what data appears on the form, open other forms, or reports, or perform other tasks. For example, you may have a form called "Customer Form" in which you work with customer data. The customer form may have a button that opens an order form in which you can specify a new order for the customer. Forms also allow you to control how other users interact with the data in the database. For example, you can create a form that displays only certain fields and allows only certain operations to be performed. This helps to protect the data and to ensure that the data is entered correctly.
- Reports. Reports are used to format, summarize, and present data. Typically, a report answers a specific question such as, "How much money do we receive from each customer this year?" or "In which cities do our clients reside?" Each report can be formatted to present the information as legibly as possible. You can run one report at a time and the current data in the database is always reflected. Reports

are generally formatted for printing, but can also be viewed on screen, exported to another program, or sent as an email attachment (McFredies 2008).
- Macro. A macro is a tool that enables you to automate tasks and add functionality to forms, reports, and controls. For example, if you add a command button to a form, associate the button's "On Click" event with a macro, and this macro contains the commands that you want it to perform each time the button is clicked. In Access, it is useful to think of macros as a simplified programming language that is written by generating a list of actions to perform. When creating a macro, select each action from a drop-down list, and then fill in the necessary information for each action. Macros allow you to add functionality to forms, reports, and controls without writing code in a Visual Basic for Applications (VBA) module. Macros provide a subset of the commands available in VBA, and it is easier for most people to generate a macro than to write the VBA code (Feddema 2008).
- Import data. Access allows you to import objects from another database quickly.

2.2 Software Application

Application software are programs that make computers useful elements, some examples are:

- A database management system (or DBMS), which can be just a utility for file management, or an elaborate program that allows the organization of data in a relational and indexed way, with its own special command language, which answers every conceivable question about a large and intricate data structure.
- A graphics package, such as a set of software, programs, that perhaps produces some acceptable type of graphs, histograms, or other, in a passable resolution (200 by 300 pixels), perhaps an integrated system of programs that allow 10 times higher resolution (2000 by 3000 pixels), in a wide variety of colors, with the ability to draw complicated three-dimensional shapes, shaded, illuminated, and textured, which are modified by means of special language commands.
- A mathematical or statistical program that allows various levels of sophistication, from the emulation of a simple digital calculator to systems with the ability to solve complicated arithmetic, algebra, and calculus operations, analyzing complex data sets using elaborate numerical techniques, using everything a new and own language.
- A word processor, which can be a simple utility for editing programs and files to view and modify them, too complicated packages that allow the use of different types of letters, reports, articles, or documents, allowing the use of various formats, as well as different sizes and styles of letters and symbols, with page numbering, automatic generation of indexes, and spell checking.

2.3 Hypotheses

The dissatisfaction of the workers of an electrical harness company for lack of timely information about their training, status of job promotions and transportation routes, will be solved, with the implementation of consultation centers accessible 24 h a day, the updated information, will generate a perception of equity facilitating the integration of human resources in the management of the production process.

3 Methodology

3.1 Definition of the Problem

Some functions of the human resources area are not available to the workers in the three shifts in the company. Attention to the inquiries for lack of timely information about their training, status of job promotions and transportation routes, of the workers, causes delays in production. Derived from the changes of shifts and the distribution of the addresses and/or points of origin for the transfer of the worker, this requires to be updated and accessible information on the transport routes.

The lack of immediacy of the worker's employment information can encourage him not to consult it, and therefore lose the internal human talent that could access an internal promotion.

3.2 Project Definition

To achieve quality, a direct focus on the customer is needed, because they determine what the requirements of your service should be (Goericke 2018).

To identify requirements, personnel in charge of each area were interviewed, collecting key information, tables and diagrams were made to know the magnitude of the entire application considering functional and non-functional requirements, concepts of main operations such as macros, reports, forms, as for the Access program (McFredies 2008), the development was done under the architecture 4 views + 1. The 4 + 1 view model is generic and is not restricted to any notation, tool or design method (Kruchten 1995).

The functional requirements, as well as non-functional requirements detected at the time of the interviews, are listed below.

Functional requirements

Functional properties play an important role in understanding a design domain, they display the behaviors of the object when the entity is subjected to a situation (Zhu 2005).

- The user must search for personal information with payroll.
- A main menu that contains the two areas: Training and Transportation Routes.
- Module to view category changes.
- Module for course calendar.
- Menu with transport routes containing a report for each of the routes.
- This system will only be for consultation of employee information.
- It must contain buttons that allow interaction between menus and modules.

No functional requirements

A critical aspect in defining non-functional properties is that they must be verifiable. Where possible, it is important to describe them in a measurable way, because it must be possible to interpret them correctly during the development phase and objectively verify them (Milanovic 2011).

- The query application must be carried out in accordance with company policies.
- The query platform will be developed in Microsoft Access 2007 with macros and forms.
- Ethics, confidentiality, and honesty must be considered when developing the software.
- The system as well as its interfaces must be understandable and easy to handle for any user within the production plants.
- Connect to a modified Excel Database, adaptable for Microsoft Access.
- The system must have an availability of 99.99% of the times in which a user tries to access it.
- It must be possible to modify the databases managed by the personnel of the Human Resources area, while the application is in use.
- Information updates should not be so tedious (with so many procedures) when storing new data.
- An installable must be delivered and after this have the original document so that future modifications can be made.

General objective

Design an application with Microsoft Access in consultation centers for staff, with information managed by the Human Resources area.

Specific objectives:

1. Define the project (Concepts of operations, requirements, architecture).
2. Detail the design (Make the graphical environment of the application, adapt the application to the database to generate specific information for each user, in the queries to the access module).
3. Run the test stream to verify and validate.
4. Design and execute the delivery protocol.
5. Design and execution of maintenance routines.

3.3 V-Shaped Software Development Model

To decide which software development model to use, it is necessary to identify if the needs are stable, who will be the end users, the size of the project, and where it will be located. In this case study, the needs are clear and fixed, and the size is medium, the users are the workers of the plant, and its location is small in geographical extension, so the V-Shaped Software Development Model is adequate. V model is shown in Fig. 1.

The V- model means verification and validation model. Testing of the product is planned in parallel with a corresponding phase of development. It consists of four main process phases—requirements, specification, design, and implementation and, has a corresponding verification and validation testing phase. Implementation of modules is tested by unit testing, system design is tested by integration testing, system specifications are tested by system testing and finally, acceptance testing verifies the requirements (Stephen and Oriaku 2014).

The specification stream (left part, project definition) consists mainly of:

- Concepts of operations: what the system should do broadly.
- System requirements and architecture.
- Detailed design.

The test stream (right part, project test and integration), consists of:

- Integration of the different parts, testing and verification of the same.
- Verification and validation of the system.
- System maintenance.

The development stream may consist of depending on the type of system and the scope of, development or customization, configuration, or coding.

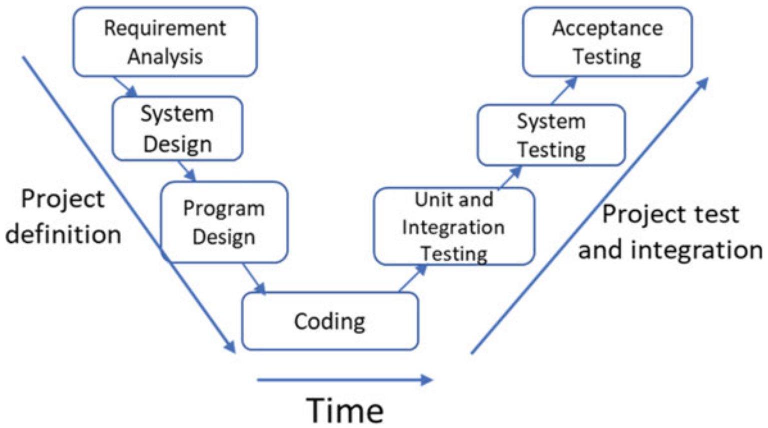


Fig. 1 V-shaped software development model

3.4 *Software Architecture*

The architecture of an IT System is arguably one of the most critical elements that shapes and holds all the software development pieces together. The software architecture of a program or computing system is the structure or structures of the system, which comprise software components, the externally visible properties of those components, and the relationships between them (Mitra 2015).

3.4.1 4 Views + 1

The "4 views + 1" model is a view model designed by Professor Philippe Kruchten and, that complies with the "IEEE 1471-2000" standard (Recommended Practice for Architectural Description of Software-Intensive Systems) that is used to describe the architecture of a software intensive system based on the use of multiple points of view (Kruchten 1995). Figure 2 shown this model. Next, it is explained what information the documentation of each of the views should have.

Logical view

This view represents the functionality that the system will provide to end users. It must represent what the system must do, and the functions and services it offers. To complete the documentation for this view, the Unified Modeling Language (UML) class, communication, or sequence diagrams can be included.

Deployment view

This view shows the system from the perspective of a programmer and deals with the management of the software; or in other words, it will show how the software

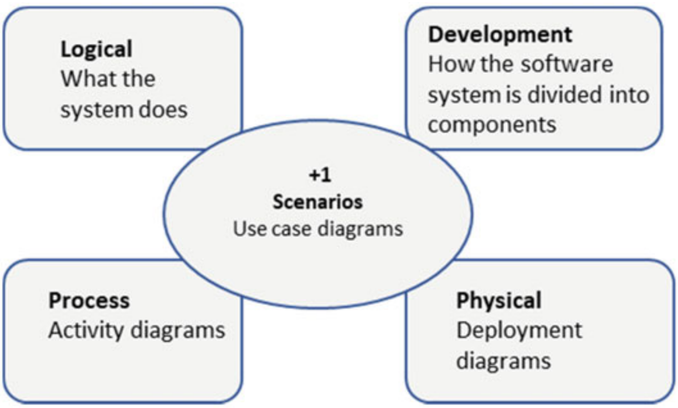


Fig. 2 The "4 + 1" view model based on (Kruchten 1995)

system is divided into components and the dependencies between those components. The UML package and component diagrams can be included to complete the documentation for this view.

Process view

This view shows from the perspective of a systems engineer all the physical components of the system, as well as the physical connections between those components that make up the solution (including services). To complete the documentation of this view, the UML deployment diagram can be included. The Process view, which captures the concurrency and synchronization aspects of the design.

Physical view

This view shows from the perspective of a systems engineer all the physical components of the system, as well as the physical connections between those components that make up the solution (including services). To complete the documentation of this view, the UML deployment diagram can be included.

"+1" *Scenario view*

In this view, it will be represented by the software use cases, and it will have the function of joining and relating the other 4 views, this means that from a use case we can see how the other 4 views are linked, thus that we will have a traceability of components, classes, equipment, packages, etc., to carry out each use case. To complete the documentation of this view, you can include the UML use case diagrams.

3.4.2 Controller View Model

The model, views, and controllers are treated as separate entities; This means that any change in the Model is automatically reflected in each of the Views. This model is shown in Fig. 3.

The advantage of this model is that the separation and the view, which separates the data from its visual representation, facilitate the handling of errors, allows the system to be scalable if required, and it is also possible to add multiple representations of the data. Some disadvantages are the number of files that must be kept increases considerably, the learning curve is higher than using other models, it's overcoming in layers, increases the complexity of the system.

3.4.3 Service Oriented Architecture "SOA"

This software architecture solves the connectivity problems and allows a real massive reusability and a greater independence of the platforms, making the existing ones profitable. Among its advantages, it stands out that it is easy to test, improves maintenance, favors reuse, and allows easy scalability.

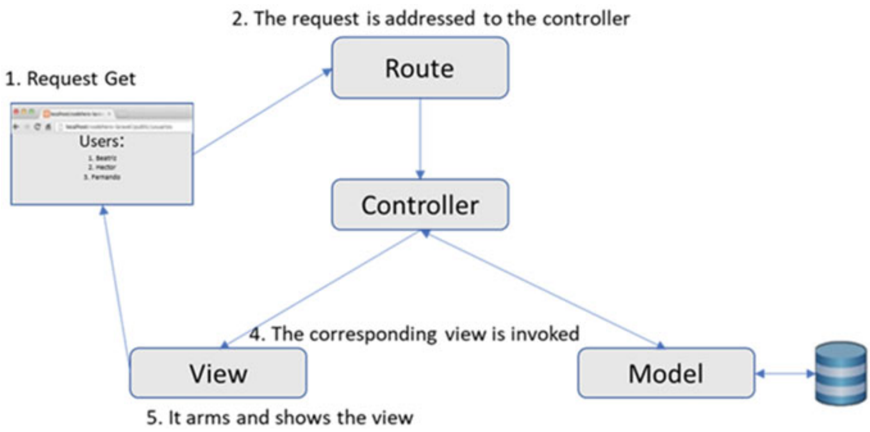


Fig. 3 Controller view model

3.4.4 Server Client

In this model, the tasks are divided between the providers of resources or services, called servers, and the applicants, called clients. A client makes requests to another program, the server, which gives it a response. The advantages of this software architecture are the centralization of control, scalability, and easy maintenance. Some of its disadvantages are traffic congestion, Software and Hardware are decisive.

3.4.5 Interactive Kiosk

An interactive kiosk is a computer located in a public place that allows users to perform multiple actions. It is also used as an information and marketing tool for companies. Today, interactive kiosks often have touch screens. Their objective is to present a friendly and easy-to-interact, interface that facilitates its use by any type of user. They can be customized to multitask so that you can collaborate with, and even perform, service workers' functions. By allowing permanent access to the public, it is intended to increase productivity and improve investment returns.

They are generally embedded in steel, sheet, or wood structures. Common components: LCD touch screen monitor, interactive software, CPU with processor, hard disk, memory, audio, video, network, and USB ports.

4 Results

4.1 Logic View

This view includes the program logic for which the class and sequence diagrams shown below were made.

- Class diagram: This is the class diagram depending on the requirements there are the classes for category, user and for the courses, which is the information that the database contains, and that the employee will have access to, the relationship between the classes, all of these are one to many, with attributes and their methods respectively. The diagram is shown in Fig. 4.
- Sequence diagram: The process is as follows, first the user enters the payroll number, it is validated from the system to the base that it is written correctly and that it exists, once the above is done, the base sends a stimulus to the system. This is not shown, the system shows the options to which the employee has access, provides the view of the modules, then extracts certain information from the

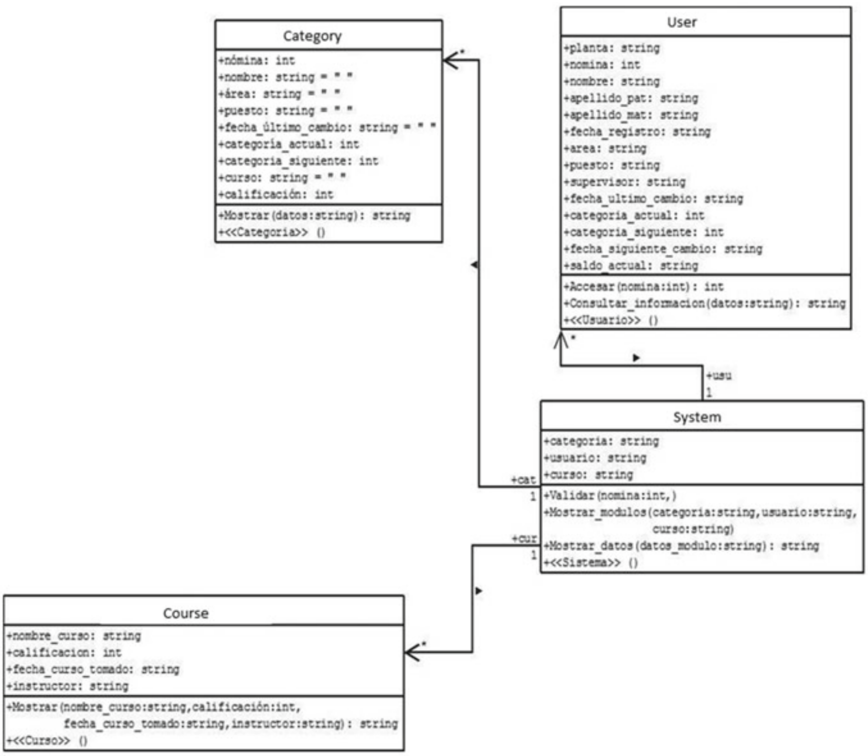


Fig. 4 Project class diagram

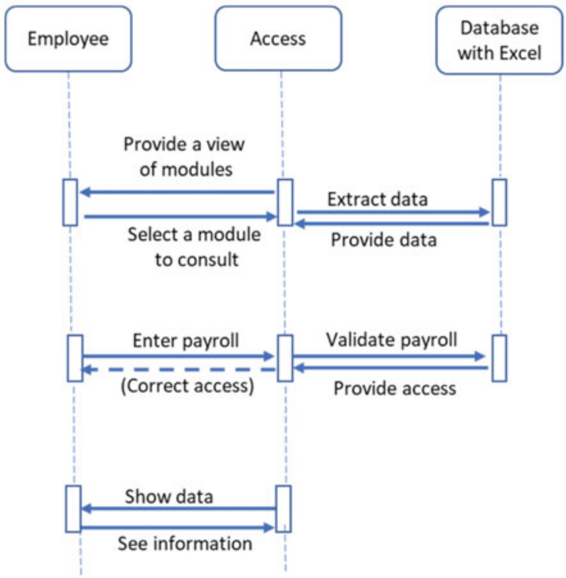


Fig. 5 Project sequence diagram

databases and provides them to the user, who views it and ends the process. The diagram is shown in Fig. 5.

4.2 Deployment View

Mockups: the following model shown in Fig. 6, helps us to know how the screen of the query application called Mockups will look, a representation taken as the main idea of each module developed.

Fig. 6 Menu of transport routes for personnel

4.3 Process View

State diagram: The following diagram, shown in Fig. 7, explains the different states that the system goes through, as well as the user stimuli that the application carries out to view the information regarding the salary modification of each employee when entering the corresponding payroll, as well as transportation routes.

Collaboration diagram: Shown in Fig. 8, it is the outline of the course calendar, the process that is followed to assign the courses depending on the shifts so that they can take them, it will only be updated and shown to the user, as a conventional and a useful calendar for them.

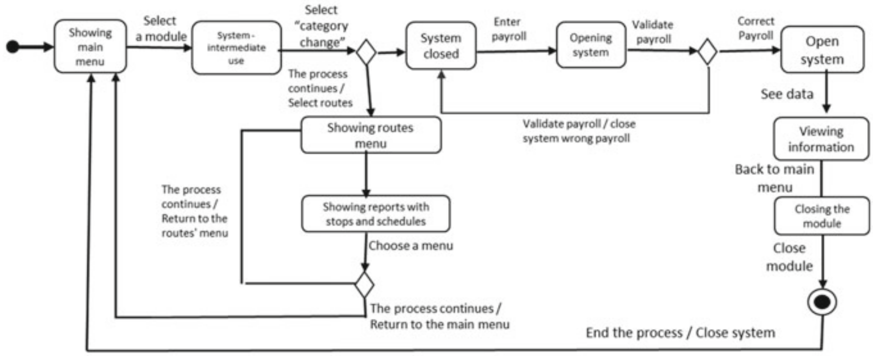


Fig. 7 States that the application goes through once it is run

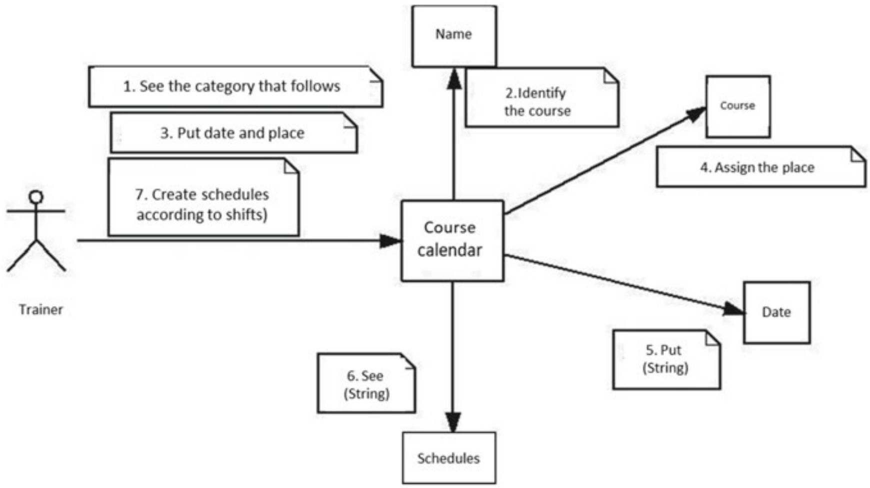


Fig. 8 Collaboration diagram to develop course calendars

Fig. 9 Scheme of the process that any user performs when interacting with the application

4.4 Physical View

High-level diagram: Shown in Fig. 9. This diagram represents the steps that a user performs to consult the information of any area from a question, entering the payroll number.

4.5 "+1" Scenario View

Use case diagram: Shown in Fig. 10. It represent*s* the actions of the different user actors who will use the system constantly, the activities of the system and in turn what the Human Resources area. Does within the system are shown.

Story/Feature Driven up: Break project into manageable pieces of functionality; sometimes named "features", "stories", "use cases", or "threads". The system is segmented sets of client-valued functionality, and development work is organized around producing these features. An advantage of the feature driven paradigm is that, as features are produced, they become available for early deployment, customer demonstrations, or early integration and test activities – all of which can help reduce uncertainty, detect functional defects early in the development cycle, or deliver early capabilities to customers (Glaiel 2013).

5 Conclusions and Industrial Implications

The necessary tests for a verification and validation of the software were carried out. The choice of the development model, architecture and programming languages was adequate to achieve the objectives of the project.

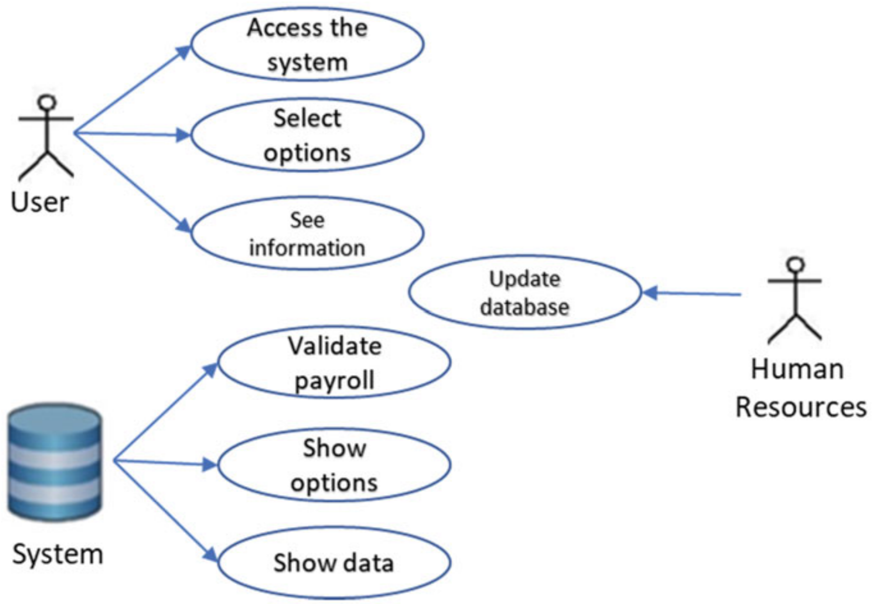


Fig. 10 Use cases of the activities carried out by each actor within the system

By having information about transportation routes in an accessible way, there were fewer losses of transport by workers. The time an employee spends in going to the training office to request information regarding any of the salary modification issues, applied test scores, course dates, transportation routes. They will already have access to the consultation module within each plant, now independent of the shift, was reduced and/or avoided, reducing this work complement, which affects an increase in productivity.

This self-service feature boosts employee morale by empowering them with instant access to their files and responsibility for maintaining accurate, up-to-date information. It also relieves HR of having to address routine, time-consuming questions and completing forms (Arthur 2015).

The delivery protocol was designed and executed, as well as the maintenance routines by the Human Resources personnel, such as information updates.

By modifying the matrices of each area, the correct connections were obtained for each one of the modules made.

Increased the perception of equity by providing information by the areas involved, the development of training and changes in the category of personnel, thus avoiding many discontents on the side of employees throughout the company.

A consultation kiosk was installed in each of the three locations of the company.

References

Arthur, D.: Fundamentals of Human Resources Management: A Practical Guide for Today's HR Professional, 5th edn. AMA Self-Study (2015)

Aybar, R.D., Flores, A.F., Gordillo, R.L., Vidal, A.P.: Proyecto Portal de Recursos Humanos experiencia en la implementación en la Universidad de Buenos Aires. Paper presented at Séptima Conferencia de directores de Tecnología de Información, TICAL 2017 Gestión de las TICs para la Investigación y la Colaboración, San José, del 3 al 5 de julio de 2017.

Chopra, R.: Database Management Systems (DBMS). S. Chand Publishing (2010)

Cordova, R.F., Cuzco, B.E.: Análisis comparative entre bases de datos relacionales con bases de datos no relacionales. Systems Engineer. Thesis. Salesian Polytechnic University, Cuenca, Ecuador (2013)

Cortes, P.C.: Influencia del software de Microsoft Access en la gestión empresarial de la micro y pequeña empresa de Lima Metropolitana en el año 2019. Bachelor of Business Administration and Management. Thesis. Peruvian University of the Americas, Lima, Perú (2020)

Feddema, H.: Access 2007 Programación con VBA. Anaya Multimedia, España (2008)

Glaiel, F.: Agile Project Dynamics: A System Dynamics Investigation of Agile Software Development Methods. Working Paper CISL# 2013-05 (2013)

Goericke, S.: The Future of Software Quality Assurance. Springer Open ISBN 978-3-030-29509 7 (eBook) (2018). https://doi.org/10.1007/978-3-030-29509-7

Kruchten, P.: Architectural Blueprints—The "4+1" View Model of Software Architecture, pp. 42–50. IEEE Software (1995)

Lawler, E.E., Bourdreau, J.W.: Human Resource Excellence: An Assessment of Strategies and Trends, 7th edn. Stanford Business Books (2018)

McFredies, P.: Access 2007. Consultas, formularios e informes. Anaya Multimedia, España (2008). ISBN: 978-84-415-2279-4 84-415-2279-0

Milanovic, N.: Non-functional Properties in Service Oriented Architecture: Requirements, Models and Methods. Information Science Reference (2011). ISBN 978-1-60566-794-2

Mitra, T.: Practical Software Architecture: Moving from System Context to Deployment Pearson Education (2015)

Riascos, S.C., Aguilera, A.: Herramientas TIC como apoyo a la gestión del talento humano Cuadernos de Administración, vol. 27, núm. 46, julio-diciembre, pp. 141–154 Universidad del Valle Cali, Colombia (2011). ISSN: 0120-4645

Stephen, O., Oriaku, K.A.: Software development methodologies: agile model Vs V-model. Int. J. Eng. Tech. Res. (IJETR) **2**(11), 112 (2014). ISSN: 2321-0869. https://www.erpublication.org/published_paper/IJETR022742.pdf, www.erpublication.org

Volini, E., Occean, P., Stephan, M., Walsh, B.: Digital HR: platforms, people, and work. In: Walsh, B., Volini, E. (eds.), Rewriting the Rules for the Digital Age 2017 Deloitte Global Human Capital Trends. Deloitte University Press (2017)

Zhu, H.: Software Design Methodology: From Principles to Architectural Styles. Ed. Elsevier (2005). ISBN 0 7506 6075 9

Digital Evolution in Supply Chain Management with Industry 4.0

María Marcela Solís-Quinteros, Luis Alfredo Ávila-López, Carolina Zayas-Márquez, and Karina Cecilia Arredondo-Soto

Abstract This chapter presents the digital trends and needs of supply chains in Industry 4.0, based on a descriptive literature review. The main changes that have been implemented in the digital field are shown, identifying the management processes for the synchronization of the digital supply network and the main computational techniques applied in industry 4.0 and software used to manage their chains of supplies.

Keywords Supply chains · Digital transformation · Industry 4.0

1 Introduction

Currently, supply chain management (SC) plays a fundamental role due to the structural, technological, and strategic changes of Industry 4.0, which requires speed in an interconnected world and which handle a large amount of information, implying that companies must have the capacity to adapt digital transformations in order to make its logistics processes more agile and innovative to meet consumer expectations.

The characteristics and elements that are part of an SC must be identified where the main idea is to present the flow of information in each of the stages under an integrated system approach, as well as the main computational techniques and software's used to

M. M. Solís-Quinteros (✉) · L. A. Ávila-López · C. Zayas-Márquez
Facultad de Contaduría y Administración, Universidad Autónoma de Baja California, Calzada Universidad #14418, Parque Industrial Internacional, 22390 Tijuana, México
e-mail: marcela.solis@uabc.edu.mx

L. A. Ávila-López
e-mail: avila.luis@uabc.edu.mx

C. Zayas-Márquez
e-mail: carolina.zayas@uabc.edu.mx

K. C. Arredondo-Soto
Facultad de Ciencias Químicas e Ingeniería, Universidad Autónoma de Baja California, Calzada Universidad #14418, Parque Industrial Internacional, 22390 Tijuana, México
e-mail: Karina.arredondo@uabc.edu.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_4

propose strategies specific management systems that are aligned with current trends in the digital synchronization of production processes.

In addition, it is essential to know the best digital transformation practices implemented in the framework of the fourth revolution because it sets the standard to follow in the changes in the supply chain and its performance.

2 Conceptual Framework of the Supply Chain

A supply chain (SC) is defined as a "system of entities (suppliers, manufacturers, warehouses, distributors, sellers, and customers) where there is a flow of materials, and information flows in both directions".

To manage it, a supply chain must have adequate management in its logistics system and good planning and synchronization (Pérez 2021). An SC relates companies that collaborate in the integration of business operations, from the primary acquisition of materials to the final delivery of the product or service to customers, relying on distribution networks and suppliers to generate value and competitive advantage (Bowersox et al. 2007).

The integration of the SC is essential for a business because it can reduce costs, improve its response capacity, eliminate activities that do not generate value for the organization, better planning, and improvement of the flow of information and its products, as well as how to help decision-making to increase the service, in such a way that the exchange of information, agility, and collaboration are important elements for good management, where the use of technology and the internet favor timely coordination in real-time (Zambrano-Yepez et al. 2020).

In a supply chain, the information related to the follow-up and tracing of each of the units during the production and commercialization process must be precisely identified to have a perspective of both technological and traceability (Riquelme 2018).

There are three main elements in the supply chain network, which are part of any production structure, which must be analyzed in detail: the scenario where suppliers operate, the different plants where the product or service is transformed, and the network of distributors (García 2006).

Therefore, supply chain management is a challenge for organizations due to the challenge of designing the synchronization and alignment of logistics processes, as well as its various actors (suppliers, producers, distributors, and customers), where it is required collaborative planning due to the large flow of information, for the efficient achievement of resources and generating added value to the product or service (Gómez-Montoya et al. 2019).

According to Hellani (2021), the global supply chain consists of a complex network of stakeholders in all industries to coordinate collaborative tasks and achieve mutual agreements. Figure 1 shows significant supply chain challenges: centralized systems, lack of transparency, scalability, challenges for integrating the Internet of Things (IoT), and upcoming technologies.

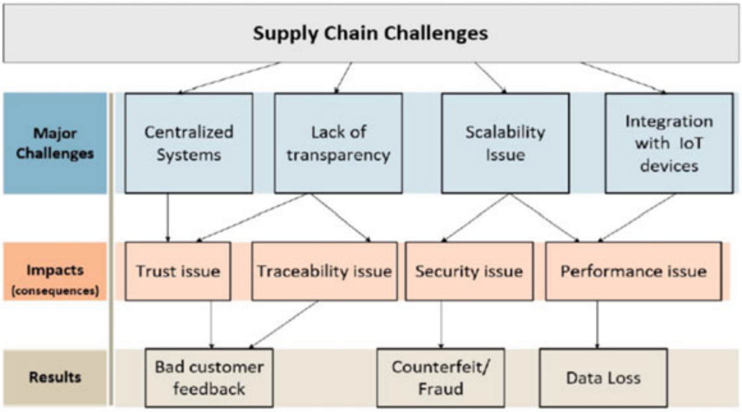


Fig. 1 Technical challenges of the supply chain. *Source* Hellani et al. (2021)

3 Synchronization of the Digital Supply Network

Managing the supply chain is key to the success of companies and the economy in general; having precision in decision making offers an important competitive advantage; however, many internal and external factors affect the performance of the supply chain (Aparicio de Castro et al. 2017).

The advancement of information technologies with ingredients of investment in science is already the presence of business development at this important point of supply. According to Del Val Román (2016), intelligent supply chains are highly automated and integrated and will be possible thanks to the integration of software and communications in the industry. Roig (2018) confirms that companies must do things better in the logistics field and in a different way to continue competing in increasingly complex and demanding markets. Companies have to connect their supply chain beyond their current operational limits if they want to stay competitive in a new digital age, which surpasses the previous one based on non-interactive technologies and the Internet.

3.1 The Smart Factory

According to Del Val Román (2016), the smart factory is the fourth pillar of Industry 4.0. It comprises intelligent production units linked to the manufacturing ecosystem, and the factory becomes a network of agents who make optimized decisions locally. Production could be organized according to a supply-demand model where the capacity of the systems is supply and demand.

This leads us to the concept of smart supply chain, where Arango (2021) points out that there is not a consensus; for example, some scholars propose that the smart supply chain is an integrated system built within and between companies to combine systems management systems and modern information technologies for supply chain intellectualization, digitization, networking, and automation. An intelligent supply chain manages its processes with a wide variety of innovative technologies, such as uncrewed aerial vehicles, cloud computing, and the Internet of Things.

3.2 Integration to Improve Efficiency

In their study, Zambrano-Yepez et al. (2020) find that the integration of the supply chain is substantial in a business since it can reduce costs, produce a better response capacity, and increase the category of the service, and help in decision making. It has representative elements of information, agility, and collaboration, which, thanks to technologies, the Internet can be developed in real-time. In the same way, it explains that the collaboration and integration of the supply chain are achieved through its management since it reduces the uncertainty when making decisions due to adequate coordination of processes between companies.

According to Lee and Whang (2004), the impacts of supply chain integration can be found in four key dimensions:

- Information integration
- Synchronization planning
- Coordination of workflow and
- New business models (Table 1).

4 Digital Transformation Applied in Supply Chains

When we talk about managing the supply chain, we refer to keywords such as planning, organization, and control of the activities that make up it. This management also includes distributing financial resources, information products, or services. All in order to maximize the product's added value that will reach the final consumer, in direct proportion to reducing the company's costs (Camacho et al. 2012).

Empirical studies have shown that the use of ICT in the supply chain gives operational efficiency in costs (distribution, production, inventory, and return on investment), quality (compliance rate, shipping errors, customer complaints), flexibility (volume, delivery, new products and variety of products) and response time (punctuality in deliveries, customer response time, time in the production cycle and out of stock), growth in sales, market share, inventory (Zambrano-Yepez et al. 2020).

Table 1 Supply chain integration dimensions

Dimension	Elements	Benefits
Information integration	Information sharing and transparency Direct and real-time accessibility	Reduced bullwhip effect Early problem detection Faster response Trust building
Synchronized planning	Collaborative planning, forecasting and replenishment Joint design	Reduced bullwhip effect Lower cost Optimized capacity utilization Improved service
Workflow coordination	Coordinated production planning and operations, procurement, order processing, engineering change and design Integrated, automated business processes	Efficiency & accuracy gains Fast response Improved service Earlier time to market Expanded network
New business models	Virtual resources Logistics restructuring Mass customization New services Click-and-mortar models	Better asset utilization Higher efficiency Penetrate new markets Create new products

Source Lee y Whang (2004)

4.1 Changes in the Supply Chain

The use and evolution of emerging technologies in the fourth industrial revolution has generated profound changes in industry and society. Tools such as the Internet of the things industry (IoT), big data, autonomous robots, simulation, cybersecurity, and cloud computing, among others, have changed the pace and way in which work is planned and executed, the interaction between processes and actors, potentiating the ability to monitor and read the market (Barreto et al. 2017). Thanks to the adoption of Industry 4.0 technologies, organizations have the opportunity to improve the efficiency of their material and information flows. Errors and interruptions in the development of logistics processes can be avoided thanks to the continuous exchange of data between the system's stakeholders (Meneses 2020).

Also, Zambrano-Yepez et al. (2020) tell us that information systems improve the internal and external logistics processes of organizations, allowing them to achieve mainly six strategic business objectives: "operational excellence; new products, services, and business models; intimacy with clients and suppliers; improved decision making; competitive advantage, and survival".

In this sense, ICTs allow obtaining greater efficiency and productivity in their processes, through a digital supply chain, in addition to achieving greater transparency and consequently improving the decision-making process, reducing inventory levels with the just in time system, having real-time visibility of inventory levels, decentralizing and reduce delivery times, improve understanding of customer needs, anticipate and detect demands by having up-to-date sales systems, higher sales, higher profit margin, customer loyalty, flexible supply chain with the consequent reduction of risk and associated costs, manage horizontal decision-making in the supply chain, obtaining better results, which leads to the achievement of competitive advantages.

5 Applications of Artificial Intelligence in Supply Chain Logistics

It is possible to interpret CS as a series of events that incorporate the nature of the term technological convergence (TC), which according to Stezano and Quezada (2020) this refers to relationships, synergies, or mergers between broad fields of scientific research and technological development (R&D). Within this framework, a wide diversity of links emerges between various fields that refer to different dimensions of science, technology, and innovation (STI).

The interpretation supporting technological convergence is the mixture of multiple fields of knowledge immersed in a single process, the supply chain. That is to say, areas of design, prototypes, standardization, material quotes, tests with various materials, production line and assemblies, packaging, storage, sales, distribution and delivery logistics, measurement of customer satisfaction are brought together, customer and after-sales service, to mention it roughly. Together, all these processes require the intervention of different areas of knowledge, and that is where the TC niche appears.

According to Tradelog (2021), artificial intelligence has triggered a series of mutations in logistics management. It has been transformed from being a reactive process to a proactive one. That is, planning times, delays, failures human errors have been reduced considerably. Consequently, when activities are automated, they take a proactive model in which the tasks are carried out almost immediately in a kind of prediction that allows the optimization and efficiency of the elements of the sales chain; of course, considering the possibilities that the machines can constitute errors, although in a more sporadic way; which translates into an increase in profitability, saving time, space and hours of work.

In a practical sense, artificial intelligence and its impact on supply chain logistics often vary. According to Arango (2021), AI in SC supports human capacity allowing an improvement that had not been considered possible, replacing to a certain extent human actions.

It is worth mentioning that to the extent that AI permeates SC, and it will practically set the standard in the transformation of SC processes, allowing machines to act autonomously and effectively develop the ability to solve problems and problems; therefore, logistics and distribution are fully automated activities, directed and controlled by machines.

It is important to emphasize that the use of new technologies such as blockchain and the Internet of things are fundamental pieces in most of the proposals to improve supply chains, since the growth and accelerated globalization requires: (1) immediate deliveries, (2) quality of services, (3) cost reduction, (4) real-time visibility of movements, (5) consumer-logistics company interconnection and (6) after-sales service. These requirements are not reversible; on the contrary, there are increasing characteristics and demands on the part of the markets, the companies themselves, and of course, the consumer (Subirana 2018).

6 Computational Techniques Applied in Industry 4.0

The advancement of technologies worldwide and the sophisticated systems have unleashed various computational options; this is clear and is part of Industry 4.0, which has monopolized the spotlight in the last decade. However, the techniques are as varied as the industry itself; we have examples from the automotive, mining, naval, energy sectors, etc.

In addition, the techniques framed in industry 4.0 make it clear that other elements such as blockchain and artificial intelligence come together to develop the processes optimally.

Salado-Cid et al. (2018) clarify that Industry 4.0 is based on the massive use of sensors, devices, and information systems to improve and optimize production products and methods by processing large amounts of data. Data occupies a leading place in this new industrial revolution and places data science as a technological pillar on which this new paradigm is based.

With the digital transformation of the industrial sector proposed by Industry 4.0, there has been a significant increase in the volume of data companies manage, thus placing data science as a fundamental technological pillar. The complexity in the use of computational techniques has promoted the development of tools based on data-intensive workflows to define expert knowledge at a high level of abstraction, hiding the details of computation at a low level (Salado-Cid et al. 2018).

This data and its management are being discussed at the international level at this time. The industry is increasingly becoming digital, and information flows quickly and efficiently. This is the so-called real-time operation, which makes the processes more specific and detailed.

Endler and Romero (2019) tell us that in addition to real-time operation and migration to the virtual world, the application of industry 4.0 promotes remote assistance, assertive and punctual maintenance, and greater control of production and quality with the In order to synchronize the demand-production binomial, innovation and profound changes in production processes, the most influenced industries are those that make greater use of cutting-edge technologies, due to competition and the great demand from their customers.

Regarding the concept of Smart manufacturing, Kusiak (2018) mentions that manufacturing has evolved and has become more automated, computerized, and

Table 2 Smart manufacturing implementing Industry 4.0 principles

Characteristics	Key elements	Reference architectures	Algorithms for decision making
Cloud computing, edge computing, big data, data analytics, IoT, 3DP, cybersecurity, AR, VR, mobile computing, IWNs, CAutoD, robots, autonomous vehicles, drones, CPS, sensors, and actuators	Smart design, production control, digitalization, automation, cybersecurity, security, connectivity, interoperability, monitoring, virtualization, coordination, collaboration, real-time, sustainability	I4SEA, hierarchical I4.0 architecture, IoT-based architecture	Modeling, optimization, simulation
Reconfigurable manufacturing, autonomy, flexibility, visibility, agile, lean, mass customization, productivity, quality, speed, standardization, additive manufacturing, connected supply chain			

Source Cañas et al. (2021)

comple4. Smart manufacturing is an emerging form of production that integrates the manufacturing assets of today and tomorrow with sensors, computing platforms, communication technology, control, simulation, data-intensive modeling, and predictive engineering. It uses the concepts of cyber-physical systems spearheaded by the Internet of Things, cloud computing, service-oriented computing, artificial intelligence, and data science. Table 2 describes in detail the characteristics and elements of Smart manufacturing within the computational framework. Techniques.

Below is a compilation of the most used techniques in Industry 4.0 related to the work and the corresponding authors.

6.1 Applied Computational Techniques

Endler and Romero (2019) analyze computational techniques in the automotive industry; the authors' proposal consists of four phases, each of which has a set of individual steps. The phases of the method are, respectively: knowledge, internalization, action, and feedback. The authors used the Interpretive Structural Modeling (ISM) technique. The technique's objective is to analyze complex socio-economic systems in the form of a map, showing the interactions between the elements of the system. It is decomposed into several subsystems (or elements) to develop a multilevel structural model based on knowledge from experts in the research field.

The authors also ranked the barriers in order of importance, establishing a priority level that should be given to them. These barriers can be both businesses, technological and scientific, concerning the automotive industry in question. As barriers in the managerial field, we can have contractual and legal uncertainties, profound changes in the organizational routine, the need for regulatory compliance, and a higher unemployment rate due to increases in the automation of processes.

On the other hand, Sánchez-Sotano et al. (2020) refer to the shipbuilding industry and describe some applications in terms of ship design to optimize overall performance. The authors refer to AI mainly related to the development of other technologies, acting as an enabler to boost the potential of each of the other computational techniques.

Espitia and Soto (2020) review deep learning applied to monitoring conditions in intelligent manufacturing processes, rescuing the best tools to monitor electromechanical systems with data-based schemes. However, they point out that with the increase in the complexity of the systems, the increase in case studies, and the need to incorporate new operating conditions, traditional machine-based schemes are insufficient to characterize such complexity because their discriminatory capacity decreases. Consequently, the study has been moving towards incorporating techniques based on deep learning. Applications such as feature extraction, dimensionality reduction, novelty detection, and transfer learning are some of the tasks performed using this technique.

The medical industry is at the forefront of computational techniques in the study by Gismondi Glave (2010). One of the most widely used computational techniques is analyzed, which is the reconstruction of organs in three and four dimensions. In tomographic modalities, mainly CT and NMR, the image format is like one image slice, and studies of several dozen successive slices are made. Conceptually, it is easy to visualize the application of fitting and splicing techniques for these slices to obtain a complete volume that provides information in a more natural way to the doctor. Currently, there is software based on non-parametric algorithms (which do not depend on prior knowledge of the statistical characteristics of the image) for the automatic segmentation of brain structures. This technique allows classifying brain tissue into different parts.

Finally, reference is made to the case of microgrids, where Gamarra and Guerrero (2015) point out that many optimization methods are based on traditional approaches, such as linear programming of intervals and mixed integers, while a growing number of articles Research tends to use heuristic optimization. Heuristics have become very popular in energy planning and design problems such as Genetic Algorithms, Particle Swarm Optimization, and Search Algorithms. Consequently, some new bio-inspired heuristics have recently been applied to microgrid planning. Scheduling operations is the most prevalent problem in terms of the economic viability of microgrids. Concerning modern mathematical techniques, it can be noted that parallel processing has not been fully explored for microgrid planning purposes.

6.2 *Beyond Computational Techniques*

Cañas et al. (2021) believe that a new generation of wireless connections, such as 5G technology, will help accelerate the fast connectivity required by industry 4.0. That mathematical models are necessary to integrate modeling languages in CPS environments, and conclude that 5G technology will meet real-time demands and replace current industrial automation networks.

Fernandez-Carames and Fraga-Lamas (2019) review the benefits and challenges of using blockchain and smart contracts to develop I4.0 applications. They conclude that blockchain can improve I4.0 technologies by providing security, trust, immutability, decentralization, and greater automation through smart contracts.

As previously, reviewed AI is one of the driving technologies of Industry 4.0. According to the European Commission, AI refers to "systems that show intelligent behavior by analyzing their environment and taking actions (with a certain degree of autonomy) to achieve specific objectives." Its application in the industrial sector has given rise to the concept of "smart manufacturing", which will allow more flexible and efficient operations in the smart factory. (Sánchez-Sotano et al. 2020).

7 Software Applied to Industry 4.0

One of the most significant transformations in humanity, according to the arguments of Diáz-Martínez et al. (2021) have undoubtedly been the fourth industrial revolution. This statement has its foundations in the impact experienced by all the activities, that is to say, the way things are done, the use and exploitation of available resources, the interaction between people, the way of working, learning, mobilizing markets; doing business, etc.

Although industry 4.0 indeed had its beginnings in Germany, considering the technological advances that gave way to artificial intelligence, little by little, this trend was gaining ground in other countries, typically the most developed first, followed by emerging economies and with an inevitable relegation, third world countries. Initially, industrial activities permeated into other fields equally important for the proper functioning of the market and the social activities themselves.

Faced with this statement, it is clear that the fourth industrial revolution is intrinsic in daily work and strongly fed by the new generations, also called digital natives, who in turn; seem increasingly demanding in terms of the type of technological devices and their functions, hence the incentive for the technological maelstrom that exists in companies (of different areas, not emphatically in industrial ones), in such a way that the period's inventions have been shortened dramatically, generating almost immediate obsolescence of software and technological equipment.

When talking about the trends of technological advances and innovations, he not only refers to the subject of the devices utilizing which most of the operations of various kinds are carried out; but also focuses on updating and constant adaptation of software that allows optimizing resources and making response times to activities more efficient.

In this sense, it is necessary to address the issue aimed at the analysis of software applied in industry 4.0, and in a certain way establish the criteria under which they are implemented and subsequently removed from the functions, or else; how they evolve in order to remain current, although this represents the generational development of these systems. The starting point about software is undoubtedly the main engine that supplies operating systems in general, the Internet of Things (IoT).

Around this topic, Fermín and Guerra (2017) counted the episodes that generated the very term IoT (Internet of Things), coined in 1999 by Kevin Ashton at the Auto-ID Center of the Massachusetts Institute of Technology. For Kevin, the interconnection of devices and people was evident. He also predicted that simple devices (not necessarily technological devices) would have access to that connectivity, creating new services and new needs in people. Hence derives the generation of Big Data, which arises from the collection of information in large quantities from said objects connected to the internet network. The term big data focuses on analyzing the behavior of activities and people, response times, amount of resources allocated, and how to achieve greater efficiency that allows its optimization.

As for Big Data, a large part of its usefulness lies in what Quijada (2020) identifies as the three "v's". (1) A high volume of data available, ie; millions and millions of bytes of valuable information for decision making. (2) High speed of flow of this data refers to millions of data per second that come from various sources, such as transactional databases, social networks, the Internet of things itself, web pages, and search engines. (3) High variety of these data can be structured in typical tables, rows, columns, or unstructured such as chats, twitter texts, Facebook, videos, images, etc.

Some of the advantages of Big Data lie in obtaining digital information in an agile way, making decisions under more accurate scenarios and in response, an increase in profitability in production, greater integration in the internal and external processes of the company, greater organization, which brings consequently the optimization of the processes.

On the other hand, according to the Aggity company (2021), intelligent operating systems should aim mainly to provide companies with technological innovation tailored to increase production and efficiency, managing automation and interconnection in production processes, thus achieving the integration of holistic teams.

- Digitization: The paper lag in operational processes is extremely important. This mainly leads to errors and waiting times, so all material must be converted to digital to be accessible at any time.
- Web workstations: Referring to the importance of having the interconnection of the different workstations, with the sole purpose of integrating the entire company into a single system. For this, it is necessary to have associates and operators equipped with computers, tablets, smartphones, or any Smart device to communicate online with computer systems and subsystems.

- Automation of processes: This aspect is essential since the correct operation of the previous ones depends on it. It consists of connecting in a systematic way to the systems and subsystems of the different departments or workstations existing in the company. The idea is to generate a factory ecosystem where all the processes converge.
- Factory computer system: Finally, the confluence occurs in the central computer system of the factory, adopted and adapted to the company's characteristics, which will establish communication and interconnection between all resources, people, and the processes involved inside.

By establishing these working mechanisms through software, companies necessarily incorporate in their daily work the organization of processes and resources, thereby allowing to analyze their efficiency, which will result in a reduction of errors and losses, which is currently the Achilles heel of companies that intend to evolve and keep pace with industrial advances and globalization.

Among the various software incorporated into industry 4.0, Cloud Computing also stands out, which according to Todoerp (software company) (2021), refers to the services that are found and can be offered and demanded through the Internet. They represent advanced technology, and therefore, it is one of the great responsible for the fourth industrial revolution. This technology is also known as cloud operation and allows files, information, and programs to be stored entirely and directly on the Internet. One of its significant advantages is that the client or user can consult the information through any device without storage capacity limitations. Some of the Cloud Computing tools are broad network Access, on-demand self-service, resource pooling or shared services, rapid elasticity, and measure service (Ruparelia 2016).

- Broad Network Access: it consists of complete access to the network. According to the Information Security Resource Center (CSRC) (2021), these are the capabilities available through the network and are accessed through standard mechanisms that promote the use of thin heterogeneous client platforms (such as smartphones, tablets, laptops, and workstations).
- On-demand self-service: Refers to self-service on-demand. This means that the consumer takes all the necessary actions to acquire the service himself instead of going through a requisition. The customer request is processed automatically by the cloud infrastructure without human intervention by the provider (Secure Cloud Development 2021).
- Resource pooling or shared services: This software is used in cloud computing environments to refer to a situation in which providers provide services to several clients with professional services. These services are adjusted to adapt to the needs of each client without the changes being evident to the end-user. The goal is that, through the systems, providers can create a sense of infinite or immediately available resources by controlling resource settings to a target level. The benefit is that it allows customers to change their service levels at will without being subject to physical or virtual resource restrictions (Techopedia 2021).

- Rapid elasticity: This term refers to the supply of scalable services. That is, it allows users to request additional space automatically. Capacities can be provisioned and released elastically, automatically to scale in or out according to existing demand rapidly. As for the consumer, the capacities available for provisioning often seem limited and can be appropriated in any quantity and at any time (IGI Global 2021).
- Measure service: Also known as tailored service, it is a reference to services in which the cloud provider measures or monitors the provision of services for various reasons, including, for example, billing, efficient use of resources or general predictive planning. It is one of the five principles that support a higher-level definition of cloud services and refers to cloud systems' overall footprint and capabilities (Techopedia 2021).

Another of the software that is incorporated into industry 4.0, according to Todoerp (2021), is Business Intelligence, which can be interpreted as the ability and practices by which it is possible to transform disjointed data into information that is synthesized to generate knowledge from it. It is essential to underline that this knowledge is essential to optimize each of the processes involved with the business itself and operations decision-making.

According to the works of Quijada (2020), some of the Business Intelligence tools are (1) Power Bi, which allows making informed decisions quickly, it is an analytical service based on the cloud, which enables any user of the business to visualize and analyze your data in a fast, efficient, and understandable way. (2) Tableau is a data discovery and exploration application that allows you to answer urgent questions in seconds. (3) QlikView enables developers and business analysts to design practical applications more quickly and easily for users. (4) MicroStrategy is a platform that covers the data analysis needs of a company of any business, performs all kinds of reports, and can be operated from the desktop application, the web interface, mobile devices, or directly in the cloud. (5) Sisense, used to create business intelligence reports that allow any user to transform data into reports since they have complete data visibility and can generate practical knowledge with minimal expenses.

Other software intensely used in industries is virtual reality and augmented reality, which consists of a set of technologies that allow the generation of real and virtual images with which you can interact in real-time to add or remove the information and, in this way, exercise simulations of what will happen in a future situation. With these tools, it is possible to access the overprinting of information, validation of tasks performed, and the guidance and resolution of incidents (Todoerp 2021).

Suppose you wanted to understand the subtle difference between virtual reality and augmented reality. In that case, it consists of: (1) Augmented reality, understood as the technology that tries to perfect the real world, superimposing or adding layers of information using elements created digitally, on the environment surrounding the user that is; all based on an authentic setting. (2) Virtual reality is based on replacing the real world with a virtual world created through a computer, where the user can interact, but without leaving the virtual world in which it is integrated (Neosentec 2021).

Finally, in terms of the most used software in the industry, there is also robotics, which plays an essential role when defining industry 4.0, since this includes machines and artificial intelligence components that do not. They are currently only capable of fulfilling specific orders, but also of anticipating tasks in a practically intuitive way according to the needs of the company and its behavior in the markets (Todoerp 2021). Finally, among the significant advantages of robotics, robots currently connect with other robots and other machines without interference and even work collaboratively (in proximity) with humans, substantially improving the productivity of the entire system (Basco et al. 2018).

8 Best Practices in the Supply Chain, New Digital Technologies and Software Used

The fourth industrial revolution, known as 4.0, has had a direct impact on production processes, where the introduction of high technology is required to connect the information in real-time; This requires that SCs evolve by identifying the following critical factors for their success: logistics (transportation), information systems, internal and external integration systems, inventory systems management, and resource planning (Ramírez et al. 2019).

Therefore, a 4.0 supply chain must be characterized by physical Internet, intelligent sensors for monitoring, warehousing automation, and delivery of addresses without addresses through georeferencing. This technological evolution requires changes in the professional profile, so an SC leader for logistics 4.0 must have: global, holistic, and strategic thinking to establish performance and monitoring metrics, oriented to information technologies, and creative and innovative thinking (Riquelme 2018).

Among the capabilities that are necessary for the management of operations in a digital supply chain derived from omnical distribution are dynamic inventory control, flexible distribution network adapted to all product delivery needs, real-time speed of the stock to reduce costs, efficiency in every one of the CS links, order fulfillment, ease of product returns (Aparicio de Castro et al. 2017).

As part of the best practices in supply chains, there is a new business management system, where a myriad of computer applications can be implemented in each area, allowing the following advantages: greater management in control with suppliers, greater efficiency in Negotiations for the ease of information exchange, cost reduction, better inventory management, reduction in supply time in real-time and greater capacity to react to market demand (Arias et al. 2007).

According to Budet and Pérez (2018), technological innovations are gaining more and more relevance in the chains of his-minister. The following practices offer competitive advantages for competitiveness and quality of services.

Blockchain. The information can be distributed to several computers simultaneously and accessible to anyone with the Internet, guaranteeing the traceability of any product in the supply chain.

Artificial intelligence. Sending data between devices or machines, combining sensors, cameras, software, databases over the Internet, to achieve more efficient operations and allowing to improve inputs in the supply chain.

Automated delivery system. These new customer delivery systems allow automating processes throughout the supply chain from picking to data management, improving quality, and shortening deadlines.

3D printing. It will reduce supply chain complexities while allowing companies to offer more complex and personalized products. Logistics providers have greater proximity to the customer, which will allow them to more accurately capture the needs for 3D production and customization of the goods to be printed, according to the needs of the end customer.

Tables 3 and 4 present the leading software used in the industry to manage its supply chains, where its applications and benefits are identified.

9 Case Study

The company that we will call the electronics factory is part of a transnational corporation that manufactures and sells electrical and electronic products for residential and non-residential construction, with applications in the industrial and public services sector, developing tools and equipment to meet the needs of growth in demand for assembly and manufacturing machines. The software they used in their supply chain only emphasized finance, leaving out the other areas.

Within the warehouse department, it was possible to identify deficiencies in the processes of reception, storage, and supply of raw materials, in addition to poor document control and information management, the presentation of results, reports, among other relevant information; as well as failures in customer orders in 43%, where 27% corresponded to the warehouse, and the rest to the production and sales departments.

It is important to note that the company realized the situation because if it continued with the same trend, the competitiveness of its supply chain was at risk, so SAP software was implemented in all areas of administration, finance, materials, and production. For a successful implementation, adaptations were made in the servers and connectivity, massive training. The training required by the employees to use the software was exhaustive, specialists and consulting support were hired.

The benefits that the company achieved with the use of SAP is that it currently has a comprehensive and complete vision of the actual state of the company, better control in the flow of materials, inventory optimization, product costing, and therefore elimination of failures in customer orders.

Table 3 Software used in the industry to manage supply chains

Software	Manufacturer	Applications	Benefits
PROTEX	Computer House Srl	Contains Manufacturing Execution, Warehouse Management, and Customer Relationship Management Systems	Integrated, easy-to-use system with intuitive, multi-tenant graphics
TEXPLUS	Datamon Plus	ERP system that plans production and scheduling with dispatch rules and effective cost and quality control	Timely information for problem solving, negotiations, and decision-making in the fulfillment of quality criteria with the client
LOOMDATA	Zeta Datatec GmbH	The system includes plant monitoring, quality control, and warehouse tracking	Ability to produce a stable and reliable system, with ease to customize the software for customers requiring more programming functions
Just MES	Up Solutions S.r.l	It consists of four integrated solutions: Product Lifecycle Management, Precise Planning, Monitoring, and Quality Control	It presents a complete solution with the capacity to administer and monitor the company's entire manufacturing process, from the conception of the idea, through its design and manufacture, to its service and final recycling
Sistema ERP NOW	Datatex	ERP integrates sales and customer service, including CRM, planning and scheduling, production order management, quality, inventory, purchasing, and warehouse. As well as specific applications for shop floor automation, fabric inspection and machine capacity management	The software has been developed to respond to the needs of its customers, who have particular and very different planning and scheduling requirements

(continued)

Table 3 (continued)

Software	Manufacturer	Applications	Benefits
Porini 365 ERP	Porini S.r.l	Quality is a priority in the processes. The software contains Manufacturing Execution System (MES), advanced warehouse management, and Product Lifecycle Management (PLM) capabilities	All software is supported in the cloud, easily accessed from the web browser. Its software components are integrated based on the latest Microsoft technologies

Source Thoney-Barletta (2020)

10 Conclusions

Industry 4.0 is changing the supply chain because they must ensure flexibility and optimization in each of their decision processes, which requires that a wide variety of innovative technologies be incorporated into their operations to digitize and automate manufacturing processes.

To enter the digital transformation of Industry 4.0, it is necessary to apply computational techniques and software that facilitate the management of its supply chains; Therefore, the use of emerging technologies provides cutting-edge improvements to maintain a comprehensive and complete view of the company in real-time.

Table 4 Leading manufacturers of supply chain management software

Software	Manufacturer	Applications	Benefits
ERP SAP Business One	SAP SE	Track orders and orders so that they reach customers promptly. Better plan production to match required inventory levels. Reduce processes and have better information to make decisions about them	Better inventory visibility, better customer service, and supplier management
ORACLE SCM	Oracle	Plan your end-to-end supply chain in the cloud. Apply built-in machine learning to improve profitability while accelerating customer service	Reduce complexity, Align plans end-to-end, Empower planners and stakeholders, Accelerate decision-making, Automate planning decisions

(continued)

Table 4 (continued)

Software	Manufacturer	Applications	Benefits
JDA Software	JDA	Efficiently integrate and synchronize forecasting of demand and warehouse and transportation execution work and delivery across multiple channels, reducing latency driven by disjointed systems	It offers visibility and orchestration in real-time, allows generating different scenarios and acting based on them
Infor CloudSuite Software	Infor Global Solutions	With SCM demand planning, a more precise and more accurate view of customer demand is achieved, which is used for your sales and operations plan. It also provides tools to help you forecast and create a demand-replenishment plan synchronized and integrated with your ERP system	Provides an intelligent and real-time organization from sourcing connecting companies with their partners in supplied links, as well as transforming processes from planning to delivery, both inside and outside the company
Manhattan Active® Supply Chain	Manhattan Associates	Enables multiple components in its common platform to optimize the planning and execution of the omnichannel supply chain with the rest of the traditional systems of the company by facilitating the implementation and reducing the risk of designing interfaces that can slow down the process	Its artificial intelligence technology refines its optimization in the flow of goods and information; enables flawless execution in stock, labor, advanced automation, robotics, and physical space

Source Castro (2016), Duarte (2020) Oracle, CTN GLOBAL, Banker (2021)

The benefits of implementing specialized software for supply chain management are visible because all company processes are optimized, all flows and information related to the product and processes are managed more efficiently, reducing costs and better decision making. In this sense, companies must adapt and plan their operations quickly and accurately to respond to new market trends.

References

Aggity: Industry 4.0 es la cuarta revolución industrial. https://aggity.com/sectores/sistema-gestion-industrial/ (19 de agosto del 2021)

Aparicio de Castro, G., González, M., Zorrilla, P.: Transformación digital de la cadena de suministro para una distribución omnicanal: La experiencia de Amazon. Distribución y Consumo **103**(2) (2017). https://www.mercasa.es/media/publicaciones/233/1495529527_Transformacion_digital_100p4.pdf

Arango, I.C.: Oportunidades para la transformación digital de la cadena de suministro del sector bananero basado en software con inteligencia artificial. Revista politécnica **17**17), 47–63 (2021). https://doi.org/10.33571/rpolitec.v17n33a4

Arias, J., Briceño, W. Nuñez, M.: Estrategias de Tecnologías de Información aplicables a la cadena de abastecimiento de las PYMES del sector de elaboración de productos alimenticios y bebidas en el Área Metropolitana de Bucaramanga. Revista Colombiana de Marketing **6**(8), 19–37. http://www.redalyc.org/articulo.oa?id=10926793003 (2007)

Banker, S.: Manhattan Active Supply Chain. https://www.manh.com/sites/default/files/sys/documents/2021/07/manh-folleto-de-manhattan-active-supply-chain-es.pdf (2021)

Barreto, L., Amaral, A., Pereira, T.: Industry 4.0 implications in logistics: an overview. Procedia Manuf. **13**, 1245–1252 (2017). https://doi.org/10.1016/j.promfg.2017.09.045

Basco, A.I., Beliz, G., Coatz, D., Garnero, P.: Industria 4.0: fabricando el futuro, vol. 647. Inter-American Development Bank (2018)

Bowersox, D., Closs, D., y Cooper M.: Administración y logística en la cadena de suministros. Mc. Graw Hill (2007)

Budet, X., Pérez, A.: Innovaciones tecnológicas en la cadena de suministro aplicadas al eCommerce. Revista de economía, empresa y sociedad. **9**, 41–57. https://comein.uoc.edu/divulgacio/oikonomics/_recursos/documents/09/4_Budet-Perez2_Oikonomics_9_A4_cast.pdf (2018)

Camacho, H., Gómez, K.L., Monroy, C.A.: Importancia de la cadena de suministros en las organizaciones. In: Tenth Laccei Latin American and Caribbean Conference. (Laccei'2012) (2012)

Cañas, H., Mula, J., Díaz-Madroñero, M., Campuzano-Bolarín, F.: Implementing Industry 4.0 principles. Comput. Ind. Eng. 107379 (2021)

Castro, J.: Tu cadena de suministro más eficiente con el ERP SAP Business One. https://blog.corponet.com.mx/tu-cadena-de-suministro-mas-eficiente-con-un-erp(2016)

Computer Security Resource Center: Broad network. https://csrc.nist.gov/glossary/term/Broad_network_access (19 de agosto 2021)

CTN GLOBAL: Soluciones/INFORM SCM demand planning. https://www.ctnglobal.com/soluciones/infor/infor-scm-demand-planning(12 agosto 2021)

Del Val Román, J.L.: Industria 4.0: la transformación digital de la industria. In: Valencia: Conferencia de Directores y Decanos de Ingeniería Informática, Informes CODDII (2016)

Díaz-Martínez, M.A., Ruíz-Hernández, S., Román-Salinas, R.V., y Estrada-Cadena, G.: Aplicación móvil "AppIndustria 4.0": una herramienta para la evaluación de las organizaciones en industria 4.0. Información tecnológica **32**(4), 53–64 (2021). https://doi.org/10.4067/S0718-07642021000400053

Duarte, E.: Blue Yonder, la evolución de JDA software. http://t21.com.mx/logistica/2020/04/27/blue-yonder-evolucion-jda-software (2020)

Endler, C.L., de Andrade Júnior, P.P.: Method of application of industry 4.0 in automotive assembly lines. Braz. J. Prod. Eng. -BJPE 104–119 (2019)

Espitia, F.A., Soto, L.R.: Novel methods based on deep learning applied to condition monitoring in smart manufacturing processes. In: New Trends in the Use of Artificial Intelligence for the Industry 4.0, 49 (2020)

Fernandez-Carames, T.M., Fraga-Lamas, P.: A review on the application of blockchain to the next generation of cybersecure industry 4.0 smart factories. IEEE Access **7**, 45201–45218 (2019)

Fermín, F.A. y Guerra, J.L. (2017). El internet de las cosas. Perspectiv@s, [S.l.], vol 10, no. 11, pp. 45–49. Disponible en: http://revistas.uigv.edu.pe/index.php/perspectiva/article/view/187 (2017)
Gamarra, C., Guerrero, J.M.: Computational optimization techniques applied to microgrids planning: a review. Renew. Sustain. Energy Rev. **48**, 413–424 (2015)
García, F.: La Gestión de Cadenas de Suministros: Un enfoque de integración global de procesos. Visión Gerencial **1**, 53–62. https://www.redalyc.org/comocitar.oa?id=465545874007 (2006)
Gismondi Glave, G.: Ingeniería biomédica. Revista Ciencia y Cultura **24**, 99–118 (2010)
Gomez-Montoya, R., Zuluaga-Mazo, A., Ceballos-Atehourtua, N. y Palacios-Jimenez, D.: Supply chain management and productivity in the literature scientific. I+D Revista de Investigaciones **4**(2), 34–44 (2019). https://doi.org/10.33304/revinv.v14n2-2019004
Hellani, H., Sliman, L., Samhat, A.E., Exposito, E.: On Blockchain Integration with supply chain: overview on data transparency. Logistic. **5**(3), 46 (2021). https://doi.org/10.3390/logistics5030046
IGI Global Publisher of Timel Knowledge: What is Rapid Elasticity. https://www.igi-global.com/dictionary/rapid-elasticity/49880 (19 de agosto 2021)
Kusiak, A.: Smart manufacturing. Int. J. Prod. Res. **56**(1–2), 508–517 (2018)
Lee, H.L., Whang, S.: E-business and supply chain integration. In The Practice of Supply Chain Management: Where Theory and Application Converge, pp. 123–138. Springer, Boston, MA (2004)
Meneses, C.R.: Evolución de la gestión de la cadena de suministro y la logística, desde una visión tecnológica y sostenible. Reto **8**(20201), 22–31 (2020)
Neosentec: ¿Qué es la realidad aumentada y qué es realidad virtual https://www.neosentec.com/realidad-virtual-y-realidad-aumentada-diferencias/ (20 de agosto 2021).
Oracle: Oracle Supply Chain Planning. https://www.oracle.com/mx/scm/supply-chain-planning/ (10 agosto 2021)
Pérez, A.: Historia de la logística. (2021) http://antonioperezcarmona.es/historia-de-la-logistica
Quijada, C.: Business intelligence. Realidad Empresarial **9**, 45–48 (2020). https://doi.org/10.5377/reuca.v0i9.10068
Ramírez, C.: Evolución de la gestión de la cadena de suministro y la logística, desde una visión tecnológica y sostenible. Revista RETO **8**(1), 22–31 (2020). https://doi.org/10.23850/reto.v8i1.2863
Ramírez, G., Figueroa, V. Orozco, I.: Determinar el factor clave en una cadena de suministro tradicional para iniciar proceso2017 de cambio a Industria 4.0. Pistas Educativas **133**(41), 540–550 (2019). http://itcelaya.edu.mx/ojs/index.php/pistas
Riquelme, B.:. La logística 4.0. Revista de Marina. **964**, 39–44. https://revistamarina.cl/revistas/2018/3/briquelmeo.pdf (2018)
Roig, M.V.: Logística y cadena de suministro en la nueva era digital. Revista de economía, empresa y sociedad. **1**(9), 7–10. https://oikonomics.uoc.edu/divulgacio/oikonomics/_recursos/documents/09/Oikonomics_9_cast_OpenCMS_a4.pdf#page=7 (2018)
Ruparelia, N.B., Molino, J., Romero, J.R.: Interoperabilidad de flujos de trabajo intensivos en datos en Industria 4.0: caso de estudio. Cloud computing. MIT Press. https://books.google.es/books?hl=es&lr=&id=umIsDAAAQBAJ&oi=fnd&pg=PR5&dq=Cloud+computing.+MIT+Press.&ots=k8CxrVqN_9&sig=GH3uv5sgZ9X0jRb4dAElQSTjCQg#v=onepage&q=Cloud%20computing.%20MIT%20Press.&f=falseSalado-Cid (2016)
Salado-Cid, R., Molino, J., Romero, J.: Interoperabilidad de flujos de trabajo intensivos en datos en Industria 4.0: caso de estudio. XVIII Conferencia de la Asociación Española para la Inteligencia Artificial (CAEPIA 2018): avances en Inteligencia Artificial. 23-26 de octubre de 2018 Granada, España. pp 1333-1338. (2018)
Sánchez-Sotano, A., Cerezo-Narváez, A., Abad-Fraga, F., Pastor-Fernández, A., Salguero-Gómez, J.: (2020). Trends of digital transformation in the shipbuilding sector. In: New Trends in the Use of Artificial Intelligence for the Industry 4.0. IntechOpen (2020)

Secure Cloud Development: On-demand Self-service. https://remonsinnema.com/cloud-2/cloud-computing/on-demand-self-service/ (19 de agosto 2021)

Stezano, F., y Quezada, F.: Convergencia tecnológica y científica en torno al sector biotecnológico en. In: Casalet, M. (ed.) El paradigma de la convergencia del conocimiento. Alternativa de trabajo colaborativo y multidisciplinario, 1st edn., pp. 25–52. Flacso México (2020)

Subirana, C.: Cómo la tecnología blockchain transformará las cadenas de suministro. Revista De Contabilidad y Dirección **27**, 47–60 (2018)

Techopedia: What does resource pooling mean? https://www.techopedia.com/definition/29545/resource-pooling (19 de agosto 2021).

Techopedia: What does measured service mean? https://www.techopedia.com/definition/14469/measured-service-cloud-computing (19 de agosto 2021)

Thoney-Barletta, K.: Software de Gestión de Cadena de Suministro para Sistemas Textiles. https://textilespanamericanos.com/textiles-panamericanos/2020/10/software-de-gestion-de-cadena-de-suministro-para-sistemas-textiles/ (2020)

Todoerp: Softwares para la industria 4.0. https://todoerp.com/software-para-industria-40/ (19 de agosto 2021)

Tradelog: ¿Cómo la inteligencia artificial y la logística está transformando al sector? https://www.tradelog.com.ar/blog/inteligencia-artificial-en-la-logistica/ (22 de junio del 2021)

Zambrano-Yepez, C., Giler, E., Vera, M. Franco, M.: Beneficios y desafíos del uso de las TIC en la cadsena de suministro. Revista de Investigación en Tecnologías de la Información **8**(15), 128–142. https://www.riti.es/ojs2018/inicio/index.php/riti/article/view/188 (2020)

Farm Based Discomfort and Perceived Mental Stress Among Farmers

Hullash Chauhan, Suchismita Satapathy, and A. K. Sahoo

Abstract In every agricultural sector, the farmers are affected with musculoskeletal disorders, which cause severe health-related problems that affect farmers' mental well-being and decrease their work capacity. This study aimed to find the mental stress level of farmers and determine the discomfort levels in farming activities. Based on the responses obtained from 153 farmers using a questionnaire. It was found that farmers reported feeling mentally tried (62.74%), feeling stressed (60.78%), feeling irritated (59.47%), feeling depressed (58.16%), feeling alone (57.51%), feeling exhausted (56.86%), and so on. Further, this study shows that all the respondents have a high lifting index based on the pre-assessment analysis of the NIOSH lifting equation, which means that they are at a significant hazard. After executing the proper lifting technique, the post-assessment test showed that the respondent had a lower lifting index. Moreover, by the method of ANFIS, an exertion has been made to predict the mental stress of farmers during their working activities in adverse climatic conditions based on some associated parameters.

Keywords Mental stress · Farmers · Climate · NIOSH lifting equation · ANFIS · Perceived stress questionnaire (PSQ)

1 Introduction

The farming sector is hazardous, with mortality between the peaks in any occupation. Farmers are repeatedly unaided for long working hours with unpredictable equipment and adverse climatic conditions with dangerous chemicals and farm animals. Agricultural activity is categorized by a rigorous and rhythmic effort that may cause body discomfort. Body discomfort is related to the material load forced by the action; this means that body discomfort is directly related to musculoskeletal disorders. The

H. Chauhan · S. Satapathy (✉) · A. K. Sahoo
KIIT Deemed to be University, Bhubaneswar, Odisha, India
e-mail: ssatapathyfme@kiit.ac.in

A. K. Sahoo
e-mail: asahoofme@kiit.ac.in

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_5

farmers working in the agricultural sectors are easier to be exposed to the risk of mental stresses and other kinds of injuries. During task performances, exposure to adverse climatic conditions may lead to occupational hazards that can adversely affect the human body. This, in turn, reduces the farmers' productivity, work quality and also increases musculoskeletal problems. Therefore, an attempt was made in this study to explore the mental state conditions of the farmers in Chhattisgarh (India).

Numerous studies show that farming activities' physical workload can cause physical discomfort (Flocerfida et al. 2019). Research on occupational musculoskeletal disorders conducted with male and female farming workers found that workers' main grumble was neck pain, back pain, forearm, wrist, trunk, leg, and hand-arm. Manual materials handling risk is related to lifting and lowering tasks in agricultural activities.

Stress could be a normal emotional response to abnormally high work demands (Padhy and Raju 2018). Psychosocial risk among farmers has been examined more and more due to the continuous changes in agriculture. Such changes include restructuring the trade, transition from family farming towards entrepreneurship, and global climate change (Kallioniemi et al. 2016). It may be conjectured that agriculture staff is in danger for psychosocial state issues (Hovey and Seligman 2006). Farmers' psychological health problems measure the general population's health considerations (Hagen et al. 2019). An Adaptive Neuro-Fuzzy Inference System (ANFIS) primarily based Maximum Power Point Tracking (MPPT) manager has been introduced. To transfer most supremacy to the load, the duty cycle of the two-switch flies back electrical converter, associated with the solar battery and the load, should be generated with the help of the projected ANFIS technique (Koochaksaraei and Izadfar 2019).

The ANFIS is planned to suggest and examine the mapping among the human property of tactile texture and people affection response (Akay et al. 2012). In this analysis, the associated degree adaptive neuro-fuzzy reasoning method (ANFIS) has been applied to review the result of operation situation on activity wrong victimization information of skilled accident assembled by ship repair yards (Fragiadakis et al. 2014).

Period and time-motion cram were wont to verify if protection affects every employee's time in final of the task. The National Institute for Occupational Safety & Health (NIOSH) lifting equation is employed to assess safety. This equation is an ergonomic tool that equates to the required weight limit and lifting index of the loaders or carriers that perform manual material handling (Flocerfida et al. 2019). The study aims to investigate the manual lifting kind (e.g., lifting model, operation condition) and judge the manual lifting task mistreatment with the NIOSH lifting equation (Klomjit and Intaranont 2005). The plan of this learning was to analyze the link between the review NIOSH lifting equation (RNLE) and the risk of in search of taking care of low-back pain (SC-LBP) (Garg et al. 2014). The investigation for the efficiency of prescribed teaching of the revised NIOSH lifting equation for academia student agency might use it in their potential work (Cole and Mc Glothlin 2009).

With the result of Psychonomics and biomedical experiments, the NIOSH lifting equation recommends a weight limit (RWL). The lifting index (LI), the shape of the spatial property multiplier factor, and the solidity force principle were investigated (Elfeituri and Taboun 2002). The floor-to-waist lifting score of the Isernhagen Work Systems Functional Capacity Evaluation (IWS FCE) and the recommended weight limit (RWL) of the NIOSH lifting equation are used globally today (Kuijer et al. 2006).

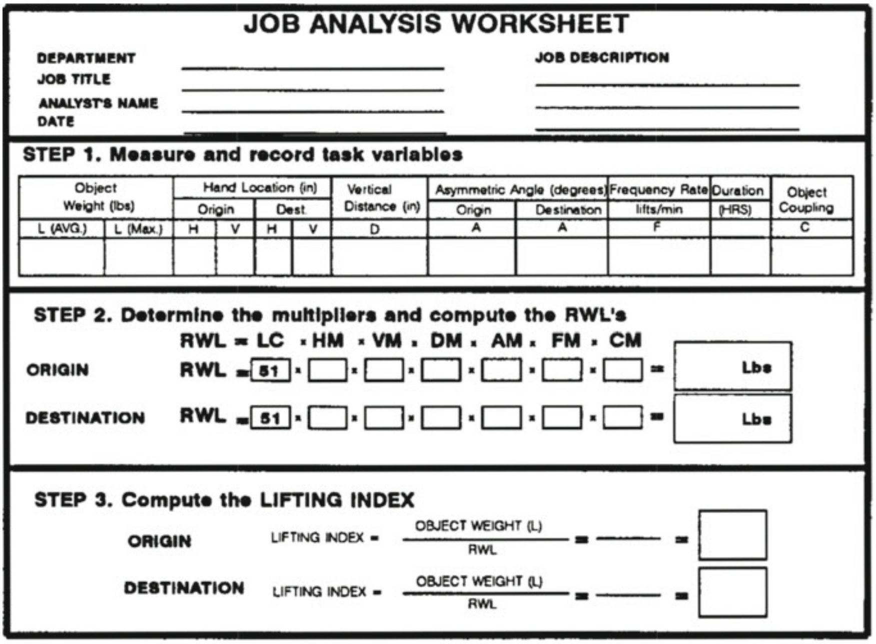
2 Methodology

In this paper, 153 farmers were considered for their "Mental disorders" evaluation while working in adverse weather condition in the agricultural fields of Chhattisgarh and Odisha (India). A designed Perceived Stress Questionnaire was distributed among 153 farmers to obtain their mental stress related data as shown in Appendix. Later, the discomfort-questionnaires tool obtainable in the "Ergo-plus" software in which The NIOSH Lifting Equation is a means by use of work-related physical condition and safety measures professional to measure the physical substance handling risks related with lifting and lower task in the working places.

These equations consider for job tasks variable to verify safe lifting practice and procedure. The major conception of the NIOSH lifting equations is the suggested Weight Limit (RWL), which define the most suitable weight (load) that almost all fit workers could move up over the manner of an 8 h-shift lacking raising the risk of musculoskeletal disorder (MSD) to the lower back. In accumulation, a Lifting Index (LI) is calculating to give a relative assess of the level of physical stress and MSD risks related with the physical lifting task calculate (www.ergo-plus.com). Then, an ANFIS model was formed by means of "MATLAB 2013" version to calculate the mental stress of framers working in their agriculture sector.

In this study, 153 farmers were considered for their "Mental disorders" evaluation while working in adverse weather conditions in the agricultural fields of Chhattisgarh and Odisha (India).

To attain the study's objectives, the authors used a descriptive research technique with primary data gathered from the respondents through observations and interviews by the study's experts. The job analysis worksheet shown in Fig. 1 was used to represent the sequence of steps, workflows, working processes, and systems. It served as a tool for examining the process in detail to identify areas of possible improvement. Time and motion study was used to measure the time necessary for a job or task to be completed using the best method. This tool helped the team evaluate if there is an improvement with the pre-assessment and post-assessment of the study. The NIOSH lifting equations used a worksheet to collect data from the respondents. This equation is considered for job tasks variables to verify safe lifting practice and procedure. The primary conception of the NIOSH lifting equation is the Recommended Weight Limit (RWL), which define the most suitable weight (load) that almost all fit workers could move up over the manner of an eight hour-shift lacking raising the risk of musculoskeletal disorder (MSD) to the lower back. In accumulation, a Lifting Index



JOB ANALYSIS WORKSHEET

DEPARTMENT
JOB TITLE
ANALYST'S NAME
DATE
JOB DESCRIPTION

STEP 1. Measure and record task variables

Object Weight (lbs)		Hand Location (in)				Vertical Distance (in)	Asymmetric Angle (degrees)		Frequency Rate	Duration	Object Coupling
		Origin		Dest.			Origin	Destination	lifts/min	(HRS)	
L (AVG.)	L (Max.)	H	V	H	V	D	A	A	F		C

STEP 2. Determine the multipliers and compute the RWL's

RWL = LC · HM · VM · DM · AM · FM · CM

ORIGIN RWL = 51 · ☐ · ☐ · ☐ · ☐ · ☐ · ☐ = ☐ Lbs

DESTINATION RWL = 51 · ☐ · ☐ · ☐ · ☐ · ☐ · ☐ = ☐ Lbs

STEP 3. Compute the LIFTING INDEX

ORIGIN LIFTING INDEX = OBJECT WEIGHT (L) / RWL = ——— = ☐

DESTINATION LIFTING INDEX = OBJECT WEIGHT (L) / RWL = ——— = ☐

Fig. 1 Job analysis worksheet. *Source* Cole and Glothlin (2009)

(LI) is calculated to give a relative assessment of the level of physical stress and MSD risks related to the physical lifting task estimated.

Therefore, an attempt has been made in this study to explore the ergonomic risks and discomfort levels of farmers in the agricultural sectors. Later, the discomfort-questionnaire tool, available in the "Ergo-plus" software, is applied. This software contains the NIOSH lifting equation, a means to measure the physical substance handling risks related to lifting and lower tasks in the working places by use of work-related physical condition and safety measures professional. A Perceived Stress Questionnaire (PSQ) was designed and distributed among 153 farmers to obtain the mental stress-related data as shown in Appendix. Then, an ANFIS model was formed using the "MATLAB 2013" version to calculate the mental stress of framers working in their agriculture sector.

2.1 NIOSH Lifting Equation

The NIOSH Lifting Equation always uses a load constant (LC) of 51 pounds (23 kgs), representing the most suggested load weight to be lifted under an ideal situation. From that initial point, the equation uses several task variables expressed as coefficients or multipliers (in the equation, M = multiplier) that supply to decrease the load constant and calculate the Recommended Weight Limit (RWL) for that lifting task. Next, the NIOSH lifting equation algorithm is presented in six steps.

Step 1—Calculate Recommended Weight Limit (RWL) and Lifting Index (LI): The RWL is obtained by applying Eq. (1), whereas the LI is obtained using Eq. (2).

$$RWL = LC \times HM \times VM \times DM \times AM \times FM \times CM \tag{1}$$

Here

LC Load Constant
HM Horizontal Multiplier
VM Vertical Multiplier
DM Distance Multiplier
AM Asymmetric Multiplier
FM Frequency Multiplier
CM Coupling Multiplier

$$LI = \frac{\text{RWL}}{\text{Actual Cargo Weight}} \tag{2}$$

Step 2—Additional output: In this step, the Frequency Independent Lifting Index (FILI) is calculated using Eq. (3).

$$FILI = \frac{ActualCargoWeight}{FrequencyIndependentRecomendedWeightLimit} \tag{3}$$

Step 3—Calculate and Record job.

Step 4—Feed data, design lifting task: The RWL and LI can be used to guide lifting task design.

Step 5—Coupling: Conclude the categorization of the coupling class among the labor hand and the objects as Good, Fair, or else Poor (1, 2, or 3).

Step 6—Duration**:** Resolving the lifting interval classified it into one of three categories: 1 used for short- interval, 2 used for moderate- interval, and 3 used for long- interval.

The RWL, LI, Frequency Independent Recommended Weight Limit (FIRWL), and Frequency Independent Lifting Index Frequency (FILI) were calculated using the NIOSH Lifting Equation. Each body segment of the female farmer was evaluated for ergonomic risk factors in the agriculture field doing her task through which we do posture analysis after lifting. After feeding all data of female farmers while doing her job, the NIOSH lifting equation calculated Force rating, Posture rating, Repetition rating, Exertion Index, Segment score.

2.2 Perceived Stress Questionnaire (PSQ)

A more accurate measure of personal stress can be identified with various instruments to measure individual stress levels. The first of these is called the Perceived Stress Questionnaire (PSQ). The Perceived Stress Scale is a classic stress assessment tool. Although the PSQ was initially developed in 1983 by the Employee Assistance Program (EAP), it is still a popular choice to help understand how different situations affect human emotions and perceived stress. Levenstein et al. have already used this instrument for clinical study purposes. In this instrument, participants are asked to indicate how often they have felt or thought in a certain way. Although some of the questions are similar, there are differences between them, and participants should treat each question as a separate question. The best approach is to react quickly. For each question, participants must choose from the subsequent alternatives: 0 = Never, 1 = Almost, 2 = Sometimes, 3 = Often and 4 = Usually. First, the reverse scores for questions 4, 5, 7, and 8 are calculated. Then, for the questions 4, 5, 7 and 8 scores are changed (i.e., 0 = 4, 1 = 3, 2 = 2, 3 = 1, 4 = 0). Then, the scores for each question are added to get a total. Individual farmers' scores calculated for 0 to 40 with higher scores show higher perceived stress. The score value ranging from 0 to 13 is low stress, and scores ranging from 14 to 26 are considered moderate stress. The scores 27–40 are considered as high perceived stress. Then, the percentage is calculated by dividing the scores by the number of farmers. The PSQ is shown in Appendix A.

2.3 ANFIS Model

The ANFIS is a fuzzy inference system implemented in the framework of an adaptive network. Soft computing approaches, including artificial neural networks and fuzzy inference systems, have been used widely to model experts' behavior. The proposed ANFIS can create maps based on human knowledge and hybrid learning algorithms using input and output data values. In modeling and simulation, the ANFIS strategy is used to model nonlinear functions, control one of the most critical parameters of the induction machine, and predict a chaotic time series, resulting in more effective and faster transient or response times.

3 Results and Discussion

3.1 Results of the NIOSH Lifting Equation

Here, female farmers performed their activities in warm climatic conditions, as shown in Fig. 2. By NIOSH lifting equation for farmers working in the field, we identified the Horizontal Location, Vertical location, Angle of Asymmetry, and Coupling. These

Fig. 2 Female farmer working in agricultures field doing her task

results are shown in Figs. 3 and 4. Figure 4 also shows the results of Recommended Weight Limit (RWL), Lifting Index (LI), Frequency Independent Recommended Weight Limit (FIRWL), and Frequency Independent Lifting Index Frequency (FILI). Figure 5 shows the evaluation of each body segment for ergonomic risk factors.

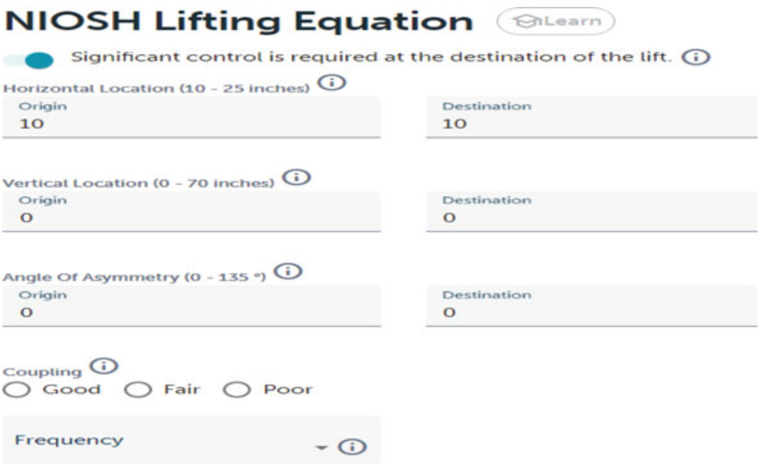


Fig. 3 NIOSH lifting equation enter all data

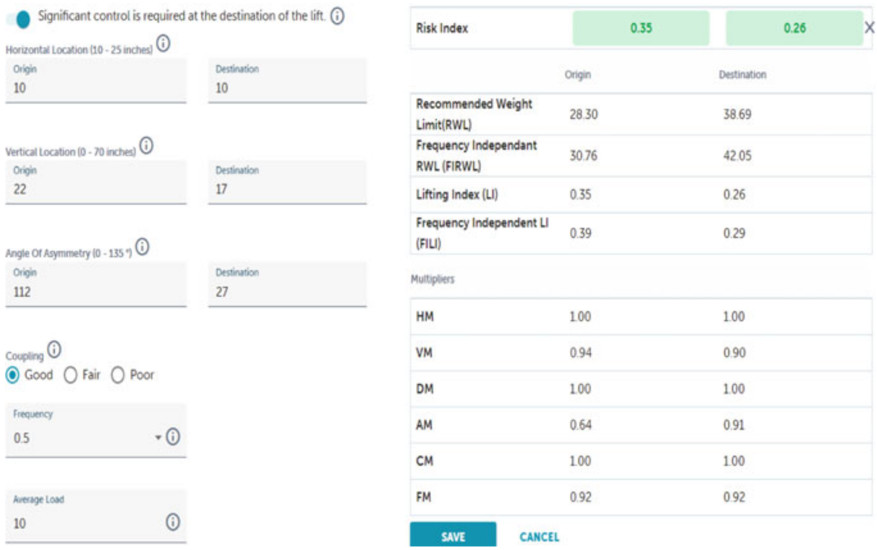


Fig. 4 Calculated RWL, LI, FIRWL, and FILI

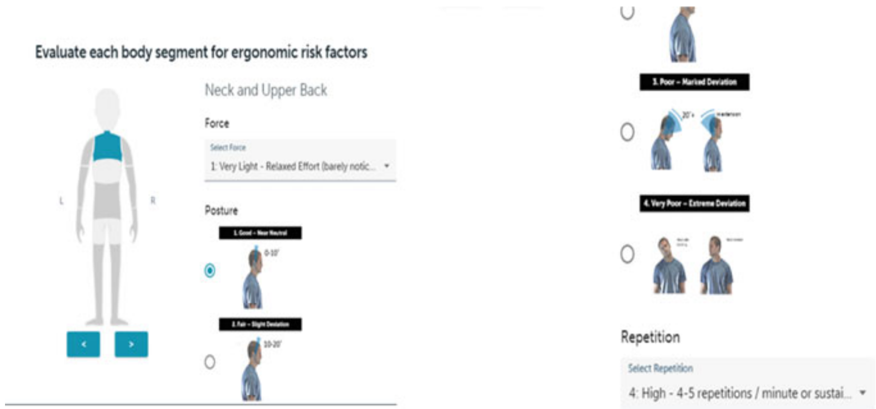


Fig. 5 Evaluated each body segment for ergonomic risk factor

Similarly, Fig. 6 shows the Force rating, Posture rating, Repetition rating, Exertion Index, and Segment scores. Finally, as shown in Fig. 7, the result of the NIOSH lifting equation indicated discomfort in the neck and upper back. Also, difficult jobs must be identified, and the task requires a medical referral.

To obtain the physiological stress, the PSQ is implemented with the 153 framers dedicated to lifting work, as mentioned below.

	Force	Rating	Posture	Rating	Repetition	Rating	Exertion Index	Segment Score
Neck and Upper Back	1: Very Light	1	3: Poor	2	4: High	2	4	2
Right Upper Arm and Shoulder	1: Very Light	1	1: Good	1	1: Very Low	0.5	0.5	0
Left Upper Arm and Shoulder	1: Very Light	1	1: Good	1	1: Very Low	0.5	0.5	0
Right Forearm and Elbow	1: Very Light	1	1: Good	1	1: Very Low	0.5	0.5	0
Left Forearm and Elbow	1: Very Light	1	1: Good	1	1: Very Low	0.5	0.5	0
Right Wrist and Fingers	1: Very Light	1	1: Good	1	1: Very Low	0.5	0.5	0
Left Wrist and Fingers	1: Very Light	1	1: Good	1	1: Very Low	0.5	0.5	0
Trunk and Lower Back	1: Very Light	1	1: Good	1	1: Very Low	0.5	0.5	0
Legs	1: Very Light	1	1: Good	1	1: Very Low	0.5	0.5	0

Fig. 6 Calculated force rating, posture rating, repetition rating, exertion Index, segment score

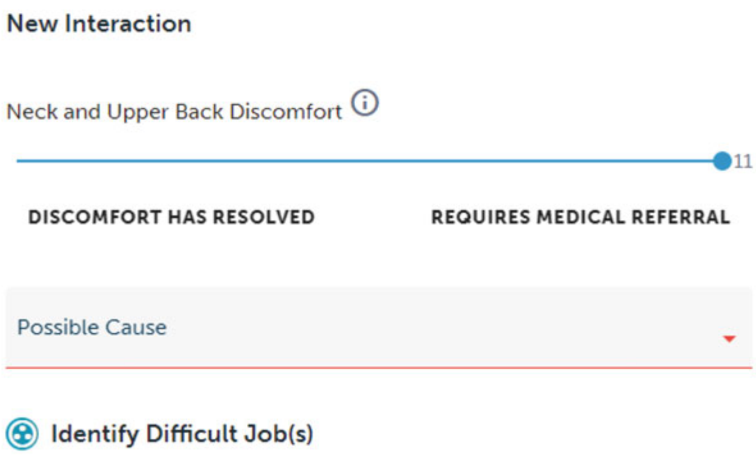


Fig. 7 Final result by NIOSH lifting equation

3.2 Perceived Stress Questionnaire (PSQ)

Based on the responses obtained from 153 framers from the questionnaire (Table 1), it was found that maximum farmers reported a feeling of mental tried (62.74%), feeling of stress (60.78%), feeling of Irritate (59.47%), feeling of depressed (58.16%), feeling of alone (57.51%), feeling of exhausted (56.86%), feeling of doing a thing because I have to, not because I want to (56.20%), feeling of light-hearted (56.86%), feeling under anxiety from deadlines (54.90%), feeling of can't reach my goals (56.86%), feeling down (54.90%), feeling the strain from other people (53.59%), feeling that

Table 1 Perceived stress questionnaire responses by farmers

S. No.	Parameters	Responses
1	I feel strain from other people	82 (53.59%)
2	I feel that too many require are being made on it	79 (51.63%)
3	I feel stressed	93 (60.78%)
4	I have many uncertainties	72 (47.05%)
5	I feel I do things I really like	56 (36.60%)
6	I find our self in state of in consistency	74 (48.36%)
7	I full of power	52 (33.98%)
8	I feel exhausted	87 (56.86%)
9	I feel criticize or judge	78 (50.98%)
10	I have numerous things to do	65 (42.48%)
11	I feel down	84 (54.90%)
12	I feel irritated	91 (59.47%)
13	I feel overloaded down with responsibility	64 (41.83%)
14	My problem looks to be piling up	75 (49.01%)
15	I feel alone or lonely	88 (57.51%)
16	I feel I am in rush	42 (27.45%)
17	I enjoy myself	32 (20.91%)
18	I have too numerous decisions to build	64 (41.83%)
20	I feel depressed	89 (58.16%)
21	I feel secure and confined	35 (22.87%)
22	I am fearful for the further	74 (48.36%)
23	I feel I am doing a thing because I have to, not because I want to	86 (56.20%)
24	I have trouble in relaxing	77 (50.32%)
25	I feel under anxiety from deadlines	84 (54.90%)
26	I feel mentally tired	96 (62.74%)
27	I am feeling short-tempered	62 (40.52%)
28	I fear I can't reach my goals	87 (56.86%)
29	I have sufficient time for myself	33 (21.56%)
30	I am light-hearted	87 (56.86%)

too many requirements are being made on it (51.63%), feeling criticize or judge (50.98%), feeling in trouble in relaxing (50.32%), and so on.

Table 2 Correlations of mental stress of framers

Parameters	Correlation of mental stress
Blood Pressure	0.357
Temperature	0.154
Oxygen saturation	0.042

Correlations are considerable at $p < 0.05$ (2-tailed)

3.3 Results of the ANFIS Model

From the correlation coefficient between the Mental Stress, physiological workload, and the associated parameter for farmers, such as High Blood Pressure (BP), Temperature, and Oxygen saturation, it was created that the "Mental Stress" was substantial at $p = 0.05$, with "High BP" (Table 2).

Equation (4) illustrates that the best fit linear regression equations were obtained to predict farmers' mental stress by considering the "Mental Stress" as dependent and three associated parameters, such as blood pressure, temperature, and oxygen saturation as independent variables.

$$MentalStress = -3.63 + 0.0381C_1 + 0.0093C_2 - 0.00448C_3 \tag{4}$$

Here, C_1 = Blood Pressure, C_2 = Temperature, C3 = Oxygen saturation.

For ANFIS membership functions = 400 epochs, mental stress calculation, errors, and ANFIS in sequence for the ANFIS models were as illustrated in Fig. 8. It was experimental that a better prediction with minimum errors for "Mental stress" of farmers was achieved by ANFIS.

4 Conclusions

The objective of this study was to identify the occupational hazards, mental stress, and physical workload among Indian farmers. Farmer's stress may also lead to negative consequences, such as mental workload, inability to concentrate, and physical health issues. More automation technology, more use of manures and fertilizer, decreased price for agricultural products, and new complicated legislation has made farmers' lives more difficult. It indicates that occupation farming leads to stress due to financial, weather, work overload, social interaction, and farm hassles. This finding described the burden of depressions that may lead to suicidal tendencies among India's farmers. New and advanced technology must be implemented to work safely, and sufficient finical support must be provided to them from the government to face no complications while working.

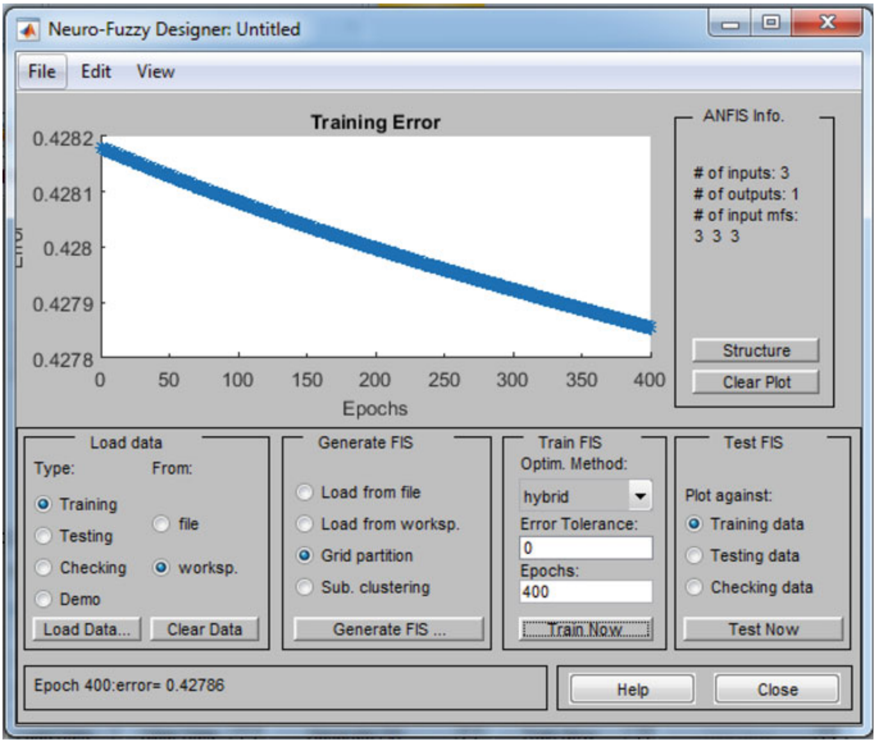


Fig. 8 Predictions by ANFIS model membership functions with 400 epochs were selected for farmers' mental stress

Some instruments must be developed to reduce the mental load of framers in the future. Further extensive research and more analysis are required to create a feasible model that can reduce the farmers' mental workload.

Appendix A

See Table 3.

Table 3 Perceived stress questionnaire (PSQ)

Sl. No	Parameters	Rating-scale (Please put √ Mark whichever is applicable)			
		1 (Almost)	2 (Sometimes)	3 (Often)	4 (Usually)
1	I feel strain from other people				
2	I feel that too many require are being made on it				
3	I feel stressed				
4	I have many uncertainties				
5	I feel I do things I really like				
6	I find our self in state of in consistency				
7	I full of power				
8	I feel exhausted				
9	I feel criticize or judge				
10	I have numerous things to do				
11	I feel down				
12	I feel irritated				
13	I feel overloaded down with responsibility				
14	My problem looks to be piling up				
15	I feel alone or lonely				
16	I feel I am in rush				
17	I enjoy myself				
18	I have too numerous decisions to build				
20	I feel depressed				
21	I feel secure and confined				
22	I am fearful for the further				
23	I feel I am doing thing because I have to, not because I want to				
24	I have trouble in relaxing				

(continued)

Table 3 (continued)

Sl. No	Parameters	Rating-scale (Please put √ Mark whichever is applicable)			
		1 (Almost)	2 (Sometimes)	3 (Often)	4 (Usually)
25	I feel under anxiety from deadlines				
26	I feel mentally tired				
27	I am feeling short-tempered				
28	I fear I can't reach my goals				
29	I have sufficient time for myself				
30	I am light-hearted				

Sources Shahid et al (2011)

References

Akay, D., Chen, X., Barnes, C., Henson, B.: ANFIS modeling for predicting affective responses to tactile textures. Hum. Factors Ergon. Manuf. Service Ind. **22**(3), 269–281 (2012)

Cole, S.S., Mc Glothlin, J.: Ergonomics case study: revised NIOSH lifting equation instruction issues for students. J. Occup. Environ. Hyg. **6**(11), D73–D81 (2009)

Elfeituri, F.E., Taboun, S.M.: An evaluation of the NIOSH lifting equation: a psychophysical and biomechanical investigation. Int. J. Occup. Saf. Ergon. **8**(2), 243–258 (2002)

Flocerfida, A., Clariz, A.K., Ann, T.R.: Niosh lifting equation for assessing manual material handling technique in a warehouse company. Int. J. Eng. Manage. **3**(2), 40 (2019)

Fragiadakis, N.G., Tsoukalas, V.D., Papazoglou, V.J.: An adaptive neuro-fuzzy inference system (anfis) model for assessing occupational risk in the shipbuilding industry. Saf. Sci. **63**, 226–235 (2014)

Garg, A., Kapellusch, J.M., Hegmann, K.T., Moore, J.S., Boda, S., Bhoyar, P., Malloy, E.J.: The NIOSH lifting equation and low-back pain, Part 2: association with seeking care in the backworks prospective cohort study. Hum. Factors **56**(1), 44–57 (2014)

Hagen, B.N., Albright, A., Sargeant, J., Winder, C.B., Harper, S.L., O'Sullivan, T.L., Jones-Bitton, A.: Research trends in farmers' mental health: a scoping review of mental health outcomes and interventions among farming populations worldwide. PLoS ONE **14**(12), e0225661 (2019)

Hovey, J.D., Seligman, L.D.: The mental health of agricultural workers. In: Agricultural Medicine, pp. 282–299. Springer, New York, NY (2006)

Kallioniemi, M.K., Simola, A., Kaseva, J., Kymäläinen, H.R.: Stress and burnout among Finnish dairy farmers. J. Agromedicine **21**(3), 259–268 (2016)

KlomjitP, I.K.: An evaluation of manual lifting tasks in the factories by NIOSH lifting equation. KMUTT Res. Dev. J. **28**(3), 331–344 (2005)

Koochaksaraei, A.A., Izadfar, H.: High-efficiency MPPT controller using ANFIS-reference model for solar systems. In: 2019 5th Conference on Knowledge Based Engineering and Innovation (KBEI), pp. 770–775. IEEE (2019)

Kuijer, W., Dijkstra, P.U., Brouwer, S., Reneman, M.F., Groothoff, J.W., Geertzen, J.H.: Safe lifting in patients with chronic low back pain: comparing FCE lifting task and NIOSH lifting guideline. J. Occup. Rehabil. **16**(4), 579–589 (2006)

Padhy, C., Raju, P.S.: Stress among farmers and its alleviation. Int. J. Manage. Technol. Eng. **8**(12), 2882–2887 (2018)

Shahid, A., Wilkinson, K., Marcu, S., Shapiro, C.M.: Perceived stress questionnaire (PSQ). In: STOP, THAT and One Hundred Other Sleep Scales, pp. 273–274. Springer, New York, NY (2011)

The Importance of Demand Management in the Just-in-Time Strategy for Mexican Maquiladora Companies

José Roberto Díaz-Reza, Adrián Salvador Morales-García, Manuel Arnoldo Rodríguez-Medina, Humberto García Castellanos, and Jorge Luis García-Alcaraz

Abstract Lean manufacturing is an industrial production philosophy that integrates several tools to eliminate waste or anything that does not add value to the product or service but does add cost and labor. This chapter presents a structural equation model that integrates three latent independent variables (Demand management, Kanban, and One-piece flow) that are related to one dependent variable (Just-in-time) to measure the effect of demand management and material flow tools on the Just-in-time. Those four variables were related through six hypotheses and were validated with information obtained from 231 responses to a questionnaire applied in the maquiladora industry of Ciudad Juarez in Mexico. The WarpPLS v.7.0 software that integrates partial least squares algorithms was used to test all hypotheses. Findings indicate the importance of demand management to achieve a just-in-time strategy in Mexican maquiladora companies. Likewise, these results show the importance of Kanban and One-piece flow to achieve a just-in-time strategy.

Keywords Mexican maquiladoras · Just in time · Demand management · Structural equation model

J. R. Díaz-Reza · A. S. Morales-García
Department of Electrical Engineering and Computer Sciences, Autonomous University of Ciudad Juárez, 32310 Ciudad Juárez, Mexico
e-mail: inv.pos07@uacj.mx

A. S. Morales-García
e-mail: al216669@alumnos.uacj.mx

H. G. Castellanos
Division of Graduate Studies and Research, Tecnológico Nacional de México/IT Ciudad Juárez, 32500 Ciudad Juárez, Mexico
e-mail: humber.gc@cdjuarez.tecnm.mx

M. A. Rodríguez-Medina · J. L. García-Alcaraz (✉)
Department of Industrial Engineering and Manufacturing, Autonomous University of Ciudad Juárez, 32310 Ciudad Juárez, Mexico
e-mail: jorge.garcia@uacj.mx

M. A. Rodríguez-Medina
e-mail: manuel.rodriguez@uacj.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_6

1 Introduction

Globalization and rapidly changing business practices put organizations under enormous pressure to constantly improve the product or process quality, delivery rate, throughput, responsiveness, and reduce costs (Mohanty and Gahan 2012). Gaining a competitive advantage in the global marketplace is a complicated task for manufacturing organizations (Taiwo et al. 2011). One such business sector is the maquiladora industry in Ciudad Juarez, Mexico. This industry has been the main driver of cross-border trade along the U.S.-Mexico border for decades; even as recessions and low-wage competition have changed the industry's behavior in recent years, maquiladoras continue to shape a regional business (Cañas et al. 2013). In 1989, the U.S.A, Mexico, and Canada formed the North American Free Trade Agreement (NAFTA) to stimulate economic growth by reducing trade barriers (Daily et al. 2012), which were signed in 1992, formalizing their economic integration with their trading partners and that as trade and investment opportunities under NAFTA increased, the benefits of the maquilas manifested themselves in continued growth in product exports and employment (Hadjimarcou et al. 2013). The effects of NAFTA have included economic, labor, and environmental impacts. The mission of the maquiladoras was unique and consisted of lowering labor costs by importing and processing raw materials for export as finished products back to the country of origin, usually the United States. (Dorocki and Brzegowy 2014).

One of the most important cities in this border strip is Ciudad Juarez, Mexico. In May 2021, 328 Manufacturing, Maquiladora, and Export Service Industries (IMMEX) had a register, equivalent to 6.26% of the national total, behind only Tijuana with 603. These companies exported more than 1630 million dollars in January and February 2021. Hence the importance for these companies to remain at the forefront within their production processes to remain in the market and, above all, continue to provide jobs for local people.

That is why, for these companies to remain in the market, they opt for essential alternatives such as Lean Manufacturing (LM) to face the changing market (Abdulmalek and Rajgopal 2007). LM is an approach that stands out in the market to increase productivity with quality and financial profitability (Tortorella et al. 2016) and reduce waste (Womack et al. 1991). LM is an integrated system with multidimensional tools such as just in time (JIT), total quality management, customer relationship, supplier relationship management, pull and Kanban, one-piece flow, demand management, among others (Eswaramoorthi et al. 2011). Socconini (2019) defines LM as a continuous and systematic process of identifying and eliminating waste or anything that does not add value to the process but does add cost and labor. These wastes are generated by movements, defects, overproduction, waiting times, inventories, over-processing, and transports.

Balancing demand and supply is essential for any company specializing in operations. Drastic changes in demand volume, product mix, or product life cycle challenge decision-makers at all levels of the organization (Coker and Helo 2016). One of the tools that help control production is Kanban since it is a management system that precisely produces the amount of work that the system can take on and is a JIT system, which avoids unnecessary surplus stock (Bermejo 2011). In a JIT manufacturing line, a Kanban is associated with each production lot and ultimately with the finished lot (Kiran 2019).

In that sense, the objective of this work is to measure the effect of demand management on Kanban, one-piece Flow, and JIT through structural equation modeling within the maquiladora industry of Ciudad Juarez, Mexico.

The rest of the article is distributed as follows. Section 2 contains a literature review highlighting each of the tools used in structural equation modeling. Section 3 details the methodology followed in carrying out this research. Section 4 presents the results obtained in each of the steps developed, and Sect. 5 presents the research's conclusions and the industrial implications.

2 Literature Review and Hypothesis

The following is a review of the literature that addresses each of the tools analyzed in this article and justifies the hypotheses put forward.

2.1 Demand Management

Satisfying customers quickly is one of the company's main objectives, which is why demand management is of utmost importance in a supply chain (SC) (González et al. 2018). Demand management creates a coordinated flow of demand throughout the CS and its markets (Mentzer and Moon 2004). The demand management process is concerned with balancing customers' needs with the capabilities of the CS (Croxton et al. 2002). Customer demand is influenced by many factors and can be predicted with some probability. However, companies must first identify the factors that influence future demand and then establish the relationship between future demand and those factors (Chopra and Peter 2008).

Thus, demand forecasting plays an essential role in basic operations management, as it is an input to planning activities (Nenni et al. 2013). These forecasts are essential for SC's decision-making and planning processes as better forecasting can contribute to better price structuring and inventory management (Yue and Liu 2006). The effects of poor forecasting are; stockouts or high inventory levels, obsolescence, low service levels, rush orders, inefficient use of resources, and the spread of the bullwhip effect through the upstream SC (Nenni et al. 2013). Crum and Palmatier (2003) mention that the elements for demand management are: (1) plan, (2) communicate, (3) influence, and (4) manage and prioritize. They also mention that when you have problems with forecasting, one or more elements of demand management are not in place or are not operating correctly.

Over the years, attempts have been made to manage demand differently and in different manufacturing sectors. For example, Zotteri and Verganti (2001) discuss two approaches to managing demand uncertainty in complex environments: centralized and decentralized order planning. Darlington and Rahimifard (2006) present a framework for responsive demand management for reducing waste overproduction in convenience food manufacturing. Levis and Papageorgiou (2009) present a systematic mathematical programming approach for active demand management in processing industries to determine optimal pricing policies, production levels of substitute products considering, among other things, customer demand elasticity.

Hung Lau (2012) examines the role of demand management in balancing distribution efficiency and responsiveness to customer needs downstream of a CS. Antoniolli (2016) proposes an information technology framework for demand management within a pharmaceutical industry supply chain dyad Raman et al. (2018) analyze the effect of supplier qualification, Internet of Things, analytics, data science, and demand management on big data through structural equation modeling. The results show that these affect SC in terms of operational excellence, cost savings, customer satisfaction, visibility, and the communication gap between demand and SC management. Can and Gürsel (2020) designed the SC system considering two demand management strategies simultaneously for the same company; engineer-to-order and make-to-order.

2.2 Kanban

Kanban is a visual method to control production, formed by a system of signals along the entire production chain that controls the replenishment process and starts with the knowledge of what the customer demands until the final product is obtained (Lendínez 2019). These signals regularly come in the form of cards that provides authorization to order or produce parts to replenish those consumed in the supermarket, in the form of "take one, make one" (Powell 2018). They signal to a subsequent task that a task has been completed and that replenishment of assembly components or material is required to continue working (Leopold and Kaltenecker 2015).

Much information on the use and implementation of Kanban for the optimization of manufacturing processes can be found in the literature. For example, Rahman et al. (2013) report the use of the Kanban system in the manufacturing industry in Malaysia to determine the effectiveness of Kanban in a multinational organization. Papalexi et al. (2016) report a case study in the pharmaceutical supply chain where they conclude that the adoption of Kanban provides a strategic benefit and improves the quality of services, and proposes an operational change.

Mukhopadhyay* and Shanker (2005) report the implementation of the Kanban system in a continuous production line of a tire manufacturing plant. Naufal et al. (2012) report a case study in a manufacturing company in Malaysia to highlight the flow of activities to establish a Kanban system to implement a Pull system. Adnan et al. (2013) report the implementation of Kanban in a company in automotive in Malaysia to improve the manufacturing system and improve JIT practice.

Thun et al. (2010) report a structural equation model to analyze the enablers of Kanban implementation and highlight the importance of worker competencies and training, short setup times, readiness, and quality. It is also possible to implement Kanban in non-manufacturing environments; Senapathi and Drury-Grogan (2021) report the implementation of Kanban in a government institution. Kanban can be implemented in parallel with other tools and methodologies; for example, Leonardo et al. (2017) report a hybrid study where Kanban is combined with CONWIP where cycle time and inventory turnover were reduced. Prakash and Chin (2014) report a 23% reduction in inventory WIP through the parallel use of Kanban/CONWIP.

Uncertainties caused by fluctuations in demand and customer requirements have led many established companies to improve their manufacturing process by adopting the Kanban system (Jadhav Bhushan et al. 2016). The Kanban system reduces production cost, makes the unit flexible to any demand, accelerates responsiveness, and helps promote the organization's management level (Wakode et al. 2015). Therefore, Kanban is a stock control system that triggers product production signals based on customer needs and demand (Jadhav Bhushan et al. 2016). From the operational point of view, the most critical issue in applying the JIT technique is to design both the location and the number of circulating kanbans, especially when the manufacturing system experiences random interferences, such as unexpected machine failures and stochastic demands (Yan 1995). In this sense, the following hypothesis is proposed:

H_1: Demand Management has a direct and positive effect on Kanban.

2.3 One Piece Flow

One-piece flow is an effective LM tool. Single-piece flow refers to the concept of moving one part at a time between operations within a work cell (Li and Rong 2009). In one-piece flow, tasks are reduced to their simplest components, machine or operator error opportunities are reduced, and, if done correctly, there is a seamless flow of activities between shop floor operators and the manufacturing product (Haider et al. 2005). According to Marton and Paulová (2013), to implement a single-part flow system requires four steps:

1. Decide which products or product families will be integrated into cells and determine the type of cell: product-focused or model-mix.
2. Determine the work items and time required to manufacture a part and list each step and its associated time.
3. Create a lean layout.
4. Balance the cell and create a standardized job for each operator within the cell.

Implementing a one-piece flow system helps companies achieve certain benefits. For example, processes are connected to a single production cell, waits and delays can be eliminated, and difficulties for the operator to handle multiple tasks due to transportation and inventory issues can be eliminated (Soliman 2020). Also, production times, production, and transportation costs are reduced, and resource savings, productivity is increased, and waste is reduced (Ioana et al. 2020), less in-process inventory, a smaller production area is occupied, and problems can be identified more easily (Hu et al. 2013).

Demand management works best when there is a uniform production flow within the systems (Breyfogle III 2007). Some primary conditions to achieve the one-piece flow process, within which it is mentioned that it is essential that the processes must be able to be scaled to the takt time or rate of customer demand (Marton and Paulová 2013). In the one-piece flow model, customer demand triggers production, i.e., it is produced on the condition that there are sales or customer demands, and it is purchased only when there is a need for production (Wu and Huang 2004). Based on the above, the following hypothesis can be put forward:

H_2: Demand Management has a direct and positive effect on One Piece Flow.

A Kanban approach provides a visual means to manage the flow within a process (Turner et al. 2012). In a production system working under the One Piece Flow scheme, production instruction is given according to sales information; and during the production process, components flow in a "Pull" manner; that is, each work procedure pulls from the previous one; where the stock of sub-production product is controlled by Kanban (Wu and Huang 2004).

Kanban is a material flow control mechanism to control the correct quantity and time to make only the quantity of products that are strictly necessary (Tardif and Maaseidvaag 2001), and the Kanban card system is used to control the production flow and inventory (Sendil Kumar and Panneerselvam 2007). An exemplary implementation of Kanban methodology is an effective tool to ensure continuous Flow (Issar and Navon 2016). In that sense, the following hypothesis can be put forward:

H_3: Kanban has a direct and positive effect on One Piece Flow.

2.4 *Just in Time*

JIT is often described as a process for achieving continuous improvement through the systematic elimination of waste and variation that encompasses production control techniques and total quality control programs, facility and line design, training, and employee participation attitude (Kiran 2019). The principle of the JIT manufacturing philosophy lies in producing the correct quantity at the right time and the right quality level (Chan 2001). IT manufacturing has been chained into a management philosophy that leverages a significant amount of knowledge and includes a complete set of manufacturing principles and techniques (Prawira et al. 2017).

Under JIT, all organizations should be managed with a concern for continuous improvement in which non-value-added activities are identified and eliminated to reduce costs and improve quality and delivery (Chen and Tan 2011). JIT manufacturing enables the organization to strengthen its competitiveness in the market by reducing waste and improving product quality and production efficiency.

Having the right product on the shelves will increase sales and customer loyalty (Zinn and Liu 2001). Demand management allows managers to sell the right product or service to the right customer, at the right time and for the right price with the primary objective of maximizing profit margins (Davizón et al. 2014). That is why better forecasting can reduce inventories of raw materials and finished goods and, in addition, smoother operational execution will reduce logistics costs and improve asset utilization (Croxton et al. 2002). Thus, the successful implementation of the JIT production system is essential for modern manufacturing companies. If they can maintain inventories constantly, they can maximize their flexibility, better manage product quality, and improve their competitive position. However, it requires particular prerequisites such as demand management (McMullen 2001). Thus, the following hypothesis can be put forward:

H_4: Demand Management has a direct and positive effect on Just in time.

Kanban is an effective tool to improve productivity and optimize the process; it will reduce downtime, make the unit flexible for any proposal, reduce waste, provide continuous deliveries to the customer, and increase plant efficiency and productivity (Wakode et al. 2015). The Kanban system's implementation helps reduce lead time, minimize inventory in a plant, and optimizes the storage area (Adnan et al. 2013; Naufal et al. 2012) and will lead to just-in-time manufacturing.

In a JIT system, production is triggered by a Kanban signal, which usually comes from the customer order. The signal flows backward from the final assembly station to upstream production sites and suppliers (Hou and Hu 2011). In order to reduce lead times, reduce inventories and increase quality, it is essential to optimize the conditions of the production system and determine the Kanban size since a large size implies a significant inventory level but a short lead time that benefits from fewer model changes on the machines (Chan 2001). The Kanban system enables a company to use JIT production and ordering systems, minimizing inventories while still meeting customer demands with better service and quality (Mukhopadhyay* and Shanker 2005). In this sense, the following hypothesis can be put forward:

H_5: Kanban has a direct and positive effect on Just in time.

Flow manufacturing means producing a single piece of product simultaneously, but with multiple handling following the process sequence (Phogat 2013). One-piece flow is a strategy to reduce lead times in cellular manufacturing systems (Miltenburg 2001). Parts in a batch that move according to the one-piece flow principle between consecutive machines do not wait for the rest of the batch to be completed, which reduces the lead time and lead time of the entire batch (Satoglu et al. 2010). Single-piece flow methods will meet customer requirements based on JIT and minimize waste on the production line (Liker 2004). In that sense, the following hypothesis is put forward:

H_6: One-Piece Flow has a direct and positive effect on Just in time.

Figure 1 shows graphically each of the hypotheses justified in the previous paragraphs.

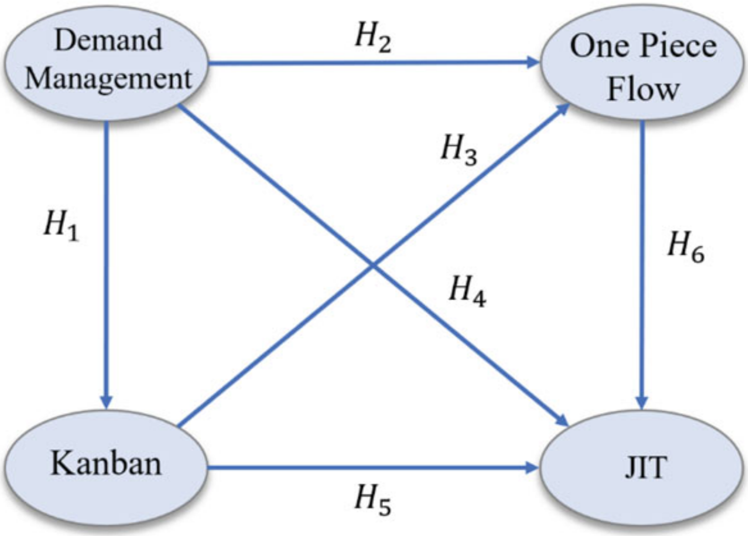


Fig. 1 Proposed model

3 Methodology

3.1 Questionnaire Design

A questionnaire was designed through a literature review in databases such as Springer, Sciencedirect, EmeraldInsight, and others to collect information. The search was conducted to identify the most critical activities when implementing LM tools. Specifically, information was sought on Kaizen, One Piece Flow, Jidoka, Poka-yoke, Visual Management, Kanban, Demand Management, Heijunka, JIT, Takt Time, Bottleneck Analysis, Andon, Gemba, Hoshing Kanri, OEE, Cellular Manufacturing, and TPM. In the same way, the economic, social, and environmental sustainability benefits obtained through the implementation of these tools were sought. It is essential to mention that only Demand Management, Kanban, One Piece Flow, and JIT were considered in the model presented in this article.

Before using the questionnaire as an information-gathering tool was validated by expert judgment with eight maquiladora company managers and three academics. This validation was done to adapt it to the environment of the region.

A 5-point Likert scale was used to answer each of the questions in the questionnaire. Finally, a demographic section was added to obtain data on the respondents. The validated questionnaire is uploaded to a specialized electronic platform due to the limitations generated by the COVID-19 contingency to be answered online. A mandatory condition is added to each question to avoid leaving questions unanswered.

3.2 Sample

Once the questionnaire has been validated by expert judgment and adapted to the regional context, the sample is identified. The sample was identified with the help of the Manufacturing, Maquiladora, and Export Services Industry (IMMEX), which identifies managers and engineers and invites them to participate. Each participant must meet specific requirements to answer the questionnaire, such as at least two years in the position, belonging to the production departments, and having knowledge of the implementation of LM tools.

3.3 Data Collection

Once the participants have been identified, an e-mail is sent inviting them to participate and the link to access the questionnaire, which was available during June–September 2020. If no response is received after two weeks, a second e-mail is sent, and if again no response is received, the case is skipped. Once the data collection period is over, the information is downloaded and stored in a database created in SPSS V.25® software for subsequent debugging.

3.4 Debugging of Information

To obtain valid questionnaires to be included in the analysis, the information in the database is debugged. Data debugging was carried out with two activities: (1) the standard deviation of each questionnaire obtained is calculated. Suppose the value of this deviation is less than 0.5. In that case, the questionnaire is discarded since it is considered that the person who answered it was not committed at the time of doing so (Kock 2019), and (2) the extreme values are identified by standardizing each of the items. Values below -4 or above 4 are considered extreme values. If extreme values exist, they are removed and replaced by the median (Hoffman 2019).

3.5 Descriptive Analysis of the Sample and the Items

To describe the sample, cross tables are made with the demographic information obtained in each questionnaire. In this sense, the aim is to know the participation of the different industry sectors, the size of the companies, and the experience of the workers.

In the same way, a descriptive analysis of the items is carried out to know the opinion of each of the people who participated. In order to know this, the median of each item is calculated. Large values in the median indicate that, in general, the activities are performed adequately in each of the tools. Conversely, small median values indicate that the activities are not adequately performed. The interquartile range (IR) is used to check the dispersion of the data. Large values of IR indicate a low consensus among participants, and small values indicate high consensus.

3.6 Validation of Information

To validate each of the variables included in the model in Fig. 1 and before performing the relevant analysis between the established hypotheses, some indexes proposed by Kock (2020) are used.

To measure predictive validity from a parametric point of view, the R^2 and adjusted R^2 coefficients were used, and to measure it from a non-parametric point of view, the Q^2 was used. These coefficients are only shown for endogenous latent variables and reflect the percentages of variance explained and predictive validity associated with each of these latent variables. For the R^2 and adjusted R^2 coefficients, values greater than 0.02 are recommended. For the Q^2 coefficient, values of 0 are recommended.

The composite reliability index and Cronbach's Alpha coefficients are recommended to measure internal reliability, and values greater than or equal to 0.7 are accepted. If a latent variable does not satisfy any of these criteria, the reason may be that one or more indicators have a weak loading on the latent variable. Consideration should be given to eliminating these indicators (Kock and Lynn 2012).

To measure the unidimensionality of the factors, convergent validity is used and is measured using the average variance extracted (AVE), whose recommended acceptable values are 0.5 (Fornell and Larcker 1981; Kock and Lynn 2012). To increase the reliability and validity of the questionnaire, items with factor loadings lower than 0.5 are eliminated.

Finally, the multicollinearity of the indicator weights is examined using the variance inflation index (VIF), so that this multicollinearity does not exist, values lower than five are suggested (Hair et al. 2012).

3.7 Structural Equation Modeling

Structural equation modeling (SEM) was used to evaluate the model presented in Fig. 1 using the partial least squares technique, whose main characteristic is its ability to minimize multicollinearity between latent variables, even in the presence of overlapping manifest variables (or indicators) (Kock 2010).

SEM is a multivariate statistical method that involves estimating the parameters of a system of simultaneous equations (Stein et al. 2012), It includes regression analysis, path analysis, factor analysis, simultaneous econometric equations, and latent growth curve models (Bollen 1989). SEM has been used in many fields of

Table 1 Model fit and quality index

Index	Measure	Recommended values
Average path coefficient (APC)		≥ 0.02 $P < 0.05$
Average R^2 (ARS)		≥ 0.02 $P < 0.05$
Average adjusted R^2 (AARS)		≥ 0.02 $P < 0.05$
Average block VIF (AVIF)	Multicollinearity	Acceptable if ≤ 5, ideally ≤ 3.3
Average full collinearity VIF (AFVIF)	Multicollinearity	Acceptable if ≤ 5, ideally ≤ 3.3
Tenenhaus GoF (GoF)	Model's explanatory power	Small ≥ 0.1, medium ≥ 0.25, Large ≥ 0.36

study because it has many advantages: first, measurement errors can be controlled, and second, mediating variables can be easily used (Kang and Ahn 2021). Third, a statistical evaluation of the theoretical model is possible (Hong 2000).

SEM is a set of statistical techniques that allow examining a set of relationships between one or several independent or Exogenous variables (IV), continuous or discrete. One or several dependent or endogenous variables (DV), continuous or discrete, and both IV and DV can be factors or measured variables (Ullman and Bentler 2012). The main objective of an SEM analysis is to confirm research hypotheses about the observed means, variances, and covariances of a set of variables. The hypotheses are represented by some structural parameters (e.g., factor loadings, regression paths) smaller than the number of observed parameters (Bowen and Guo 2011).

The model was run in WarpPLS V. 7.0® software (Kock 2020), as it estimates several model fit indices, which have been designed to be meaningful in the context of PLS-based SEM analyses (Kock 2010). These indices are shown in Table 1.

3.7.1 SEM Effects

A structural equation model can identify direct effects, indirect effects (mediators), and total effects. The direct effect is the path from the exogenous variable to the outcome while controlling the mediator. The indirect effect describes the path from the exogenous variable to the outcome through the mediator. Finally, the total effect is the sum of the direct and indirect effects of the exogenous variable on the outcome (Gunzler et al. 2013). In other words, a direct effect is the influence of one variable on another; it is represented in a structural model by a single path (each arrow in Fig. 1). An indirect effect assesses the impact of one variable on another, as the influence of that variable acts through one or more intervening variables (Holbert and Stephenson 2003).

For each of the direct effects, a value of β is shown. A hypothesis test is performed to determine if this effect is statistically significant or not, if the latent independent variable affects the latent dependent variable. The null hypothesis is as follows, H_0: β = 0 versus the alternative hypothesis H_1: β ≠ 0. This hypothesis test is performed with 95% confidence. So if the P-value of the test is less than 0.05, the null hypothesis is rejected, and it can be concluded that there is a direct effect. Hypothesis tests are also performed for indirect and total effects to verify that these are statistically significant.

3.7.2 Software for Structural Equation Modeling

Currently, there is much software to solve structural equation models, which can be classified according to the desired approach and the type of information with which they will be evaluated, so it can be said that there are parametric and non-parametric approaches, depending on the characteristics and attributes of such information.

The first commercial software to appear on the market was LISREL, widely accepted and still used in scientific articles. However, over time other software and approaches have appeared, and to mention which is the best would be a mistake since there are many advocates and users of these. Based on this type of information, there are two approaches to solving structural equation models: Covariance-based structural equation modeling (CB-SEM) and Partial least squares-based structural equation modeling (PLS-SEM).

Some of the most common and commercial software are listed below: EQS, AMOS, CALIS (A module of SAS), SEPATH (a module in Statistica), MPLUS, Lavaan (a module in R), Smart PLS, WarpPLS, OpenMx (R package), Ωnyx, STATA, and cSEM. In the author's own experience, the best software for PLS-SEM is Smart PLS and for CB-SEM is IBM AMOS. An any-any different opinion is entirely respectable.

However, let me say the following when choosing software and approach to evaluate the structural equation model:

- Always check if there is normality in the data being integrated into the model.
- Check if the sample size is large enough. In my own experience, PLS works best when the sample is small, and AMOS works best when large.
- Check the efficiency indices provided by the software, as some differences are present.
- If the model is the product of research and will be published, review the frequency with which that journal and editorial boards accept articles using one software or the other.

3.8 Sensitivity Analysis

Generally, sensitivity analysis measures variations in the model inputs given by the variables or parameters and variations in the model assumptions (Fassò and Perri

2002). In this case, a sensitivity analysis was performed for each of the assumptions raised in Fig. 1; that is, the probability that the activities are performed adequately (+) was calculated in an LV. In addition, the probability that a variable does not perform the activities adequately or that this variable is present in a low scenario (−) was calculated. This was done independently for each variable and each hypothesis. The probability that an independent LV presents in its high scenario and a dependent LV (+ and +) was calculated. In addition, the probability that both variables occur in their low scenario was calculated (−, −).

Finally, we calculated the probability of a combination of both; an independent LV would be present in a high scenario and a dependent LV in its high scenario (+ and −) or vice versa (−, +). Likewise, the probabilities $P(Z_i > 1)$ and $P(Z_d > 1)$, $P(Z_i > 1)$ and $P(Z_d <$ -−), $P(Z_i < -1)$ and $P(Z_d > 1)$ y $P(Z_i < -1)$ and $P(Z_d < -1)$ are calculated. Z_d is the probability of the dependent variable, and Z_i is the probability of the independent variable.

Likewise, the conditional probabilities were calculated for each of the hypotheses proposed. That is the probability that a dependent LV will occur in a high or low scenario, given that the independent LV will occur at its high or low level. The conditional probability is represented by the word "If." In other words, the conditional probabilities are calculated as follows $P(Z_d > 1)/P(Z_i > 1)$, $P(Z_d > 1)/P(Z_i < -1)$, $P(Z_d < -1)/P(Z_i > 1)$ y $P(Z_d < -1)/P(Z_i < -1)$, Where Z_i represents an independent variable, Zd represents a dependent variable, −1 represents a low level, and 1 a high level.

4 Results

4.1 *Final Questionnaire*

After validation by expert judgment, a final questionnaire was obtained consisting of three sections, the first comprising demographic data, the second consisting of 87 items divided into 17 LM tools. The third section corresponds to benefits (economic sustainability with eight items, social sustainability with six items, and environmental sustainability with six items). It is essential to mention that only four latent variables were used (Demand Management, Kanban, One Piece Flow, and JIT).

4.2 *Description of the Sample*

Once the questionnaires were downloaded from the electronic platform, 239 valid questionnaires were obtained. Table 2 presents a summary of the respondents' work experience. It can be seen that more than 50% have more than two years in their current position. In other words, they have experience and knowledge of production

Table 2 Participants' work experience

years of experience	Frequency
0–1	70
1–2	43
2–5	56
5–10	33
More than 10	36
Not answer	1

Table 3 Participants' job position versus industrial sector

Participants' job position	Industrial sector										Total
	1	2	3	4	5	6	7	8	9	10	
Manager	3	0	1	0	0	0	0	1	0	2	7
Engineer	13	0	1	3	0	0	1	0	0	5	23
Supervisor	11	0	4	1	1	1	4	5	0	6	33
Technician	35	0	11	18	3	6	5	2	0	16	96
Other	24	2	5	4	2	4	10	4	0	17	72
Total	86	2	22	26	6	11	20	12	0	46	231

1 automotive; 2 Aeronautics; 3 Electric; 4 Electronic; 5 Logistics; 6 Machining; 7 Medical; 8 Rubber and plastics; 9 textiles and apparel; 10 Other.

processes and LM tools. In addition, 28% of the participants have more than five years of experience in their jobs. Therefore, it can be concluded that the participants' answers are reliable.

Table 3 shows the participation according to the industrial sector and the position held by the participants. It can be seen that the automotive industry is the predominant sector with 37.2% participation. The above is understandable since most companies established in the city work directly or indirectly for the automotive sector. The position that was most registered was that of technicians, with a participation of 41.5%. Some 31.1% of the participants hold positions other than those mentioned here, 10.2% are supervisors, 9.95% are engineers, and only 3% are managers.

4.3 *Statistical Validation of the Information*

Table 4 presents the validation of the latent variables presented in the model in Fig. 1, according to the R^2 and adj. R^2 values, it is concluded that there is predictive validity from a parametric point of view. Concerning the composite reliability and Cronbach's alpha values, it is concluded that the variables have internal consistency and measure what they are intended to measure in each of the questions. According to AVE values

Table 4 Latent variable validation

Indexes	Demand management	Kanban	One-piece flow	JIT
R^2		0.430	0.524	0.439
Adj. R^2		0.427	0.518	0.434
Composite reliability	0.859	0.907	0.891	0.857
Cronbach´s alpha	0.781	0.846	0.817	0.777
AVE	0.605	0.765	0.732	0.599
Full Collin. VIF	2.578	1.914	1.957	1.749
Q^2		0.429	0.495	0.440

greater than 0.5, it is concluded that there is convergent validity, according to the values below 3.3 of Full Collin. VIF, it is concluded that there are no collinearity problems. Finally, it is concluded that there is sufficient predictive validity from a non-parametric point of view since the values of Q^2 are above zero and close to R^2. Therefore, these variables can be integrated into an SEM for subsequent causal analysis with such validation.

It is essential to mention that some items in each of the latent variables were eliminated to increase the questionnaire's internal consistency and convergent validity. In this sense, the variable Demand Management was left with four items, Kanban with 3, One Piece Flow with four, and JIT with three items.

4.4 Description of Items

Table 5 presents the description of the items for each of the latent variables after validation. As mentioned in the methodology, the median was used to measure central tendency and the IR as dispersion. The highest values of the median and the highest values of the IR are marked in bold.

Regarding the values of the One-Piece Flow variable items, it is concluded that most of the participants agree that most of the time, the quantity specified by the customer is produced. However, in general, the participants agree that the activities of the One-Piece Flow tool are carried out. Likewise, the activity that has the least dispersion in responses is that production at a particular workstation is based on the current demand of its downstream workstation with a value of 1.834.

Concerning Demand Management, most participants believe that an item is only produced when the customer requests it, with a median of 3.780. The activity with the lowest dispersion is where production at a particular workstation is based on the current demand of its downstream workstation with a value of 1.552.

Concerning Kanban, the median values greater than 4 of the three activities are very close, and the dispersion values are small. The above means that the participants agree that the workers always know what to produce; the product is consistently produced or transported based on a production order. Each production request is

Table 5 Items description

Variable	Item	25	50	75	IR
One-piece flow	Is production on a particular workstation based on current demand from your downstream workstation?	2.704	3.657	4.538	1.834
	Is a production batch made only if it has the customer's purchase order?	2.581	3.723	4.646	2.065
	Is only the specific quantity requested by the customer made?	2.614	3.774	4.668	2.054
	Do the workstations make good use of the pull system?	2.487	3.420	4.332	1.845
Demand management	Do you have models to forecast demand?	2.522	3.517	4.385	1.863
	Do you always have the necessary material to carry out production orders?	2.700	3.591	4.435	1.735
	Is production on a particular workstation based on current demand from your downstream workstation?	2.876	3.643	4.428	1.552
	Do we produce an item only when users request it?	2.887	3.780	4.615	1.728
Kanban	Do you always know how much to produce?	3.201	4.080	4.763	1.562
	Is the product not manufactured or transported without its production order?	3.088	4.061	4.785	1.697
	Is each request to manufacture a product always accompanied by its official order?	3.191	4.116	4.811	1.620
Just in time	Does the raw material inventory have strictly what is necessary?	2.536	3.560	4.476	1.940
	Are production orders manufactured in the estimated time?	2.818	3.703	4.535	1.717
	Does the machinery work uniformly to schedule?	2.944	3.762	4.568	1.624

always accompanied by its official order. In the case of Kanban, the activity that had the least dispersion was that it is always known how much to produce.

Finally, the participants agree that the machines work uniformly as planned, with a median value of 3.762 and the smallest deviation of 1.624, indicating consensus among people.

4.5 *Structural Equation Modeling*

Regarding the validation of the structural equation model, according to the values of the APC, ARS, and AARS indexes and their $P < 0.05$ values, it can be concluded that the model has predictive validity. In general, it is concluded that there is a direct and positive effect of the independent LVs on the dependent LVs, except for One Piece Flow on JIT. The AVIF and AFVIF values show no problems of collinearity between the relationships of the variables. Finally, it is concluded that the model has a good explanatory power since the value of GoF is 0.560; that is, the data fit the model adequately.

In this sense, the different effects between the variables can be analyzed. The efficiency indexes of the model are listed below:

Average path coefficient (APC) = 0.364, $P < 0.001$

Average R^2 (ARS) = 0.464, $P < 0.001$

Average adjusted R^2 (AARS) = 0.460, $P < 0.001$

Average block VIF (AVIF) = 1.920, acceptable if ≤ 5, ideally ≤ 3.3

Average full collinearity VIF (AFVIF) = 2.050, acceptable if ≤ 5, ideally ≤ 3.3

Tenenhaus GoF (GoF) = 0.560, small ≥ 0.1, medium ≥ 0.25, large ≥ 0.36

4.5.1 Effects in SEM

Once the SEM has been validated, the relationships between the variables are analyzed. Figure 2 shows the validated model, the hypotheses with the blue arrow were statistically significant, and the hypothesis with the red arrow was not statistically significant. For each hypothesis, a β value is shown, indicating the change in the dependent LV due to the independent LV. A *p*-value for contrasting each of the hypotheses is also shown. Finally, an effect size (ES) indicates the variance (R^2) explained by the independent LVs over the dependent LVs.

According to the P-values of each of the hypotheses, it is concluded that five of the six hypotheses initially proposed are statistically significant and only the one relating One Piece Flow to JIT was not statistically significant.

The H_1 values reflect that Demand Management has a direct and positive effect on Kanban with a value $\beta = 0.655$, indicating that when Demand Management increases its standard deviation, Kanban will increase by 0.655 units. The R^2 value of Kanban is explained by 0.430 by Demand Management since the latter is the only variable affecting Kanban. So, it can be concluded that companies must have models to forecast demand and have the necessary material to manufacture only when users request it, which facilitates the use of Kanban. The conclusion for each remaining hypothesis will be made in the conclusion section.

Table 6 shows the summary results of the model in Fig. 2. Here we present the direct effects and the indirect and total effects. In the case of Demand Management,

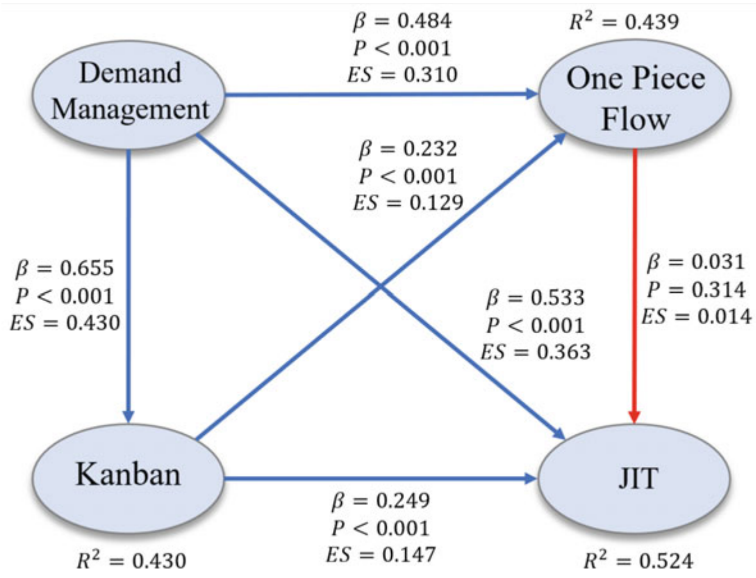


Fig. 2 Evaluated model

Table 6 Summary of results of the evaluated model

Hi	Hypothesis	Direct effect	Indirect effect	Total effects
H_1	Demand management → Kanban	$\beta = 0.655$ $P <$ 0.001 ES = 0.430		$\beta = 0.655$ $P <$ 0.001 ES = 0.430
H_2	Demand management → One piece flow	$\beta = 0.484$ $P <$ 0.001 ES = 0.310	$\beta = 0.152$ $P <$ 0.001 ES = 0.097	$\beta = 0.637$ $P <$ 0.001 ES = 0.407
H_3	Kanban → One piece flow	$\beta = 0.232$ $P <$ 0.001 ES = 0.129		$\beta = 0.232$ $P <$ 0.001 ES = 0.129
H_4	Demand management → JIT	$\beta = 0.533$ $P <$ 0.001 ES = 0.363	$\beta = 0.183$ $P =$ 0.002 ES = 0.125	$\beta = 0.716$ $P <$ 0.001 ES = 0.488
H_5	Kanban → JIT	$\beta = 0.249$ $P <$ 0.001 ES = 0.147	$\beta = 0.007$ $P =$ 0.437 ES = 0.004	$\beta = 0.256$ $P <$ 0.001 ES = 0.151
H_6	One piece flow → JIT	$\beta = 0.031$ $P =$ 0.314 ES = 0.014		$\beta = 0.031$ $P =$ 0.314 ES = 0.014

there is a direct effect of $\beta = 0.483$ with an $R^2 = 0.310$ but, in addition, it contributes indirectly through Kanban with a value of $\beta = 0.152$ and an $R^2 = 0.097$, which means that, if good demand management is done, a Kanban system will be set up correctly, and this will favor One Piece Flow.

4.6 Sensitivity and Conditional Probability Analysis

Table 7 shows the sensitivity analysis and the conditional probability for each of the hypotheses proposed. It shows the probabilities that the variables are presented in their high (+) and low (−) levels independently, or that they are presented jointly in their different scenarios (&), and the conditional probability (If) is presented for each hypothesis.

Concerning H_1, there is a probability of 0.155 and 0.142 that Demand Management is present at its high and low levels, respectively. In the case of Kanban, there is a probability of 0.192 and 0.121 that they occur at their high and low level, respectively. In the case of the joint probability, there is a probability of 0.075 that both will occur at their high level and a probability of 0.079 that both will occur at their low level. In the case of the conditional probability, there is a probability of 0.486 that Kanban will occur at its high level, given that Demand Management will occur at its high level. Otherwise, there is a probability of 0.599 that Kanban will be present at its low level, given that Demand Management is also present at its low level. In this sense, it is vital that each of the managers of the different departments involved in Demand Management ensure that each activity is carried out correctly, as this facilitates the implementation of Kanban.

Table 7 Sensitivity analysis

			DEM		KAN		OPF	
			+	−	+	−	+	−-
			0.155	0.142	0.192	0.121	0.197	0.155
KAN	+	0.192	& = 0.075 If = 0.486	& = 0.008 If = 0.059				
	−	0.121	& = 0.000 If = 0.000	& = 0.079 If = 0.559				
OPF	+	0.197	& = 0.071 If = 0.459	& = 0.000 If = 0.000	& = 0.079 If = 0.413	& = 0.004 If = 0.034		
	−	0.155	& = 0.008 If = 0.054	& = 0.075 If = 0.529	& = 0.017 If = 0.087	& = 0.071 If = 0.586		
JIT	+	0.188	& = 0.088 If = 0.568	& = 0.000 If = 0.000	& = 0.071 If = 0.370	& = 0.004 If = 0.034	& = 0.071 If = 0.362	& = 0.013 If = 0.081
	−	0.130	& = 0.004 If = 0.027	& = 0.071 If = 0.500	& = 0.013 If = 0.065	& = 0.075 If = 0.621	& = 0.008 If = 0.043	& = 0.050 If = 0.324

The conclusion for each of the hypotheses is presented in the corresponding section.

5 Conclusions and Industrial Implications

5.1 *Conclusions from the Structural Equation Model*

Concerning the values of H_2 and H_4, it can be concluded that Demand Manager has a direct and positive effect on One Piece Flow and JIT, since when Demand Manager increases or decreases its standard deviation by one unit, One Piece Flow and JIT increase or decrease by 0.484 and 0.363 respectively. The above means that if companies have models for forecasting demand, have materials to place production orders, and have these products manufactured only when users request them will facilitate One-Piece Flow and JIT production.

In addition, Demand Management facilitates that the production in a station is made according to the current demand of its subsequent workstation. In addition, a production batch will only be manufactured if there is a purchase order from the customer with the indicated quantity. In addition, it facilitates the implementation of a Pull system. In conclusion, proper demand management makes it easier to have the necessary raw material, facilitates that production orders are completed in the estimated time, and facilitates that the machinery works uniformly to the programmed.

The β values in H_3 and H_5 show that Kanban has a direct and positive effect on One Piece Flow and JIT, since when Kanban increases its standard deviation by one unit, One Piece Flow and JIT increase by 0.232 and 0.249 units, respectively. Therefore, Kanban facilitates One-Piece Flow and JIT. The above means that if the quantity to be produced is always known, parts are also only manufactured and moved with a production order. That production always goes with an official order, facilitating One Piece Flow and Just-in-Time. Kanban then facilitates that production at one station is done based on the current demand of its downstream workstation. Furthermore, a production batch will only be manufactured if a customer's purchase order is with the quantity indicated.

Kanban also makes it easier to have only the raw materials needed; it also makes it easier to complete production orders on schedule. It also makes it easier for machinery to work uniformly on schedule. Finally, the β and P values in H_6 show that One-Piece Flow does not have a direct and positive effect on JIT, as this hypothesis was not statistically significant.

5.2 Conclusions from the Sensitivity Analysis

As could be observed in Table 6, the values of the conditional probabilities are high, i.e., the probability that an LV is presented at its high or low level, given that an L is presented at its high or low level. Therefore, the probabilities of Kanban, One Piece Flow, and JIT occurring at their high level, given that Demand Management occurs at its high level, are 0.486, 0.459, and 0.568, respectively. So, the people in charge of demand management have to make sure to perform those activities properly to facilitate a good use of Kanban; in addition, good demand management facilitates one-piece flow and just-in-time production.

To facilitate working with One Piece Flow and just-in-time, it is important to ensure that activities are appropriately performed while working with Kanban as the odds of One Piece Flow and JIT occurring at their high level as Kanban also does are 0.413 and 0.362, respectively.

References

Abdulmalek, F.A., Rajgopal, J.: Analyzing the benefits of lean manufacturing and value stream mapping via simulation: a process sector case study. Int. J. Prod. Econ. **107**(1), 223–236 (2007)

Adnan, A.N.B., Jaffar, A.B., Yusoff, N.B., Halim, N.: Implementation of Just in Time Production through Kanban System. System, **3**(6) (2013)

Antoniolli, P.D.: Information technology framework for pharmaceutical supply chain demand management: a Brazilian case study. Braz. Bus. Rev. **13**(2), 27–55 (2016)

Bermejo, M.: El Kanban. UOC, Barcelona, España (2011)

Bollen, K.A.: Structural equations with latent variables, vol. 210. Wiley (1989)

Bowen, N.K., Guo, S.: Structural equation modeling. Oxford University Press (2011)

Breyfogle, F., III.: The three Rs of business. Quality **46**(5), 42 (2007)

Can, C., Gürsel, A.S.: Supply chain design approaches for dual demand management strategies. In: A. Information Resources Management (ed.) Supply Chain and Logistics Management: Concepts, Methodologies, Tools, and Applications, pp. 491–526. IGI Global (2020). https://doi.org/10.4018/978-1-7998-0945-6.ch024

Cañas, J., Coronado, R., Gilmer, R. W., Saucedo, E.: The impact of the Maquiladora Industry on U.S. border cities. Growth Change **44**(3), 415–442 (2013). https://doi.org/10.1111/grow.12014

Chan, F.T.S.: Effect of kanban size on just-in-time manufacturing systems. J. Mater. Process. Technol. **116**(2), 146–160 (2001). https://doi.org/10.1016/S0924-0136(01)01022-6

Chen, Z.X., Tan, K.H.: The perceived impact of JIT implementation on operations performance: Evidence from Chinese firms. J. Adv. Manage. Res. (2011)

Chopra, S., Peter, M.: Administración de la cadena de suministro. Pearson Educación (2008)

Coker, J., Helo, P.: Demand-supply balancing in manufacturing operations. Benchmark.: Int. J. **23**(3), 564–583 (2016). https://doi.org/10.1108/BIJ-04-2014-0028

Croxton, K.L., Lambert, D.M., García-Dastugue, S.J., Rogers, D.S.: The demand management process. Int. J,. Logist. Manage. **13**(2), 51–66 (2002). https://doi.org/10.1108/09574090210806423

Crum, C., Palmatier, G.E.: Demand management best practices: process, principles, and collaboration. J. Ross Publishing (2003)

Daily, B.F., Bishop, J.W., Massoud, J.A.: The role of training and empowerment in environmental performance. Int. J. Oper. Prod. Manag. **32**(5), 631–647 (2012). https://doi.org/10.1108/01443571211226524

Darlington, R., Rahimifard, S.: A responsive demand management framework for the minimization of waste in convenience food manufacture. Int. J. Comput. Integr. Manuf. **19**(8), 751–761 (2006). https://doi.org/10.1080/09511920500501632

Davizón, Y.A., Soto, R., Rodríguez, J. d. J., Rodríguez-Leal, E., Martínez-Olvera, C., & Hinojosa, C. (2014). Demand management based on model predictive control techniques. Math. Probl. Eng. **2014**, 702642. https://doi.org/10.1155/2014/702642

Dorocki, S., Brzegowy, P. (2014). The maquiladora industry impact on the social and economic situation in Mexico in the era of globalization. Wójtowicz, W.M., Winiarczyk-Raźniak A. (red.). Environmental and Socio-Economic Transformations in Developing Areas as the Effect of Globalization, pp. 93–110. Wydawnictwo Naukowe Uniwersytetu Pedagogicznego, Kraków

Eswaramoorthi, M., Kathiresan, G., Prasad, P., Mohanram, P.: A survey on lean practices in Indian machine tool industries. Int. J. Adv. Manuf. Technol. **52**(9), 1091–1101 (2011)

Fassò, A., Perri, P.F.: Sensitivity analysis. Encycl. Environ. **4**, 1968–1982 (2002)

Fornell, C., Larcker, D.F.: Evaluating structural equation models with unobservable variables and measurement error. J. Mark. Res. **18**(1), 39–50 (1981)

González, A.D., Aponte, B.J., González, A.J., Vasquez, F.D.: Procesos de negocio de la cadena de suministro avícola. Revista Venezolana De Gerencia **23**(82), 479–495 (2018)

Gunzler, D., Chen, T., Wu, P., Zhang, H.: Introduction to mediation analysis with structural equation modeling. Shanghai Arch. Psychiatry **25**(6), 390–394 (2013). https://doi.org/10.3969/j.issn.1002-0829.2013.06.009

Hadjimarcou, J., Brouthers, L.E., McNicol, J.P., Michie, D E.: Maquiladoras in the 21st century: Six strategies for success. Bus. Horizons **56**(2), 207–217 (2013). https://doi.org/10.1016/j.bushor.2012.11.005

Haider, A.A., Jahanzaib, M., Akhtar, K.: Experimental comparison of one piece flow production: a simulation based approach. Ed. Advisory Board e **19**(1), 97–104 (2005)

Hair, J.F., Sarstedt, M., Ringle, C.M., Mena, J.A.: An assessment of the use of partial least squares structural equation modeling in marketing research. J. Acad. Mark. Sci. **40**(3), 414–433 (2012)

Hoffman, J.I.E.: Chapter 9—Outliers and extreme values. In: Hoffman, J.I.E. (ed.) Basic Biostatistics for Medical and Biomedical Practitioners, 2 edn., pp. 149–155. Academic Press (2019). https://doi.org/10.1016/B978-0-12-817084-7.00009-7

Holbert, R.L., Stephenson, M.T.: The importance of indirect effects in media effects research: testing for mediation in structural equation modeling. J. Broadcast. Electron. Media **47**(4), 556–572 (2003). https://doi.org/10.1207/s15506878jobem4704_5

Hong, S.: The criteria for selecting appropriate fit indices in structural equation modeling and their rationales. Korean J. Clin. Psychol. **19**(1), 161–177 (2000)

Hou, T.-H., Hu, W.-C.: An integrated MOGA approach to determine the Pareto-optimal kanban number and size for a JIT system. Expert Syst. Appl. **38**(5), 5912–5918 (2011). https://doi.org/10.1016/j.eswa.2010.11.032

Hu, L.Y., Huo, Y.R., Jin, C.Q., Zheng, Y., Zheng, Q., Xu, Y.Y.: One-piece flow implementation research in the garment enterprises. Adv. Mater. Res. (2013)

Hung Lau, K.: Demand management in downstream wholesale and retail distribution: a case study. Supply Chain Manage. Int. J. **17**(6), 638–654 (2012). https://doi.org/10.1108/13598541211269247

Ioana, A.D., Maria, E.D., Cristina, V.: Case study regarding the implementation of one-piece flow line in automotive company. Procedia Manuf. **46**, 244–248 (2020). https://doi.org/10.1016/j.promfg.2020.03.036

Issar, G., Navon, L.R.: Kanban. In Issar, G., Navon, L.R,. (eds.) Operational Excellence: A Concise Guide to Basic Concepts and Their Application, pp. 69–71. Springer (2016). https://doi.org/10.1007/978-3-319-20699-8_16

Jadhav Bhushan, D., Solanki Niranjanbhai, M., Badhe Swapnil, K., Bhoir Parag, B.: Implementation of Kanban system for ready sub-assemblies in maintenance area. Int. J. Innov. Res. Sci. Eng. **2**(03), 10 (2016)

Kang, H., Ahn, J.-W.: Model setting and interpretation of results in research using structural equation modeling: a checklist with guiding questions for reporting. Asian Nursing Res. (2021). https://doi.org/10.1016/j.anr.2021.06.001

Kiran, D.R.: Chapter 26—Just in time and Kanban. In D.R. Kiran (ed.) Production Planning and Control, pp. 369–379. Butterworth-Heinemann (2019). https://doi.org/10.1016/B978-0-12-818364-9.00026-3

Kock, N.: Using WarpPLS in e-collaboration studies: an overview of five main analysis steps. Int. J. e-Collab. (ijec) **6**(4), 1–11 (2010)

Kock, N.: Factor-based structural equation modeling with WarpPLS. Austr. Market. J. (AMJ) (2019). https://doi.org/10.1016/j.ausmj.2018.12.002

Kock, N.: WarpPLS© User Manual: Version 7.0. ScriptWarp Systems, Laredo, TX, USA (2020)

Kock, N., Lynn, G.: Lateral collinearity and misleading results in variance-based SEM: an illustration and recommendations. J. Assoc. Inf. Syst. **13**(7) (2012)

Lendínez, L.C.: Kanban. Metodología para aumentar la eficiencia de los procesos (2019)

Leonardo, D.G., Sereno, B., Silva, D.S.A., d., Sampaio, M., Massote, A. A., & Simões, J. C.: Implementation of hybrid Kanban-CONWIP system: a case study. J. Manuf. Technol. Manage. **28**(6), 714–736 (2017). https://doi.org/10.1108/JMTM-03-2016-0043

Leopold, K., Kaltenecker, S.: Kanban Change Leadership: Creating a Culture of Continuous Improvement. Wiley (2015)

Levis, A.A., Papageorgiou, L.G.: Active demand management for substitute products through price optimisation. In: Meyr, H., Günther, H.-O. (eds.) Supply Chain Planning: Quantitative Decision Support and Advanced Planning Solutions, pp. 89–115. Springer, Berlin, Heidelberg (2009). https://doi.org/10.1007/978-3-540-93775-3_4

Li, S.G., Rong, Y.L.: The reliable design of one-piece flow production system using fuzzy ant colony optimization. Comput. Oper. Res. **36**(5), 1656–1663 (2009). https://doi.org/10.1016/j.cor.2008.03.010

Liker, J.K.: Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. McGraw-Hill Education (2004)

Marton M, Paulová I.: One piece flow-another view on production flow in the next continuous process improvement, pp. 30–35. Slovak University of Technology Bratislava (2013)

McMullen, P.R.: An ant colony optimization approach to addressing a JIT sequencing problem with multiple objectives. Artif. Intell. Eng. **15**(3), 309–317 (2001). https://doi.org/10.1016/S0954-1810(01)00004-8

Mentzer, J.T., Moon, M.A.: Sales Forecasting Management: A Demand Management Approach. Sage Publications (2004)

Miltenburg, J.: One-piece flow manufacturing on U-shaped production lines: a tutorial. IIE Trans. **33**(4), 303–321 (2001)

Mohanty, M.K., Gahan, P.: Buyer supplier relationship in manufacturing industry-findings from Indian manufacturing sector. Bus. Intell. J. **5**(2), 319–333 (2012)

Mukhopadhyay*, S.K., & Shanker, S. (2005). Kanban implementation at a tyre manufacturing plant: a case study. Prod. Plan. Control **16**(5), 488–499. https://doi.org/10.1080/09537280500121778

Naufal, A., Jaffar, A., Yusoff, N., Hayati, N. (2012). Development of Kanban system at local manufacturing company in Malaysia–case study. Procedia Eng. **41**, 1721–1726. https://doi.org/10.1016/j.proeng.2012.07.374

Nenni, M.E., Giustiniano, L., Pirolo, L.: Demand forecasting in the fashion industry: a review. Int. J. Eng. Bus. Manage. **5**, 37 (2013)

Papalexi, M., Bamford, D., Dehe, B.: A case study of Kanban implementation within the pharmaceutical supply chain. Int. J. Log. Res. Appl. **19**(4), 239–255 (2016). https://doi.org/10.1080/13675567.2015.1075478

Phogat, S.: Introduction to JIT: a review. Int. J. Latest Res. Sci. Technol. **2**(6), 97–101 (2013)

Powell, D.J.: Kanban for lean production in high mix, low volume environments. IFAC-PapersOnLine **51**(11), 140–143 (2018). https://doi.org/10.1016/j.ifacol.2018.08.248

Prakash, J., Chin, J.F.: Implementation of hybrid parallel Kanban-CONWIP system: a case study. Cogent Eng. **1**(1), 938922 (2014)

Prawira, A., Syahrial, I., Purba, H.: Application of just-in-time manufacturing techniques in radioactive source in well logging industry. Manage. Sci. Lett. **7**(3), 119–124 (2017)

Rahman, N.A.A., Sharif, S.M., Esa, M.M. Lean manufacturing case study with Kanban system implementation. Procedia Econ. Finance **7**, 174–180 (2013). https://doi.org/10.1016/S2212-5671(13)00232-3

Raman, S., Patwa, N., Niranjan, I., Ranjan, U., Moorthy, K., Mehta, A.: Impact of big data on supply chain management. Int. J. Log. Res. Appl. **21**(6), 579–596 (2018). https://doi.org/10.1080/13675567.2018.1459523

Satoglu, S.I., Durmusoglu, M.B., Ertay, T.: A mathematical model and a heuristic approach for design of the hybrid manufacturing systems to facilitate one-piece flow. Int. J. Prod. Res. **48**(17), 5195–5220 (2010). https://doi.org/10.1080/00207540903089544

Senapathi, M., Drury-Grogan, M.L.: Systems thinking approach to implementing Kanban: a case study. J. Softw.: Evol. Process **33**(4), e2322 (2021). https://doi.org/10.1002/smr.2322

Sendil Kumar, C., Panneerselvam, R.: Literature review of JIT-Kanban system. Int. J. Adv. Manuf. Technol. **32**(3), 393–408 (2007). https://doi.org/10.1007/s00170-005-0340-2

Socconini, L.: Lean Manufacturing. Marge Books, Paso a paso (2019)

Soliman, M.: Takt time, cycle time, one-piece flow and Hejunka. Book (2020). ISBN-13, 979-8698815402

Stein, C.M., Morris, N.J., Nock, N.L.: Structural equation modeling. In: Statistical Human Genetics, pp. 495–512. Springer (2012)

Taiwo, A., Emmanuel, B., Olayinka, O.: A roadmap to lean production implementation for small scale Nigerian wire and cable companies. J. Mech. Eng. Autom. **1**(2), 119–125 (2011)

Tardif, V., Maaseidvaag, L.: An adaptive approach to controlling kanban systems. Eur. J. Oper. Rese. **132**(2), 411–424 (2001). https://doi.org/10.1016/S0377-2217(00)00119-3

Thun, J.-H., Drüke, M., Grübner, A.: Empowering Kanban through TPS-principles—An empirical analysis of the Toyota production system. Int. J. Prod. Res. **48**(23), 7089–7106 (2010). https://doi.org/10.1080/00207540903436695

Tortorella, G.L., Fettermann, D d., Fries, C.E. Relationship between lean manufacturing implementation and leadership styles. In; Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management (2016)

Turner, R., Ingold, D., Lane, J.A., Madachy, R., Anderson, D.: Effectiveness of Kanban approaches in systems engineering within rapid response environments. Procedia Comput. Sci. **8**, 309–314 (2012). https://doi.org/10.1016/j.procs.2012.01.065

Ullman, J.B., Bentler, P.M.: Structural equation modeling. In: Handbook of Psychology, 2nd edn. (2012). https://doi.org/10.1002/9781118133880.hop202023

Wakode, R.B., Raut, L.P., Talmale, P.: Overview on Kanban methodology and its implementation. IJSRD-Int. J. Sci. Res. Dev. **3**(02), 2321–2613 (2015)

Womack, J. P., Jones, D.T., Roos, D., Carpenter, D.: The machine that changed the world:[based on the Massachusetts Institute of Technology 5-million-dollar 5-year study on the future of the automobile]. Rawson Associates (1991)

Wu, X.B., Huang, J.: Business process redesign based on "one piece flow": concept, methodology and application. In: 2004 IEEE International Engineering Management Conference (IEEE Cat. No.04CH37574) (2004)

Yan, H.: The optimal number of Kanbans in a manufacturing system with general machine breakdowns and stochastic demands. Int. J. Oper. Prod. Manage. **15**(9), 89–103 (1995). https://doi.org/10.1108/01443579510099670

Yue, X., Liu, J.: Demand forecast sharing in a dual-channel supply chain. Eur. J. Oper. Res. **174**(1), 646–667. https://doi.org/10.1016/j.ejor.2004.12.020

Zinn, W., Liu, P.C.: Consumer response to retail stockouts. J. Bus. Logist. **22**(1), 49–71 (2001)

Zotteri, G., Verganti, R.: Multi-level approaches to demand management in complex environments: an analytical model. Int. J. Prod. Econ. **71**(1), 221–233 (2001). https://doi.org/10.1016/S0925-5273(00)00120-1

Production Processes

The Use of Quantum Computing with 3D Modeling in the Industrial Sector

Bogart Yail Márquez, Jenniffer Deyanira Castillo, and Arturo Realyvásquez-Vargas

Abstract This chapter represents the results obtained through the investigation about the computer problem solving of 3D tridimensional figures in the industrial sector and defines the quantum computer paradigm, which defines the capacity storage of information in amplitude values based in cubits and not in bits as commonly used and known. The present research establishes a state-of-the-art knowledge in quantum computing and modeling whose development platforms are open-source type. A methodology is established based on the project to be developed: problem approach, justification, objectives, state of the art, research methodology, result and analysis, conclusions.

Keywords Quantum computing · Modeling · Algorithms · Qubit

1 Introduction

Over the years, thanks to the previous intervention and study of computers, it has been possible to evolve on a large scale because of these computers, today they can be of small size, but that does not interfere with its operation or performance. The next level will be molecular.

Today, we live in a new era thanks to the technologies evolving quantum computing (quantum technology). This type of technology has been present for quite some time, specifically in the mid-twenty-first century, which has been very useful for the world

B. Y. Márquez (✉)
Systems and Computing Department, Master in Information Technology, Tecnologico Nacional de Mexico, Tijuana Campus, Mexico City, Mexico
e-mail: bogart@tectijuana.edu.mx

J. D. Castillo · A. Realyvásquez-Vargas
Industrial Engineering Department, Tecnológico Nacional de México, Tijuana Campus, Mexico City, Mexico
e-mail: jenniffer.castillo@tectijuana.edu.mx

A. Realyvásquez-Vargas
e-mail: arturo.realyvazquez@tectijuana.edu.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_7

and humans because it brings improvements and advances on a smaller scale for many years, specifically in the field of medicine.

Nowadays, quantum computing has given rise to multiple technologies with high potential that can affect other technologies because it is known as a great power that can reach the quantum. On the other hand, the world leaders and leading companies in the technology market are preparing for this new era with investments or programs that are not left behind by not having knowledge and interaction with this technology.

Figure 1: the graph represents the evolution of the development of quantum computers in terms of the number of qubits.

3D modeling is a development process that makes a mathematical representation of an object through specialized software that makes a product called a 3D model. However, what if 3D modeling could have something to do with quantum computing? Currently, there is no study on this issue of how quantum computing could help in various fields such as in medicine with the creation of 3D figures because these are used in some therapies, and with the latest technology quantum computing, these processes could have a greater impact thanks to the precision used. Documentation

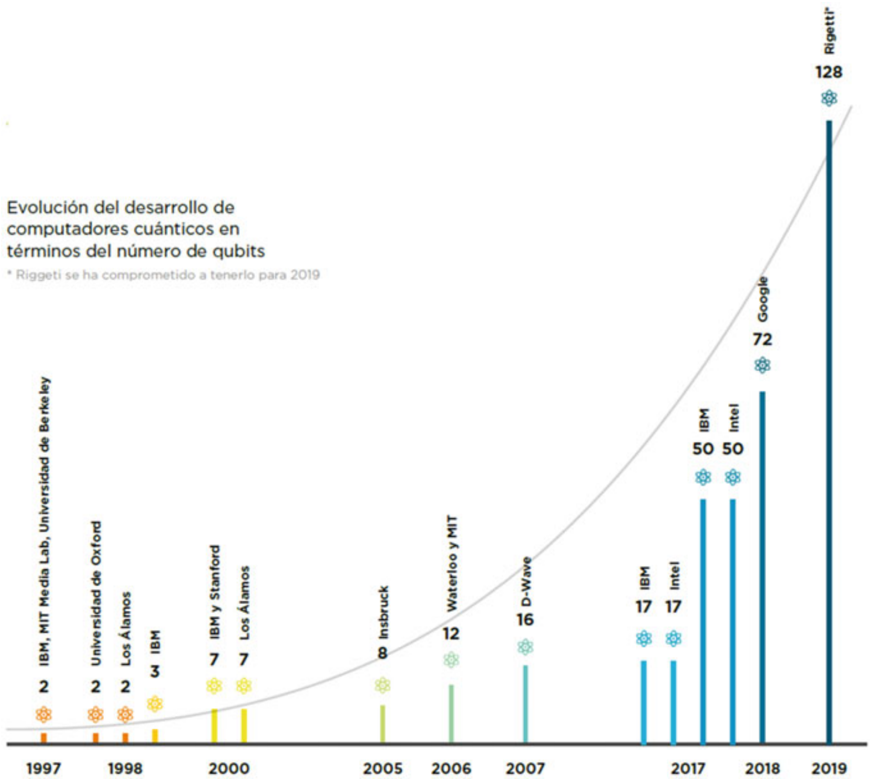


Fig. 1 Evolution of quantum computer development from 1997 to 2019 (in qubits)

Fig. 2 Scanner. Device that performs the scan and a sample of the result

and referencing of this research will be addressed and analyzed. It will include opinions, positions, and developments of greater relevance and impact on this technology because of an extensive bibliography with interesting readings.

2 Project Problem Definition

2.1 Knowledge Transfer in the Supply Chain

Current computers come to process a large number of calculations, but depending on the work, this can take time; an example is when they make a scan of the current denture of an orthodontic patient, the patient undergoes a reading of his oral cavity and a device is scanning it and capturing it in the software of 3D figures as we can see in Fig. 2, in which it will be taken as a reference for future modifications, it is a case study where the use of 3D figures are used in the medical sector, that said the use of a faster processor to perform such calculations would be of great use.

Figure 2: The graphic depicts the making of 3D digital impressions of a person's mouth using the scanner device.

2.2 Justification

If we take into consideration the mistakes that a not so precise work can make by having to skimp on time, it can become fatal if we get to use it in the medical sector; therefore, a more accurate calculation would be beneficial, or as at the time the swine flu sprouted, the mathematical calculations to create the antidote had to last a long time after each test. However, if it had been achieved with a supercomputer (referring to the quantum computer), it could be achieved in less time.

Modern quantum computing technology could help us perform calculations exponentially when performing mathematical operations. These mathematical operations are used when creating a three-dimensional model; since these computers could do quick calculations, the models could be rendered more straightforward and fast, which could benefit a lot in the medical sector, as previously mentioned. Diagnoses could be made in short times, such as with a cancer patient's diagnosis. The patient is often started with chemotherapy, spending weeks or even months. However, with the diagnosis still in process with a current computer, it is still not known if the chemotherapy is working, giving the probability of a 50/50 if it is helping or not, which is fatal for the patient. Then we could say that medical diagnoses could be made in minutes or a couple of hours with the quantum computer, giving the doctor the answer if the patient's treatment is helping.

3 State of the Art

In this section, the fundamental concepts of the research are presented. Information technology is defined from its primary conceptualization, which starts from the qubits and its advantages. Next, the concept of Mo-Cap or Motion Capture and its importance for implementing new technologies are addressed. Then it addresses the concept of simulation, universal quantum computing, computational modeling of complex systems.

Nowadays, computers perform multiple tasks that, in many cases, require too much time for their processing to be completed and executed. When carrying out multiple studies for quite some time, the search was made to reduce the time of execution of the activities, which initiates the development of faster and faster machines. It could be said that quantum processors seem to be the future of computers. Currently, the architecture and even talking about transistors to build processors will reach its limits within a few years. Then it will be necessary to apply and create architecture more efficiently. Quantum processors have great potential, should be efficient, and work in a couple of seconds. Currently, processors cannot even complete some tasks in millions of years.

The operation of quantum computers is based on the rules linked to quantum uncertainty. When reaching the level of a solitary particle, nothing is absolute. In other words, the electron can rotate in any direction. In quantum computers, instead of using bits like ordinary computers, they use quantum bits (qubits). Qubit values can be 0 or 1, just like regular bits. One noticeable difference is that qubits can simultaneously store the values 0 and 1. This property indicates the full potential of exploiting such computers (Thiago de Oliveira 2019).

The technology offered by quantum computing can reach its limits; it can reach the atomic limit. This level is physically possible to do fewer things because it will require a more detailed analysis. After all, this leads to one of the essential conclusions of numerical calculations. With the advent of the first digital computer, no drastic or significant changes have been achieved. In the last 60 years, the technology that has been developed is small, fast computers. The valves move directly to the transistor and eventually move the microchip; these were some examples of speed evolution. However, they have not made a significant breakthrough when making a more powerful computer.

Thanks to the applications of quantum computing, that is an advantage which you can contemplate in everyday life applied to different areas such as medical, automotive, in research on quantum computers and paradox of the superposition of Richard Primer where he mentions that there are many areas where you can observe the power and performance of a quantum computer. It can have an essential efficiency because it can be in many states simultaneously and operate simultaneously in all of them through a single central processing unit. This deduces that the greater the information processing capacity, the shorter the response time in the solving processes.

It is necessary to create more effective models for global climate to cure a disease and develop an environmental policy. Thus, a more helpful search service to better understands the problems and the content available on the Internet to get a better response when searching for information, due to the information about the laboratories where theoretical ideas are transformed into practices (Thiago de Oliveira 2019).

The term Motion capture (Mo-cap) is recording the movement of objects or people. This method is used in military, entertainment, sports, medical or computer vision validation, and robotics applications. In filming and video game making, this refers to recording movements of human actors, using that information to animate digital characters in 2D or 3D through computer animation. When the capture includes faces and fingers or delicate expressions of motion, this is regularly referred to as interpretation capture. Mo-cap is commonly called motion tracking in many fields, but motion tracking usually refers to match movies in movies and games.

In motion capture sessions, the actions of one or more actors are sampled at high speeds per second. These techniques use images obtained from multiple cameras to calculate 3D positions in space; the purpose of motion capture is to record only the actor's movements, not his appearance. This animation information is mapped into 3D models, which can recreate the same actions done by the actor.

Figure 3 shows how a man wears the clothes for the Mocap.

The use of capture systems for computer-animated characters is relatively new, beginning to be used in the late 1970s, but only so far have these systems spread worldwide.

Capturing moves for the realization of animated characters involves mapping the human body and its movements to be represented by the animated character or avatar. The mapping can be direct, like a human's arm controlling an animated arm, or indirect, like a hand and fingers that control the color or position of an avatar.

Of course, the idea of copying human movement to recreate it by some animated character is not new. Since the early nineteenth century, different methods for the capture and recording of the movement were invented and perfected; throughout history, the most important were the following:

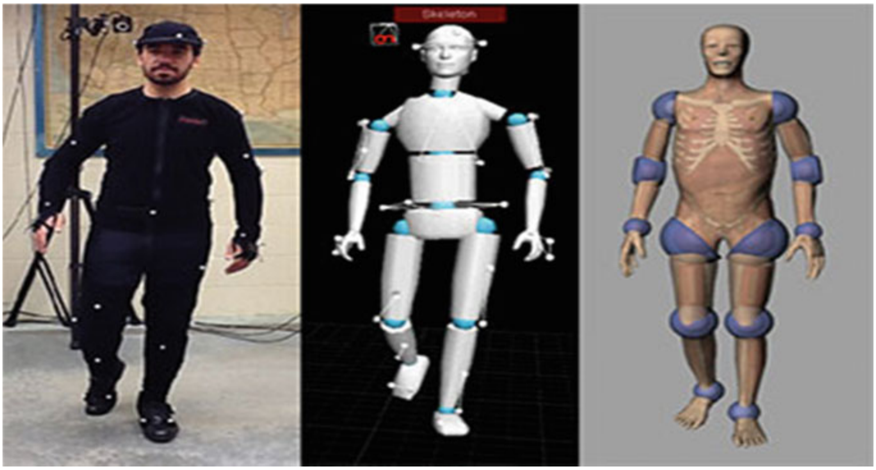


Fig. 3 Simulation using the mo-cap for anthropometry

The first form of motion capture was achieved by filming actors performing their parts through multiple cameras to capture the motion in 3D. This was called otoscopy, a method devised by filmmaker Max Fleischer in 1915 that consisted of animators drawing their drawings on stills of the filmed actions of live actors. This method was adopted by Disney, which used rotoscoping to create their first feature film Snow White and the Seven Dwarfs. The motion capture method gave the animated feature a sense of fluidity and realism never before seen in animation.

The advancement of quantum technologies is quite promising because they are expected to have a high impact in various areas, sectors, and industries. However, we will focus on medicine, which is one of the fields where it will have the greatest impact. Quantum technologies' main characteristic is the use of properties from the microscopic world that cannot always occur under a microscope and therefore have greater potential for development and research. An example that we could mention is how the particles of electrons or photons can have several positions simultaneously due to this property, which is the quantum superposition.

Quantum physics came about 100 years to transform the world's vision and get things done more simply when it seemed to be impossible. One of the objectives is to improve in several areas, one of which is the health sector. Although not much influence has been seen in the sectors by quantum computing (Health Nology 2020).

The application of quantum computers for medicine can solve classical computers' problems. Quantum computers can perform multiple simulations on chemical reactions, and these in turn help to better design drugs. Being able to design medicines is one of the most important applications because their development requires many years of study, research, and work to put them on the market for the public and their application. With quantum computing, this will be possible due to the time simulations; it would save much money and, above all, time for this. If this technology were implemented, the drugs could be closer to the general population.

Currently, in medicine, traditional medical training is induced and also surgical training which is based on the learning method, in which teachers in the field directly or indirectly teach students the necessary skills and knowledge (Evgeniou and Loizou 2013), due to the pressure on the health sector when carrying out their practices or their residencies, medical students have reduced the time they spend on the practical part of their education (JAMA 2009) so that in some countries cases of medical malpractice are increasing.

To treat this problem and those future doctors have a good quality in their surgical interventions, they have come to induce surgical education methods based on the simulation of situations in operations, obstetrics, and urology. Because of this, several academic aspects have been investigated, such as training boxes, training mannequins, surgical simulators, a recreation of the surgical environment, and because their perspective is towards skill.

Therefore, when using Neuron Perception®, an introduced motion capture system, to analyze body movements. However, really if you had the opportunity to apply quantum computing to these kinds of systems for the rehabilitation of some parts of the body or simulations of surgery, it would be highly effective because you could combine several areas of medicine, and you could go as far as what would seem impossible.

The proposition of light is not a continuous wave divided into small packages or quantum. This idea in appearance is simple, but it serves to solve a specific problem where the superposition of states and matter is interested in two: the superposition of states and entanglement. Because over time, physicists developed and reached surprising conclusions about the state of matter.

At Hefei University of Science and Technology, He-Liang and his colleagues explain that calculating beta numbers with a conventional computer would quickly saturate computers, making it exceedingly difficult to obtain maximum performance. The researcher Huang and his colleagues have been able to calculate for the first time the beta numbers in a quantum computer, the algorithm proposed by Lloyd was merely theoretical when they managed to execute the algorithm on a quantum computer, we realize that this potential can be exploited in the future when more control is achieved.

The road to the modern world

Globalization acts in labor markets, so automation serves as a basis for companies to continue competing. Jobs are related to research, and work has been generated in automation. Automation is a necessary investment for companies; inefficient machines hinder production and end up being a factor for the withdrawal from some companies' market. Computers are responsible for the efficiency of automation and transmitting information quickly to companies to accelerate the market.

3.1 Theoretical-Conceptual Framework

A symmetry is any property that does not vary even if your point of view changes. Many of these are critical to problem-solving such as data extraction, understanding brain structures, or network analysis. Therefore, an algorithm extension is ideally used with mathematics. Scientific advances realized those simple modeling systems were impossible because quantum equipment was proposed in 1980. However, the more advances, the more complicated it was to do the simulation.

Quantum mechanics was developed between 1900 and 1925, and it is still the base stone on which the physics of matter, chemistry, and technology that start from computer chips to Led lighting is based. Although they have done this successfully, some of the simpler systems seemed to be left out for humans because of the human ability to model quantum mechanics. Simulating systems of even a few dozen interacting particles will require more computer power than any conventional equipment can provide for thousands of years.

Because a lower-level quantum computer is more powerful than a current supercomputer, we have realized it can do amazing things, so we have taken it upon ourselves to understand that it could be leveraged in medical or video game industry advances by performing mathematical calculations at an astonishing speed. We can realize that a calculation of the rotation of a cube on an ordinary computer is surprising, but when compared to a quantum one, it would be exceptional.

3.2 Universal Quantum Computer

Universal computing is implemented as a discrete unitary matrix transformation sequence that forms a quantum circuit. This circuit works with many energy levels, and as it grows in several qubits, the system becomes more unstable because of decoherence. This phenomenon is nothing more than the corruption of information that appears when some qubits of computing intertwine with the environment, collapsing into altered states (Shor 1995). The development of these computers is overly complex, and there are only a few available cases: this is the case of IBM and its IBM Q 50 prototype with 50 qubits (Linke et al. 2017), Google and its 72-qubit computer (Kelly 2018), or Rigetti, with 19 qubits, but with plans to implement a 128-qubit quantum computer by the end of 201,922. IonQ, on the other hand, is a quantum computing software and hardware company based in College Park, Maryland. They are developing a computer and general-purpose trapped quantum ion software to generate, optimize and execute quantum circuits. They have chosen to develop a system based on ion traps and implement an 11-qubit quantum system to run complex algorithms on two-qubit logic gates. However, they have come to hold in chain 79 qubits for simple logic gates of a qubit. Their system has earned them to obtain by the end of 2018 the recognition of the best quantum computer to date in terms of power and performance.

Meanwhile, Microsoft uses topological qubit technology for its quantum computer. Topological qubits are qubits protected from outside noise by doubling their values distributed at two different points. An electronic fraction achieves this: the division of an electron into two whose quantum information is distributed in both parts. This way, if one of the two halves is affected by disturbances, the second half can withstand the first. In addition, topological qubits have been designed with additional protection against interference by a technique called fundamental state degeneration. A qubit is achieved to have two fundamental states discriminated by another technique that manages to differentiate both states, called warped. This differentiation of states is sensitive to changes in ambient noise, so at any time, it is possible to know if the qubits are interfered with about their initial state.

3.3 Complex Systems with Computer Modeling

A system can be defined as a "set of interacting elements" (Bertalanffy, 1968). Complex systems (e.g., multicellular organisms, ant colonies, ecosystems, economies, societies) are characterized by having a structure composed of several levels. In these complex systems (Vicsek 2002; Gilbert 2004), members at lower hierarchical levels often show significant experience. The system's behavior arises from the self-organization of its components without this organization being controlled or directed by any entity outside the system. The essential components of these complex systems (cells, ants, individuals, populations, companies) perceive their environment and respond to changes in it potentially differently.

Nowadays, computers allow us to explore and analyze formal models that we cannot solve mathematically. In this way, we can rigorously implement and analyze the behavior of formal models of complex systems using new technologies, and it was unfeasible until recently. A model that is implemented and runs on a computer is necessarily formal and does not differ substantially from a traditional mathematical model. Both computational and mathematical models are formal models; the only fundamental difference is that they are expressed in different languages. Any computational model can be expressed in mathematical language as a set of equations—potentially complicated to solve—(see, e.g., Leombruni and Richiardi 2005). In essence, a formal model (whether computational or mathematical) can be seen as a set of propositions admitted as true (axioms) plus a set of inference rules that can be used to deduce new propositions from axioms from previously inferred propositions.

3.4 Software with Computer Modeling

Quantum computing, we remember that it uses the laws of quantum mechanics, so the qubits can be in superposition and take values of 0 and 1, or even all values in between. Unlike classic bits, which can take the values 0 or 1, only one at a time.

is Microsoft's open-source programming language for developing and running quantum algorithms. It is part of the Microsoft Quantum Development Kit (QDK), including Q# libraries, quantum simulators, extensions for other programming environments, and API documentation. In addition to the standard Q# library, the QDK includes libraries for chemistry, machine learning, and numerical values.

As a programming language, Q# draws familiar elements from Python, C#, and F#, and supports a basic procedural model for writing programs with loops, if / then statements, and standard data types. It also introduces new operations and data structures specific to quantum computing. One of the first possible quantum computing applications could be the molecule simulator published in 2017 in the journal Nature, where quantum computing is used to model molecules, which is very complicated for classical computers, even for supercomputers. The most widely used language in quantum computing is Python. To work on quantum computing programming, IBM created Qiskit (qiskit.org), open-source software that allows for public and collaborative development. Its primary purpose is to create and manipulate quantum programs and run them in prototypes such as IBM Quantum Experience (quantum-computing.ibm.com) or other simulators. Qiskit can also be installed in Python using the 'pip install qiskit' command and used generally on a Jupyter Notebook. Qiskit is made up of four packages, which touch on different aspects of the quantum world:

- Terra: they are the roots on which Qiskit rests, and this provides a basis for creating quantum circuits and programs.
- Aqua: It is made up of a library of quantum algorithms on which applications for quantum computing can be programmed.
- Aer: offers high-performance simulators for quantum circuits by using realistic simulations that can be carried out with the same errors due to noise that could occur during an actual run-on device.
- Ignis: this package can combat and characterize noise and errors in quantum devices.
- Qiskit started as a prototype, with its first version in March 2017 in the academic world. The most recent version that works stably is from last December 2019. The command 'qiskit.__ qiskit_version__' means.
- With Qiskit, you can create circuits, the classical equivalent of a quantum program. A circuit is a kind of program in which registers are defined as if they were the registers of a microprocessor, and instructions are added, which in the quantum world or Qiskit are gated with which the different qubits are transformed or by making the different operations according to interest.
- Like the first digital computers, quantum computers offer the possibility of exponentially more powerful technology than current systems. They can change companies, entire industries, and the world by solving problems that seem impossible today.

Although progress has been staggering in recent years, quantum computing is still experimental. However, according to the latest research, by 2023, 20% of organizations will budget for quantum computing projects. Experts estimate that by 2025 they will already be able to generate $780 million annually in income and cost savings for all industries that decide to bet on it. As this technology advances, savings will increase, and it is estimated that in 2050 this figure will reach values that will be between 450,000 and 850,000 million dollars annually.

Like all technology in its infancy, quantum computing and, therefore, quantum programming languages face a series of challenges that can hinder their evolution. Quantum programming languages are not necessarily wholly independent but are often built on classical syntax. A primary concern when running quantum programs is the appearance and accumulation of errors. The longer the quantum hardware runs, the higher the error rate. Therefore, it is vital to understand how error correction can be done. It would be advantageous in this situation if the analyzes were done automatically. Although there are different types of analysis, there is one that stands out for its importance, and it is the one that evaluates the uncertainty arising from each line of code.

On the other hand, experts must keep the accumulation of errors to a tolerable level. For this, it would be essential to have reference points to develop optimizations, which allow solving these failures in an organic way and without delays in development. Finally, debugging is another issue to pay attention to because it is difficult to solve in quantum programming languages, and to date, there are no control points available for it.

- The principal quantum number n. This quantum number is related to both the energy and the average distance between the nucleus and the electron, measured in energy levels. However, the average distance in units of length also increases with n. The values of this number, which corresponds to the number of the energy level, theoretically vary between 1 and infinity, but only atoms that have up to 8 energy levels in their ground state are known (since the atomic number and the principal quantum number are related by 2n 2 = z < 110.
- The azimuthal quantum number (l = 0, 1, 2, 3, 4, 5, …, n − 1) indicates the shape of the orbitals and the energy sublevel in which the electron is located. There are s, p, d, f, g, and h orbitals.
- The magnetic quantum number (m, ml) indicates the spatial orientation of the energy sublevel (m = −l,…,0,…,l). For each value of l, there are 2l + 1 values of m.
- The spin quantum number (s, ms) indicates the direction of rotation of the magnetic field produced by the electron when it rotates on its axis. It takes values ½ and − ½.

Turing Machines of Quantum Computing Benioff's quantum computer (sequences of 2-state quantum systems replace the TM tape) Feynman's quantum computer (quantum combinational logic circuit) Deutsch's quantum computer (the first Quantum TM, maintains the tape in computational state superposition).

In complexity theory, the class PSPACE is the set of decision problems that a deterministic Turing machine can solve. We have two large subsets NP and P. P is the class of complexity that contains decision problems that can be solved in polynomial time. P contains most natural problems, linear programming algorithms, simple functions. For example, the sum of two natural numbers is solved in polynomial time

(O (2n)). The NP complexity class contains problems that polynomial-time cannot solve, subdivided into NP-Complete and NP-Hard.

When it is said that an algorithm cannot solve a problem in polynomial time, we always try to find another procedure that can improve it. Complete problems we have: the Hamiltonian circuit, the traveling man problem, which finds the shortest path in a graph from origin to end, passing once through each vertex. The BQP class is defined based on a quantum computer. The corresponding class for a Turing machine is called BPP. BQP contains P and is contained in and in PSPACE. BQP represents the class of algorithms that can be solved in a quantum computer in polynomial time with an average margin of error lower than 1/4. In other words, there is a quantum algorithm whose upper bound in time is polynomial to solve this problem, such that the probability of obtaining a wrong answer is less than 25%. The 1/4 level of error is arbitrary; any real value k such that $0 < k < 1/2$ could be used without changing the BQP set. The idea is that if the probability of error is small, running the algorithm enough times leads to an exponentially small probability that most runs are wrong.

Quantum Algorithms Deutsch-Jozsa5 Algorithm, proposed by David Deutsch and Richard Jozsa in 1992 and later improved by Richard Cleve, Artur Ekert: determine whether a black box type function f: $\{0, 1\} \rightarrow \{0, 1\}$ it is «constant» or «balanced». It is one of the first examples of a quantum algorithm that is exponentially faster than any classical deterministic algorithm. Shor6 algorithm, proposed by Peter Shor in 1995, decomposes in factors a number n into time O (log (n)) 3 and space O (log (n)). It is responsible for much of the attention that has been devoted to quantum computing because of its relationship to the fundamentally important RSA problem in cryptography. Grover7 algorithm, published by Lov Grover in 1996, is a practical utility problem that could be solved faster than the best possible classical algorithm. The algorithm performs a search in an unordered database with N entries in several steps of order $O(\sqrt{}n)$ (sublinear), consuming a memory space of order O(log (n)) (logarithmic).

Imperative Quantum Programming Languages Q language is the second quantum imperative programming language implemented. It is an extension of C++. Functional languages. QFC Uses a type of flowchart syntax QPL uses a text type QML syntax Based on the functional programming language Haskell qGCL Quantum Guarded Command Language (qGCL) based on GCL, created by Edsger Dijkstra. It is a quantum program specification language 4.4. Quantum Computing Simulators C/C++ CHP Eqcs Based in GUI Bloch Sphere Simulator of Quantum–Mechanical gates and Spintronics Java Bloch Sphere Simulator of Quantum–Mechanical gates and Spintronics jQuantum—Quantum Computer Simulator Quantum Algorithm Designer Quantum Search Applet JavaScript jsqis - Javascript Quantum Information Simulator Mathematica QDENSITY Qmatrix MATLAB/Octave CS 596 Quantum Computing Quantum Computing Functions for MATLAB (QFC).NET Cove Quantum Information Suite 7).

4 Methodology

Research is carried out regarding quantum computing and problem-solving aimed at the technological community, with the sole purpose of considering the impact of this technology in each career, so noticing its benefits, supporting ourselves with surveys and two interviews with professors of the technology, listening to their opinion on the subject, the main topic is disclosed and break down with several questions to fill out the information we are looking for.

Information seen in the topic is this: Troubleshooting with a minimal margin of error, advertising the benefit of quantum computing, and problems raised and resolved more effectively public interest in the topic.

4.1 Methodology for Making a Diagnosis

The methodology we employ is empirical, where it will be drawn strictly from concrete and verifiable evidence on the data, broken down into interviews, surveys, and experimentation defining the purpose of what is done supported by theories and literature of the simulator "Q#" where the design, data collection and finally the creation, measurement, and results will be carried out.

4.2 Methodological Approach

Over time technology has evolved, making computers solve problems, mathematical calculations, and programming; we decided to develop this project practically a simulation of movements in 3D objects using Microsoft programming language "Q" where it will represent so that we can observe its behavior and the time it takes to perform these operations. Since quantum computing is pervasive and too complicated to carry out, our options are limited when it comes to the present since its costs are high (Table 1).

Blender is a cross-platform computer program dedicated to modeling, lighting, rendering, animation, and creating three-dimensional graphics and digital composition using the procedural technique of nodes, video editing, sculpture (includes dynamic topology), and digital painting.

Table 1 Survey scale

1	2	3	4	5
Never	Rarely	Often	Frequently	Always
Very poor	Poor	Fair	Good	Excellent

The program was initially distributed for free but without the source code, with a manual available for sale, although it later became free software. It is currently compatible with all versions of Windows, macOS, GNU/Linux (including Android), Solaris, FreeBSD, and IRIX.

> NeoAxis Engine 2020.4 Released - Full source, NeoAxis Token. This version is mainly a restructuring of the SDK due to the change to a schema provided by the source code. You can easily work with all sources and debug your project more effectively. Starting with this release, NeoAxis opens a new product usage target that is not directly related to 3D and 2D. This is the creation of window applications. In the SDK, you can find the Sample Window application demo. In addition, to accelerate the development of NeoAxis Engine, our company invites investors. At the end of the news, you can find information on the progress of mobile device support.

4.3 Microsoft Quantum Development Kit: Getting Started

Krysta Svore, the principal researcher at Microsoft, shows the new Microsoft Quantum Development Kit, now in a preliminary version.

The quantum development kit makes it easy for you to start experimenting now with quantum computing and includes:

- A native programming language centered on the quantum called Q#.
- On-premises and Azure-hosted simulators for you to test your Q solution #.
- Sample Q# code and libraries to help you get started.

In this demonstration, we walk through code examples and explain quantum principles such as overlap, and entanglement apply. It explains how quantum communication works using teleportation as its first “Hello World” inspired program. Moreover, keep looking to see more complex calculations with molecular hydrogen.

The open-source quantum development kit for Q# and Azure Quantum enables quantum applications that are durable for today’s quantum hardware and future scalable hardware. Optimization is a class of problems whose solutions are the leading candidates to run on scalable quantum computers. Therefore, optimizing specific processes is beneficial because it can perform multiple calculations that today are impossible. Above all, the capacity in computers is minimal compared to quantum supercomputers. The Quantum Development Kit also provides tools for formulating optimization problems that run on large-scale or hardware-accelerated computing resources in Azure. We can access quantum computing and cloud optimization solutions through a development interface, which can leverage unique capabilities offered and optimization solutions.

Quantum computing uses a type of operation called teletransportation, which becomes fundamental to quantum algorithms and an excellent manual to begin its journey through quantum computing. Teletransportation allows communication between the quantum bits of a single piece of quantum hardware or even between remote quantum computers, serves as a basis for a future quantum internet and shares many quantum operations, algorithms that can be created and developed.

Each qubit is assigned a name message and can encode the qubit message per message, applying an X operation, an analog of a NOT that is of the classical logic. Therefore, if the message becomes 1, operation X is applied to the flipping of the qubit message, its state to teletransportation of the message. The two qubits are taken as input messages. The first step is to assign one more qubit, and we call it here; it is also initialized in the state 0. Now we use the H operation or Hadamard gate to place our qubit here in an overlapping state H takes the state from 0 to 0 plus 1 and the state from 1 to 0 minus 1 remembers that a qubit is a quantum bit is information and can be in a supposed superposition of values not just 0 or 1 as a classic bit, but a combination of 0 and 1. This leads to a massive parallelism that we can explore in quantum algorithms and is an essential quantum operation that we will use at the beginning of most quantum algorithms.

Bits are intrinsically related; if I do something to one of them, it instantly changes the state of the other, even if they have spread through the universe of each other. This interlaced pair is a crucial resource for sending a message. The development kit comes with an integrated universal quantum simulator that can run small instances of your quantum programs on your local hardware for around 30 simulated qubits. The qubit restriction is driven purely by your development machine. In general, 16 GB of RAM are needed to simulate 30 qubits, simulating one more qubit requires twice as much memory simulating one less half of the memory, simulating 40 qubits requires about a thousand times more memory than 30 qubits that have around 16 terabytes, so it also offers a hosted simulator and elbows that come around 16 terabytes, so we also offer a hosted simulator and Azure allows you to go beyond 40 qubits to try the program they offer.

5 Conclusions and Industrial Implications

The primary information obtained in this case would be the results of each question will generate a graph to understand the information collected and represent it graphically so that it is accurate and precise and can be interpreted more straightforwardly for the reader.

Nowadays, we are exposed to technological progress since classical computers show excellent progress, especially their capacity. These will increase linearly and in terms of their differences to quantum computing because its advance and growth would be exponential.

As verification, we could observe that the resolution made by the quantum computing simulator provided by Microsoft (Q#) to perform and program the calculations is optimized and efficient way when solving the problem. Through updates that are being implemented, besides solving mathematical problems, it is to simulate different aspects and environments of animations, referring to flights, races, and medical operations and in the industrial sector.

References

Bertalanffy, L.: General System Theory. George Braziller Publisher, New York (1968)
Evgeniou, E., Loizou, P.: Educación quirúrgica basada en simulación. ANZ J. Surg. **83**, 619–623 (2013)
Gilbert, N.: Agent-Based Social Simulation: Dealing with Complexity. Centre for Research on Social Simulation, University of Surrey (2004)
Health Nology: La computación cuántica, el último aliado de la salud. Health Nology (2020). https://www.healthnology.es/la-computacion-cuantica-el-ultimo-aliado-de-la-salud/
Kelly, J.: A Preview of Bristlecone, Google's New Quantum Processor (2018, 5 marzo). https://ai.googleblog.com. https://ai.googleblog.com/2018/03/a-preview-of-bristlecone-googles-new.html#:~:text=Bristlecone%20is%20Google%27s%20newest%20quantum,qubit%2C%20with%20nearest%20neighbor%20connectivity
Kneebone, R.L.: Pratica ensayo y actuación: un enfoque para el entrenamiento quirúrgico y de procedimientos basado en simulación. JAMA **302**, 1336–1338 (2009). https://doi.org/10.1001/jama.2009.1392
Linke, N.M., Maslov, D., Roeteller, M., Debnath, S., Figgatt, C., Landsman, K.A.: Experimental comparison of two quantum computing architectures. Proc Natl Acad Sci 114 (2017)
Leombruni, R., Richiardi, M.: Why are economists sceptical about agentbased simulations? Phys A: Stat Mech Its Appl 355(1):103–109 (2005)
Shor, P.W.: Scheme for reducing decoherence in quantum computer memory. Phys Rev A 52 (1995)
Thiago de Oliveira, E.: Inteligencia artificial, computación cuántica, robótica y Blockchain. ¿Cuál es la realidad de estas tecnologías en los tiempos actuales y futuros? Revista Científica Multidisciplinar Núcleo do Conhecimento (2019, 21 junio). https://www.nucleodoconhecimento.com.br/administracion-de-empresas/inteligencia-artificial-2
Vicsek, T.: Complexity: the bigger picture. Nature 418(6894):131; Avelar-Sosa, L., García-Alcaraz, J.L., Castrellón-Torres, J.P.: The effects of some risk factors in the supply chains performance: a case of study. J. Appl. Res. Technol. **12**(5), 958–968 (2014). https://doi.org/10.1016/S1665-6423(14)70602-9

Unemployment in the Industry with the Arrival of Robotics in Mexico

Bogart Yail Márquez

Abstract The following research will demonstrate the impact of robots on unemployment in industry and how the replacement of humans with machines has changed. In addition, due to the statistics found in the information collected throughout the investigation, a more precise idea will be given of the risk that some workers run that their employment is threatened by robotization, the consequences that this entails if it should it occur. Likewise, the most important reasons that some companies might consider for making the decision to implement a significant change in their way of working are considered, be it the savings in labor costs that they could have thanks to robotics or the evolution of technologies. Global sales that robots have had in the industry. Finally, robotization, it is possible to give us an idea of what could happen over the years, the implementation of software algorithms is possible to have a clear vision of the future impact on society.

Keywords Robots · Unemployment · Society impact · Automation · Software · Algorithms

1 Introduction

At the present time, we live in a society that constantly changes, science and technology develop fast, brings great benefits in the long run for humanity, but every great change implies relevant consequences, which perhaps at first did not take on the importance that they should, but that after a while they become present and can become considerable. The specific benefit to which we refer thanks to the development of technology is the impulse of robotics, which can give us multiple advantages, such as greater productivity in companies, cost reduction, or the capacity of the robots

B. Y. Márquez (✉)
Systems and Computing Department, Master's in Information Technology, Technologico Nacional de Mexico, Tijuana Campus, Mexico City, Mexico
e-mail: bogart@tectijuana.edu.mx

Industrial Engineering Department, Technologic Nacional de Mexico, Tijuana Campus, Mexico City, Mexico

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_8

to work 24 h a day, but not everything is profit with this new way of working, since, without realizing it, this situation can affect many people causing a mismatch in the labor market, and therefore, a decrease in jobs. Due to that importance, that will be the topic that is shown below: Unemployment in the industry with the arrival of robotics.

2 Problem Statement

2.1 Project Problem

Unemployment in society today is a growing problem in people's lives, since having a job represents the income that allows people to survive. However, there are several factors that cause unemployment, but, in this case, we will focus on how the arrival of robots has affected the fact of having to replace a person, and therefore, leaving them without their job. It is worth mentioning that not all tasks carried out by humans will be replaced, but there will always be a percentage of unfortunate people who can lose their jobs due to robots. A study conducted by MIT from 1990 to 2007 tells us "That each manufacturing robot destroys 6 jobs, in USA" (MIT 2018). Now let's think about what it is like in the rest of the world and how many jobs have been destroyed.

2.2 Justification

Unemployment can be defined as "people of working age who are in forced unemployment, outside of any productive activity and, consequently, without the possibility of generating their own income" (Galindo 2015). This problem is something that has been existing for many years, it is well known that there are different causes why this problem arises, however, with the arrival of new technologies and automation of processes, the work of workers has shifted to a second plane, since human labor is still required, but it is no longer so essential, thus causing less use of them, since for companies the use of these machines represents a lower cost and/or a profit in the productivity compared to human labor, since its performance and cost is much lower than what an industrial robot offers to companies.

Now entering the context of the subject, we choose to limit this research to Mexico because although it is true that the world is constantly changing in terms of technologies and it can be said that Mexico is not as developed as other countries in which it seems that they are years later on, the truth is that if these technologies have been used in the jobs of this Country and unemployment is something that has been happening in recent years as new technologies (industrial robots) have emerged here. Despite this, we want to investigate how the fact of having to implement robots and thus automate processes has impacted our country, but at the cost of replacing people, as well as knowing the opinion of these people. With this research we intend to determine a midpoint on the situation of the impact of the use of robots in industries about the unemployment that this can cause, since the information that is had is divided between that the use of this technology will not generate unemployment, since that will open the doors to other jobs and among the fact that this will generate unemployment even though other jobs will generate the need for human work will be less required. This is a dilemma for which we want to give our opinion based on what we will investigate next.

3 State of the Art

At this point we will address some key concepts of the research, as well as important points of the investigated topic. First, we will know the definition of industrial robots and we will also briefly see a little about how robotics has evolved from its beginnings to the present, as well as the definition of robot, we will also give a brief explanation about what employment and unemployment are, equally In this way, we will address the main reasons for unemployment in Mexican industries in relation to robots and how this has affected people not being able to get a job.

Industrial robots are robots designed to work in manufacturing, ideally in industrial production plants, today most robots are installed in vehicle assembly lines, these robots normally work in cells separate from humans to avoid accidents, however with the arrival of the collaborative robots this is changing. These robots are generally mechatronic arms that have sensors and actuators that allow them to make different movements to perform different functions, such as (Martinez 2020):

- Welding
- Packaging
- Loading
- Assembly
- Classification
- 1947: The Original Idea: Physicists John Bardeen, Walter Brattain, and William Shockley develop the first transistor at Bell Labs. Heinrich Grunebaum developed the Alquist engine, which became the godfather of controlled engines. It revolutionized rewinding processes in many years (60) of automation technology.
- 1959: First computer-controlled machining tool. The first Simatic controller on a capstan lathe was presented at the sixth version of the EMO fair in Paris. The logic was still hardwired.
- 1967: Before power electronics: Before diodes, thyristors and IGBTs were available, currents were rectified with selenium rectifiers, or giant mercury arc rectifiers emitting mysterious blue light. Electronic units. In 1967 AMK introduced the first mass-produced infinitely variable three-phase squirrel-cage current motor. Eight

years later another AMK innovation allowed several three-phase motors to be operated with angular synchro for the first time.
- 1968: PLC: The success story of the PLC began with Dick Morley's Modular Industrial Control
- 1978: As for machines: the programming devices of the pre-PC era were very big and heavy. CNC machine programming—once again introduced by AMK represented a remarkable process.
- 1987: Coincidence: A customer requested that a Beckhoff control system be equipped with a hard drive. The simplest solution was to integrate a PC. It soon became apparent that the PC could do more than act as a data collector for the control system, and the era of PCs in the automation industry began.
- 1997: Integration push: Automation technology increasingly consists of intelligent, decentralized control and with control components that can communicate with each other via Industrial Ethernet. Digital Factory and Virtual Commissioning: The world of digital product development merges with automation technology. Control programs for production processes are developed based on simulation.
- 2004: The functionality of the PLC was discovered on a chip.

What is a Cobot? "On paper, collaborative robots are those that are de- signed to work together with human personnel, being able to even share the same space safely. Thanks to this combined man–machine way of working, manufacturers take advantage of technological tools such as their precision, speed, and effectiveness over time, while benefiting from the intellectual capabilities of human personnel free from tedious or compromising tasks. Your safety. Cobots, as they are also known, are usually relatively small, articulate and with the ability to perform the same activities that a human hand could do, with the appropriate components." (EDS Robotics 2021).

The word employment refers to both a job and an occupation or trade. However, the most widespread use of employment is that which indicates all that activity where a person is hired to perform a series of specific tasks, for which they receive financial remuneration. The word employment derives from the verb" employ", which in turn comes from the French employer, and means" action and effect of employing." Hence, it can also refer to the use made of something, for example," The use of renewable resources in the construction of houses mitigates the environmental impact" (Enríquez 2015).

On the other hand, the opposite of employment is unemployment, that is, people of working age who are in forced unemployment, on the fringes of any productive activity and, consequently, without the possibility of generating their own income. It refers to the situation in which an individual lacks employment and salary. The terms unemployed are also used as unemployment in some countries. The unemployed person is characterized by having an average age to be active (between 18 and 65 years old), having a willingness to work, being in search of a job that nevertheless cannot obtain any job (Galindo 2015).

McKinsey Global Institute (2017) affirms that automation and robotization put 52% of jobs in Mexico in check. This is equivalent to 25.5 million jobs that are at risk from the so-called fourth industrial revolution. How many of these jobs will disappear? They also affirm a projection that serves to draw a map of occupational risk: the most vulnerable activities are routine and take place in predictable environments. In Mexico, retail is the sector with the most jobs at risk, 5.5 million; it is followed by manufacturing, 4.9 million; agricultural activities, 4.7 million and construction industry with 1.6 million. They also point out that low wages in Mexico will lead to a less intense impact of automation in the Latin American country: of the total of 68 million people who will make up the Mexican workforce in 2030, about 9 million will be displaced.

> Mexico has a young population and a growing workforce. The level of salaries can decrease the implementation of automation in the country. (McKinsey 2017)

Both robots and Robotic Process Automation (RPA) they have become an imminent reality for the industry. In recent years, we have witnessed how various companies have entered this field for various purposes, such as avoiding repetitive tasks that do not require the human intellect to complete, streamline processes or allocate resources that were previously used in automatic activities. To execute others in which greater value is generated. Most of these organizations are in the discovery phase (that is, socializing concepts, options, and risks with various stakeholders) or are still exploring the business case for RPA, through short, evidence-focused engagements. Value that justifies your investment.

A Deloitte survey of RPA Centers of Excellence (CoE's), during 2017, it shows that 53% of the participating companies have already started their foray into the world of robotics and that 73% of them plan to increase their investment in the matter in the next three years. However, when analyzing the results, we found that only 3% of the companies surveyed have managed to scale their digital workforce. Most of these organizations are in the discovery phase (that is, socializing concepts, options, and risks with various stakeholders) or are still exploring the business case for RPA, through short, evidence-focused engagements. Value that justifies your investment (Deloitte 2017).

A survey done by the OECD (2018) interviewed young people aged 18–24 and indicated that almost half are resigned to not having access to permanent employment due to automation, although 63% are enthusiastic about the possibility of working flexibly. At the same time, 62% feel confident that they will find the job they want, but 44% think that the skills they learned will not be required. 58% already know what they want to do in 10 years; however, 71% say they wanted more vocational help from their schools.

According to the OECD (2018), these are the main reasons why a robot is better than a human being in a job.

- In terms of production, they are more productive, such as lower manufacturing costs and more efficient resolution (speed and quality).
- Thanks to automation, we live in today's technological world.

- They have a very small margin of error, and this can produce millions of articles in series all the same, with practically no differences.
- Robots have much more flexibility than humans since those in charge of the machines just must program them and that's it. And thus, discussions between employees and the manager are avoided.
- From the point of view of entrepreneurs, robots are better because humans are not as efficient and have physiological needs, such as rest, among others. With which they do not take advantage of the time 100.
- Robots can fill jobs or jobs that may be unsafe for a human being.
- To support this information, Deloitte exposes reasons like what the OECD says, "Next, we tell you the main advantages obtained thanks to robotics programs and that organizations approve with authority are the following:

  - Higher productivity
  - Cost of implementation
  - Improved compliance
  - Cost reduction
  - Flexibility to expand or reduce capacity
  - Punctuality/ability to work 24/7
  - Availability of better management information.

Among the seven advantages mentioned, we want to place special emphasis on the first three; and it is that more than 90% of the organizations believe that the programs with robots have exceeded their expectations in terms of productivity, implementation costs and improvement of compliance" (Deloitte 2020). Mexico ranked as the fourth world importer of industrial robots, behind China, Germany, and the United States, according to figures from the World Trade Organization (WTO), which show the increasing level of automation in the country and that goes hand in hand with the digitization of the manufacturing sector. Mexico imported industrial robots worth 158 million dollars (mm) in consolidated figures to 2016, while the first place corresponded to China, with 878 mm; followed by Germany, with 346 mm, and the United States of America, with 291 mm.

A new study has looked at something more quantifiable: how new technologies are changing employees' daily jobs right now. According to this report by researchers from the University of Illinois (2019), which focused on the automation of work in warehouses, "emerging technologies will not replace the more than one million employees who currently work in warehouses in the short term. Centers, but it can make life more difficult for them in the next ten years". Just as computers changed our way of life in the past, the report shows how technologies do today with the daily work of those who organize, store and package products. Automation can help workers by reducing" monotonous and physically strenuous activities," such as lifting heavy packages, but they also had a downside: They affect their health and morale, as they are pressured to work faster. And under increased scrutiny. In other words, productivity is boosted, but negatively impacts employees (Vox 2019).

3.1 Software in Robotics

While the digital revolution requires workers to develop new skills to move towards the future of employment, only 20% of the employed population in Mexico has the possibility of job training, the rest will have difficulties responding to the new demands of the labor market, explained Omar Estefan, in charge of the office of the Undersecretariat of Social Security, of the Ministry of Labor (STPS). When participating in the inauguration of the forum The Future of Work is Now, convened by the Organization for Economic Cooperation and Development (OECD), the official stated that the challenge of job training is great and the reality that exists in the country is that half of the employers prefer to hire new collaborators before investing in the training of their employees.

At the meeting, Paolo Falco, director of employment and social affairs of the OECD, stressed that training is one of the main challenges for Mexico. To solve this problem, as well as that of informality in the labor market, more public resources are needed, Falco emphasized, and these can be obtained by expanding the tax base, that is, by increasing taxes, he said. The risk of not addressing this situation as soon as possible is that" social tensions" will be generated. Spending is essential, as this could worsen in the coming decades, he insisted. The specialist recalled that according to the OECD study" The Future of Work", 14% of jobs in this country could disappear due to automation. However, Omar Estefan went further and cited data from the Bank of Mexico: in agriculture 97% of jobs are at risk; in construction, 84%, and in manufacturing, 85%.

There are some types of software that can be known as:

1. Offline Programming

RoboDK's most loved software category, Offline programming software provides a way to program your industrial robot without the need to be physically connected to the robot at the time. This means that you do not need to take the robot out of your production process to program it. This reduces downtime, improves scheduling quality, and allows you to quickly switch between product lines, among other benefits. Offline programming market is quite fractured, with packages often tied to individual robot brands. Then there is offline programming software that can be used with any brand of robots, like RoboDK.

RoboDK is a simulator focused on industrial robot applications. This means that robot programs can be created, simulated, and generated offline for a specific robot arm and robot controller. In other words, RoboDK is software for offline programming. Creating a program for a robot requires selecting a robot, loading the robot's tools, and using one or more CAD-to-path features to create programs by adding destinations or using specific tools (such as converting from CNC programs to robot programs).

An extensive Library of industrial robots is available. Industrial robots are modeled in RoboDK in the same way that they behave using vendor-specific con- trollers, including axis limits, direction of motion, and axis link. Offline programming means programming robots outside of the production environment. Offline programming eliminates the production decrease caused by in-plant programming (teach pendant programming). Simulation and off-line programming allow you to study multiple scenarios of a work cell before setting up the production work cell. Errors commonly made in the design of a work cell can be predicted over time. Offline programming is the best way to maximize ROI for robotic systems and requires appropriate simulation tools. The time for the adoption of new programs can be cut from weeks to a single day, allowing the robotization of production in the short term.

3.2 Simulators

Robot simulators come in many forms. Some only allow simple 2D simulation of specific aspects of robotics, while others include 3D simulation with complex physical engines and realistic environments.

If you want, you can spend a lot of time testing all the different simulation packages available, the usability and quality of these vary greatly. Unfortunately, it is difficult to tell in a promotional video how easy it is to use a simulator. You have to go out and try it for yourself.

Besides being an offline programming tool, RoboDK is also a great simulator. It is simple enough to allow you to easily program your robot while being powerful enough to handle many different use cases. Some examples of simulation in robotics are:

- CoppeliaSim is a program to model and simulate any type of robots. Perhaps the most complete option and therefore the most complex.
- FreeCAD is a fantastic modeling tool that also provides a simulation envi- ronment of a 6-axis industrial Robot, such as Kuka.
- WeBots, provides the necessary interfaces to simulate a 3D robot.
- Open Roberta Lab is a block programming environment based on the cloud, which allows programming in a simple way, some of the most used robots. In 2D.
- VEXcode VR, allows programming a virtual robot using a block environment similar to Scratch, or a text console (Python).
- EXTRA: One of the best robot simulators out there today is Gazebo. Dynamic simulation, advanced 3D graphics, sensors and noise, plugins.

3.3 Middleware

One of the most misunderstood types of robot software is middleware, the most popular is ROS (Robot Operating System). Robot middleware provides a framework for running and managing complex robotic systems from a single, unified interface.

In other words, it is software that sits between an operating system and the applications that run on it. Basically, it works as a hidden translation layer to enable communication and data management in distributed applications.

Some people describe it, middleware is the" software glue" that helps robot builders avoid reinventing the wheel when designing a new robotic system. You probably wouldn't use middleware to control a single robot on a production line. However, if you are building your own robotic system with multiple components or looking to coordinate multiple robots, you could use middleware to make life easier during the scientific research and technological development (R&D).

There are as many development technologies as there are types of middleware. Some of the most common are in Java language (containers EE, EJB, RMI, CORBA, AJAX...), .NET, Microsoft (ASP.net), PHP with Laravel, JavaScript (Node/Express, Angular), etc. All of them are very powerful and generally the choice of one or the other is conditioned by the type of development to be carried out, the execution environment and the skills of the personnel dedicated to maintaining the solution.

3.4 Planning of Mobile Robots

Mobile robots are programmed differently than other robots, which means using a different type of software. For example, route planners are used to programming the robot's path through the environment, while obstacle avoidance algorithms react to changes at the moment. Many exciting software tools are available for programming mobile robots, ranging from warehouse logistics to autonomous vehicles.

The tasks involved in navigating a mobile robot are perceiving the environment through its sensors to create an abstraction of the world, planning an obstacle-free path to reach the selected destination point, and guiding the vehicle through the constructed reference. Simultaneously, the vehicle can interact with some aspects of the environment. Thus, the concept of operation is defined as the onboard tools' programming that allows it to perform the specified task. An example of this last notion is the automatic transport of materials and tools within a flexible manufacturing cell (FMS), which implies not only the physical movement of said elements from the material input station to the machine that requires it but also can perform operations such as automatic tool change or automatic material unloading on the machine that has requested it (Newman and Kempf 1985).

The system comprises two parts: a hardware part and a software part. The physical devices that make up the hardware part are the mobile robot, a computer, and the Wi-Fi connection. The software includes the developed tool, an operating system on which it runs, and a series of libraries that allow us to communicate with the robot through connection instructions, movement, or image capture. The application runs on the computer, connecting with the mobile robot through Wi-Fi. The mobile robot used is the SRV-1 model with a stereoscopic vision system from the Surveyor company. The stereoscopic vision system comprises two cameras, each including its processor. The application runs on the .NET Framework on the Windows operating system. It is implemented in the C# programming language and developed in the Microsoft Visual Studio programming environment with the help of the TrueVision 3D graphics engine.

3.5 Real-Time Route Planning

Route planning software is used in many areas of robotics. Like our PRM feature, primary route planners are used to speeding up industrial robotics' programming phase. Real-time route planning is much more complex than essential route planning because it continually updates the program to respond to environmental changes.

This allows the robot to be reactive and makes the robot more insecure. Software companies specializing in real-time route planning tend to focus their efforts on only one type of robots, such as humanoid robotics, mobile robotics, or robotic arms.

The mobile robot used is the SRV-1 model with a stereoscopic vision system from the Surveyor company. The stereoscopic vision system comprises two cameras, each including its processor. The application runs on the .NET Framework on the Windows operating system. It is implemented in the C# programming language and developed in the Microsoft Visual Studio programming environment with the help of the True Vision 3D graphics engine. The tool performs the planning of trajectories between the initial coordinate (the situation where the robot is) and a destination coordinate that is indicated. In addition, it simulates road planning with scenarios previously loaded with obstacles, or we also have the possibility of recognizing that terrain through image analysis through stereoscopic vision. Therefore, the user will see what situation the robot is in and what it can see from its cameras in the first person.

3.6 UAV Control (Drone)

A growing type of robotic software is drone control. This refers to any software that is used to program and coordinate UAVs (UAV/drones).

There have been a growing number of application areas for drones in the last decade or so, with drones now used in agriculture, inspection, and security. Drone software focuses on particular application areas or aspects of drone control (e.g., data collection, image analysis, mapping, among others).

IAI Heron, also known as Machatz-1, is a UAV (Unmanned aerial vehicle) Israel´ı, developed by Malat, a division of the Israel Aerospace company.

Industries. His way of operating has also given him the qualification of MALE (Medium Altitude Long Endurance). These operations last approximately 52 h at an altitude of 35,000 feet. Although it has been shown to perform 52 h of continuous flight, the maximum operational duration of the flight is less due to the flight pattern and the plane's load.

This last system already integrates PID control to stabilize the flight, but it needs a pilot on the ground to always direct it. The following systems have a more advanced control that allows them to be autonomous when performing a task:

INRIA in France is developing vehicles to follow a predetermined route and solve problems that may arise along the way (EOL/Liliana Toledo). The French National Institute for Computer and Automation Research (INRIA) is working on solutions to meet quality transportation needs. It uses a PID controller to control the different speeds that a vehicle can reach in the city. It could stabilize the system at a constant speed, facilitating energy savings. The so-called Cybercars are fully automated road vehicles with driving capabilities. They require the vehicle's location within the city and its ability to know where it can and could move, considering the obstacles and unevenness that are found on the road. All this is thanks to a system called SLAMMOT, which allows locating and detecting objects and their movements so that the car can create a map in real-time.

3.7 Artificial Intelligence for Robots

Moreover, finally, we can talk about artificial intelligence (AI) used with robotics for many years, almost as long as robotics has existed. However, recently there have been a growing number of software solutions specifically for using AI with robots in particular application areas.

As with the other types of robot software, AI tends to focus on specific aspects of these applications, such as analyzing images collected in agricultural environments, filtering operational data in manufacturing environments, or coordinating swarms of mobile robots in logistics.

In one of its latest updates, UiPath, one of the leading RPA manufacturers (partners), highlighted the incorporation of Artificial Intelligence into its software robots. Nevertheless, what can AI bring to this technology? In which specific use cases can it be applied? In this article, we answer these two questions. Read on and discover the future that has already arrived.

Software robots are not a new tool, although many companies still do not know them or know the potential they can have. Both the evolution of the market and the new behavior of consumers and users, directed towards a clear digital trend, have boosted the digital transformation in organizations.

This has caused us to find ourselves in the ideal scenario to continue investing in new business solutions and directing the strategy to the search for an optimization of the processes that take place in an organization.

Artificial Intelligence is a concept that can be applied to different tools to provide them with more excellent functionalities and enhance their capacity in certain aspects, such as autonomous decision-making.

4 Methodology

Methodological approach to conclude this issue, we will use tools that help us collect data and use a database. As the primary tool, we will use a survey designed to gather information to know the workers' points of view. As a secondary tool, speaking of the database, we will use the one provided by INEGI. They provide us with data about the Non-Economically Active Population located on their website.

Sample Definition. We decided to define the sample in the company called Jabil Healthcare, and we decided that they were employees of common areas, since the tasks in these types of areas usually use robots such as parts assembly, component manufacturing, material packaging, to mention some examples of the tasks performed by robots. The survey that was carried out has ten multiple-choice questions to gather different opinions and quickly compare the results with the data obtained. Finally, we received 40 results since this was shared with small company workers.

Data Collection Strategies Due to the type of research we are planning to carry out, we consider that the types of data that we should focus on were two:

- Processed data: This type of data was considered since it is distinguished by being previously verified and analyzed, which would greatly help our research due to the results we intend to make known.
- Data analyzed: And finally, this type of data was also considered in the graphs, models, tables, etc., that could help us to obtain valuable information, in addition to being able to guide us towards a conclusion regarding the development of the topic.

The instruments that we used to obtain the information that we considered necessary for the subject in question were databases that contained helpful information on the current situation of people talking about unemployment in our country. Finally, it was also necessary to use surveys as an instrument. In this way, we could get an idea of how industrial robotics works or what effect industrial robotics has on a company in the city where we live and obtain closer data on local unemployment.

- Databases on the subject. It showed relevant information about the unemployment that existed in 2019. Since we took that year due to the pandemic, we did not want to take the year 2020 as a base due to external issues of the people.
- Surveys. In it, we will show the point of view of the company's people to know and analyze to give a more accurate conclusion about the effect that robotics has on people's employment.

Data Analysis Strategies. To better analyze all the information that we were able to obtain on this subject, first, with the surveys carried out previously, we will make graphs to visually analyze the opinion of workers on the subject in question. Then, with the INEGI database, we will summarize the data shown there to be more precise about how unemployment is in our country. Moreover, finally, we will see how the data in this database is related to the analysis of the surveys.

5 Results and Analysis

With the growth of technologies, the implementation of robots in the industry has become a necessity in companies if they want to become or remain competitive. Because of this, it was thought that everyone would lose their job, but the reality is different since the main ideas of this were based on fiction, where they show you that robots completely replace humans and go to be dominated. Thanks to this unfounded fear and the unemployment that exists today in our country, this raises doubts regarding the use of robots in industries.

Throughout the investigation, we have realized that you are not fired on the bosses' whim but because of the benefits that a robot can give to the company that uses it. We could see unemployment in 2 different ways, and the first view is due to the human factor. According to data provided in the INEGI database in 2019, there is a population available, which means that people have given up or lost their job. Interest in finding a job is equivalent to 14% of the population of 38,218,968 unemployed. With this factor, a population stopped looking for a job and therefore stopped insisting.

The second view is due to the robots factor; the jobs they have taken are because their benefits are greater than having a person hired. Some of the benefits of being automated with robots are the following:

- In terms of production, robots are more productive, such as lower manufacturing costs and more resolution efficiency.
- They have a minimal margin of error, which can produce millions of articles in series all the same, with practically no differences.
- Robots have much more flexibility than humans since those in charge of the machines have to program them, and that is it. Moreover thus, discussions between employees and the manager are avoided.
- Robots are better because humans are not as efficient and have physiological needs, such as rest. With which they do not take advantage of the time 100%.
- Robots can fill jobs or jobs that may be unsafe for a human being.
- Now, how has the arrival of robots impacted the industry? We can divide this in 2 ways, positively and negatively. Focusing first on the negative, the implementation of robots carries some risks and challenges for organizations. According to German Ortiz for Deloitte (2019) are the following:

  – Technological risks. Vulnerability in cybersecurity and data privacy, as robots detect, generate, and process data about their environment and human beings. The complexity of algorithms and new risks arising from machine-to-machine interactions act independently.
  – Operational risks. Lack of operational and physical controls for the incursion of robots in less controlled environments outside the manufacturing plant. Risks of business continuity and resistance (as the degree of dependence on robots increases, organizations can become inoperable), and security problems in the workplace, when sharing, robots and humans, the physical space.

- Legal and regulatory risks. Regulation of norms and standards on the use of robots in various sectors, applications, and environments that carry risks of non-compliance; lack of compliance and assurance mechanisms that are applicable and appropriate for robots. Liability issues arising from robot-related accidents and forensic investigation challenges in robot situations.
- Strategic and reputational risks. Organizational strategy not adapted to address the competitive risks of the rapid proliferation of robots; loss of trust and reputation of the organization in security matters or ethical violations by robots.
- Financial risks. Risks associated with capital-intensive projects for the massive deployment of robots, such as loss of investment or deficit in returns.

Having talked about the risks involved in having robots within the company, it is necessary to mention another negative aspect, which is the dismissal of certain people who worked in an area where they will be the most affected by this change, during 1997–2007 it was estimated that one robot could destroy up to 6 jobs. Today it is estimated that only specific sectors are in danger of being automated. The sectors with the highest risk in Mexico, according to the McKinsey Global Institute (2017) "They are the retail trade, with 5.5 million jobs; manufacturing follows, with 4.9 million; the agricultural sector, with 4.7 million; accommodation and food services, with 4.7 million, and construction, with 1.6 million jobs that are in danger of being replaced by machines".

On the other hand, once the negative aspects of the implementation of robots have been discussed, the positive things continue. Thanks to automation, we live in the technological world today. The incorporation of robots cannot be left behind since, as we mentioned before, from the benefits, we can affirm that leaving a sector of people without a job will create new opportunities, performance, and lower risks so that companies can remain competitive. According to OECD research (2017), "Companies that use technological innovations effectively are between 2 and 10 times more productive than those that do not".

According to a study carried out in 2017 by the McKinsey Global Institute in Mexico, it represents a potential of 52% of jobs that can be automated, replaced by robots. In accurate figures, this translates into 25.5 million of the 49.3 million jobs in the country (see Fig. 1).

Concerning the survey carried out by INEGI, we can see that if this were to happen, there would be approximately 25.5 million unemployed for automating said position and more than the 5,667,986 million people who give up looking for a job. This would be a problem for the country since if we add the 5.6 million people with the 25.5 million jobs at risk, this will cause a big problem for people who want to succeed. It should be emphasized that this is only a guess on the idea of this robotics effect. Experts affirm that this situation could arrive in the year 2050 with a prolonged effect since the replacement will be so that companies adapt to new technologies and know which positions will be automated. We realize that the effect is minor, but it will eventually be more significant with the passing of the years and technological advances.

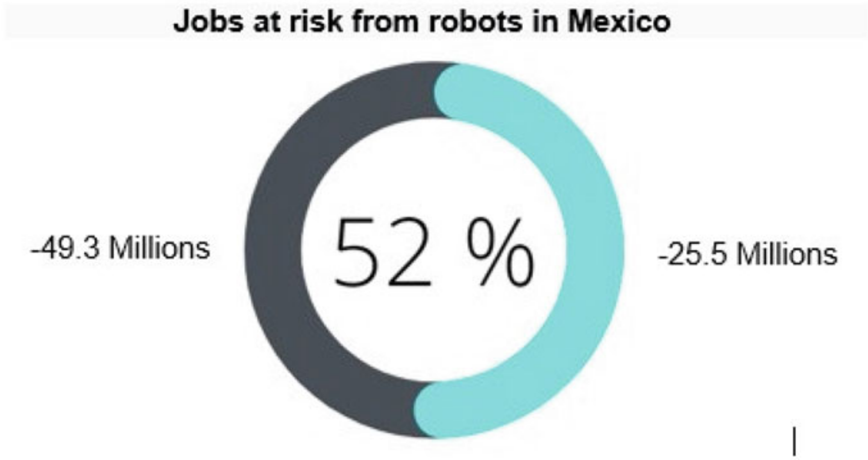


Fig. 1 Graph "Jobs at risk from robots in Mexico". *Note* Chart made by us with data from McKinsey

Focusing on Mexico, its impact is mainly beneficial for our country. According to the World Trade Organization (WTO 2017), "Mexico ranked as the fourth world importer of industrial robots, behind China, Germany, and the USA". These figures are, without a doubt, a sign of the growth that Mexico has had in the degree of automation that we have in our territory, through robotization, and growth has been observed in the areas of electronics and medical devices, food and beverages, packaging, pelletizing and in the industrial zone. Part of this figure mentioned above was thanks to KIA Mexico, where it bought more than 437 million dollars in 2015, only behind China. In recent years, it has been seen that we have reached a better position in different Latin American countries.

In the manufacturing industry, it is more common to see that collaborative robots, called Cobots, are used more. Unlike machines on large assembly lines, these machines are used for more straightforward tasks. Where there is more demand for the use of cobots is in the sector of small and medium-sized companies (SMEs) where 72% of the Economically Active Population (EAP) is used, so that they can automate processes that are very exhausting for human beings being able to leave the operator without a job, however since these cobots are harmless, if the company requires it, it is possible to put a human to work on a par with the cobots (see Fig. 2).

In general terms, the availability of work in Mexico will not be destroyed. However, new demands will appear since robots will merely complement and improve tasks in conjunction with the worker. It is estimated that at least 10% of the jobs in Mexico may be fully automated, at least today. The McKinsey Global Institute (2017) also points out "that low salaries in Mexico will lead to a less intense impact of automation in the Latin American country: of the total of 68 million people who will make up the Mexican labor force in 2030, some 9 million will be displaced". Ultimately, the greatest threat to employment is not automation but for an inability to remain competitive.

Fig. 2 Robot known as "Cobot" (COBOTX 2022). *Note* Image for public use, without Copyright

By carrying out a detailed analysis of the information we obtained thanks to the graphs that the Google form gave us, we were able to observe and realize very relevant aspects for our cause, which allowed us to have a clearer idea.

In addition to being able to delve into what a local industry is, and, in this way, learn more about the effect of automation in an industry that could most likely benefit from the implementation of robots in their respective work areas, since, as mentioned above, the industrial processes that are handled in this company are ideal for robots to be considered primarily on this industry. Likewise, these graphs were also of great help to us to be able to obtain closer data on local unemployment.

The results obtained thanks to the research were many, and thanks to them, we were able to have a notion of how industrial robotics has impacted not only in our city but also in various parts of the world, but emphasizing and focusing on the objective that We considered ourselves from the beginning, we can say that the level of automation of the jobs present in the city has been increasing in a company like Jabil Healthcare that is dedicated to the creation and distribution of medical products, they are of great automated labor helps.

Nevertheless, even so, unemployment in the city, and more specifically in that company, is not significant since it is a company that continues to provide jobs to Tijuana citizens because it has three plants in the region. We will have to wait for how the situation changes shortly. However, it does not seem to have a significant variation in the next few years since many studies estimate that the significant changes in job automation are expected to occur within at least five more years.

It is essential to mention that the general data obtained in the investigation were alarming, since, in effect, the arrival of robots in the labor sector has inevitably caused job losses, according to information led by MIT, which tells us that, in more than a decade, for every robot that was implemented in the industry, six jobs were lost, not to mention that 6 out of 10 current professions could automate 30% of their tasks, which makes the situation, and these data could be reflected in Mexico if we continue on the same path. The good news is that statistically, technological advances always generate more jobs. Although some economists fear that this time the same will not happen, there is still a glimmer of hope since, in the end, unemployment due to the arrival of Robots depends on many factors, such as the inevitable cost/benefit comparison between workers and robots. However, as the last hope, things are likely not to change significantly for many more years, and while that time passes, perhaps the technology can make a claim and create new jobs for future years.

6 Conclusions and Industrial Implications

Throughout the research that has been carried out, it has been wanted to know and demonstrate the impact that robotics has had on the jobs of the Mexican industry since it is a subject of considerable relevance, which sometimes is not given the importance that an issue of this magnitude should have because it still does not cause severe problems in Mexican society. Likewise, as the information obtained throughout the investigation was wide and varied, we could find data that contributed significant things to our work, such as the percentage of jobs that are threatened by robotization in Mexico and that robots will not replace workers. This relevance is emerging in SMEs with cobots, which was a great help for our research objective.

Investigating the origin of the implementation of robotics in industries provided us with fundamental data that allowed us to see the progress or evolution that said implementation had had today. Similarly, considering the timeliness of the data on the subject in question was essential to give us an idea of the evolution that robotics will have over the years. For that reason, the way we decided to organize the information we collected was with some pie charts, since, in that way, we could better compare the data obtained.

References

Castro, A.A.: 2.7 millones de robots industriales desplegados en fábricas de todo el mundo: IFR. Modern Machine Shop Mexico. https://www.mms-mexico.com/noticias/post/27-millones-de-robots-industriales-desplegados-en-fabricas-de-todo-el-mundo-ifr. Last accessed 6 Oct 2020

COBOTX: Review. February 2022, from: Cobotx Technologies (2022). Site web: https://cobotx.hu/robot-mint-szolgaltatas/

Deloitte: Las principales ventajas de trabajar con robots. Deloitte. https://www2.deloitte.com/es/es/pages/operations/articles/principalesventajas-trabajar-con-robots.html. Last accessed 19 Oct 2020

EDS, Robotica: ¿Qu´e es un robot colaborativo? https://www.edsrobotics.com/blog/robot-colaborativo-que-es/. Last accessed 10 Sep 2020

Gautam, R., Gedam, A., Zade, A., Mahawadiwar, A.: Review on development of industrial robotic arm. IRJET **4**(3), 1752–1755 (2017)

Galindo, M.: "Empleo" en Serie de Estudios Económicos, México DF: México ¿como vamos?, vol. 1, pp. 2–8 (2015)

Manufactura: 52% del empleo en M´exico puede ser suplido por robots. https://manufactura.mx/industria/2017/03/22/52-del-empleo-en-mexico-puede-ser-suplido-por-robots. Last accessed 23 Mar 2017

Manufactura M´exico es el 4º importador de robots en el mundo. https://manufactura.mx/industria/2017/07/31/mexico-es-el-4o-importador-de-robots-en-el-mundo. Last accessed 6 Aug 2017

Manyika, J., Lund, S., Chui, M., Bughin, J., Woetzel, J., Batra, P., Ko, R., Sanghvi, S.: Jobs lost, jobs gained: what the future of work will mean for jobs, skills, and wages. McKinsey & Company. https://www.mckinsey.com/featured-insights/future-of-work/jobs-lost-jobs-gained-what-the-future-of-work-will-mean-for-jobs-skills-and-wages. Last accessed 11 May 2019

Martinez, F.: ¿Qu´e son los robots y para que sirven? Dynamo-Electronics (2020, 10 agosto). https://dynamoelectronics.com/que-son-los-robots-y-para-que-sirven/. Last accessed 10 Aug 2020

Mercader Uguina, J.R.: El impacto de la rob´otica y el futuro del trabajo. Scielo **67**(269), 150–174 (2017)

MIT Una historia de desempleo, automatización, robots y falsa prosperidad. MIT Technology Review. https://www.technologyreview.es/s/10317/una-historia-de-desempleo-automatizacion-robots-y-falsa-prosperidad. Last accessed 27 June 2018

Newman, P.A., Kempf, K.G.: Opportunistic scheduling for robotic machine tending. In: The Second Conference on Artificial Intelligence Applications, Miami Beach, FL, December 11–13, pp. 168–173 (1985); Epstein, J.M., Axtell, R.L.: Growing Artificial Societies: Social Science from the Bottom Up. The MIT Press (1996)

Reportero Industrial: Evoluciöon de la automatizaciöon industrial (2014, 14 julio). https://www.reporteroindustrial.com/temas/Evolucion-de-la-automatizacion-industrial+98784 Last accessed 27 Oct 2020

Staff, F.: Automatización pone en riesgo más del 50% de empleos en M´exico: BM. Forbes México (2020, 28 septiembre). https://www.forbes.com.mx/economia-automatizacion-pone-en-riesgo-mas-del-50-de-empleos-en-mexico-bm/. Last accessed 1 Dec 2020

Human Decision-Making Evaluation: From Classical Methods to Neurocomputational Models

Miguel Ángel Serrano, Francisco Molins, and Adrián Alacreu-Crespo

Abstract Decision-making involves numerous associated cognitive processes (memory, attention, learning, motor system) and is responsible for the final behavior of employees. Decision-making can be effective or lead to errors with significant consequences for organizations (economic or human). For this reason, decision-making is currently being studied extensively from different fields and with different approaches. From Psychology, human decision-making has classically been subject to manual or computerized methods from which general conclusions were drawn. However, decision-making is a highly complex process involving numerous sub-processes that increase the mental workload. In this regard, in recent years, numerous algorithms have been developed from computational models that allow different parameters of decision-making to be extracted and that are making it possible to scrutinize the processes underlying decision-making. Thus, based on Bayesian statistics, computational decision-making models can provide more specificity in studying human decision-making through complex and more robust algorithms to explain and predict this process. Therefore, this chapter aims to review the paradigms of human decision-making assessment (from a classical to a computational perspective) that allow the reader to have a clear and updated view of evaluating human decision-making. Considering that the tasks shown come from laboratory contexts or basic science, practical implications, and guidelines for their use by ergonomists and mental workload experts in industrial settings will be shown.

Keywords Decision-making · Algorithms · Computational methods · Psychology

---

M. Á. Serrano (✉) · F. Molins
Department of Psychobiology, University of Valencia, Avda. Blasco Ibañez, 21, 46010 Valencia, Spain
e-mail: m.angel.serrano@uv.es

F. Molins
e-mail: francisco.molins@uv.es

A. Alacreu-Crespo
Departamento de Psicología y Sociología, Área de Personalidad Evaluación y Tratamiento Psicólogico, Universidad de Zaragoza-Campus de Teruel, C/Atarazana, 4, 44003 Teruel, Spain
e-mail: aalacreu@unizar.es

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_9

1 Introduction

This chapter provides a complete overview of decision-making evaluation methods from the psychological perspective. It includes algorithms and computational methods recently applied to deepen our understanding of decision-making. However, as is often the case, basic science is far from practical application and cognitive ergonomics. Therefore, we must warn the reader that the decision-making assessment methods presented throughout this chapter have not been applied in industrial contexts and come from basic science. Therefore, this chapter aims for the reader to learn how decision-making is evaluated and the parameters that can be extracted from these methods, proposing in the final part how these methods could be applied in organizational contexts, including industry.

1.1 Decision-Making and Ergonomics

Ergonomics is defined as a scientific discipline that tries to understand the interaction between human beings and the other system elements, trying to optimize this interaction. Cognitive ergonomics focuses on the cognitive processes activated in work environments, with special attention to technology, focusing on the mental load. One of the critical areas that greatly influences mental workload is critical incidents, where workers must control the situation under time pressure and with little information and where decision-making is critical. Decision-making is one of the most relevant cognitive processes that increase mental load since it involves implementing numerous associated processes (memory, attention, learning, motor system). It is also responsible for the final behavior of the worker. Thus, decision-making can be effective or lead to errors with significant consequences for organizations (economic or human).

For this reason, decision-making is currently being studied extensively from different fields and with different approaches, especially from psychological science. Psychology has for many years been interested in human behavior and, specifically, in the cognitive processes that explain and help predict it. Thus, there has been a growing interest in decision-making as the ultimate cognitive process prior to behavior in the last two decades. In addition, recent research focuses on the more specific processes underlying that decision-making.

In particular, the evaluation of human decision-making has classically been subjected to manual or computerized methods from which general conclusions can be drawn. However, as indicated above, decision-making is a highly complex process involving numerous sub-processes that increase the mental workload. In this regard, in recent years, numerous algorithms have been developed from computational models that allow different parameters of decision-making to be extracted and that are making it possible to scrutinize the processes underlying decision-making. Thus, based on Bayesian statistics, computational decision-making models can provide more specificity in studying human decision-making through complex and more robust algorithms to explain and predict this process. Therefore, this chapter aims to review the paradigms of human decision-making evaluation (from a classical to a computational view) that allow the reader to have a clear and updated view of evaluating human decision-making.

This objective will be achieved by describing and explaining different decision-making tasks giving a comprehensive and complete perspective of the different decision-making processes that involve human beings functioning in different life's contexts and focusing especially on industrial contexts. First, different types of decision-making will be described in general terms. Subsequently, we will briefly describe ways of measuring social decision-making for organizations focused on social interaction in their way of proceeding, including some recently developed algorithms. It will be described in more depth the tasks that measure decision-making related to cognitive load, which is more related to the mental load that industry workers may suffer, influencing many of their important decisions that must be made correctly to achieve a good result. Finally, considering that the tasks come from laboratory contexts or basic science, practical implications and guidelines for their use by ergonomists and mental workload experts in industrial settings will be shown.

2 Decision-Making in Humans

From a cognitive perspective, different instruments have been developed to measure decision-making in humans. The most popular reinforcement learning tasks are the Iowa Gambling Task (IGT) and the Cambridge Gambling Task (CGT). These computerized tasks measure decision-making based on cognitive decision-making and involve several cognitive processes such as working memory, reinforcement learning, and reversal learning (Dougherty et al. 2005a, b). Another kind of task comes from other fields as economics (Gächter et al. 2007), such as the "mixed monetary gamble task" or the "risk and loss aversion task" and evaluated specific biases under risk uncertainty. Moreover, as most human decisions are made in a social context, other tasks, as Trust Game, Prisoner's Dilemma, and Ultimatum Game, are designed as competing or cooperating tasks between two or more individuals and evaluate social decision-making.

Finally, some authors use self-rated questionnaires that evaluate decision-making styles, how someone usually decides, or decision-making competence, that is the capacity to make good decisions and involves four fundamental skills: having a meta-cognitive understanding of one's abilities, assessing values, assessing beliefs and combining beliefs and values to identify choices (Scott and Bruce 1995; De Bruin et al. 2007). In some of these tasks, mainly reinforcement learning tasks and social decision-making tasks, it is possible to apply computerized models based on cognitive neuroscience that can extract several sub-components from the decision-making process. Therefore, applied science should be brought closer to basic science and vice versa to join forces to improve decision-making models and their real implications for human behavior.

In the following sections, we will describe, from a cognitive point of view, social decision-making (Sect. 3) and cognitive decision-making (Sect. 4), explaining models and tests used for their analysis from a primary and seminal perspective.

2.1 Social Decision Making

One of the essential characteristics of people is their capacity and, at the same time, their need to organize themselves in groups (Wilson and Wilson 2007; Kurzban and Neuberg 2015). Humans interact in different ways with both positive and negative consequences. That is why evolution had probably favored the development of structures and psychobiological mechanisms that encourage the formation of groups (De Dreu and Kret 2016). For these reasons, humans are considered a social species, involved in different social contexts that require making choices. Based on that, researchers had implemented several social decision-making tasks to evaluate how people make social choices. Most of those tasks involve two or more people to replicate real-life social situations. However, excepting the participant, the other people can be confederates or even simulated by software. Below we describe some of the most critical social decision-making tasks and their computational models.

2.1.1 Prisoner's Dilemma

The Prisoner's Dilemma (Rapoport and Chammah 1965) is a dyadic decision-making paradigm theorized to model cooperation. The basic scenario is that two subjects, A and B, suspected of committing a robbery together, are isolated and urged to confess. Each is concerned only with getting the shortest possible prison sentence for himself; each must decide whether to confess without knowing his partner's decision. Thus, they should choose between two possible strategies: confess or not confess. Both prisoners, however, know the consequences of their decisions: (1) if both confess, both go to jail for five years (Punishment = P); (2) if neither confesses, both go to jail for one year (Reward = R); and (3) if one confesses while the other does not, the confessor goes free (for turning state's evidence) and the silent one goes to jail for 20 years (Temptation = T if the participant not confess; Sucker's payoff = S if the participant confess). The contingencies of this game reward cooperation more than competitive behaviors.

The outcome of this task is the cooperation index (CI) that classically was calculated as CI = (R − P)/(T − S). However, based on reinforcement learning computational models, it is possible to calculate CI considering how individuals update their decisions to cooperate or not in function of the accumulated experience about the reward and punishments across the task. One of the most used is the *Experience weighted attraction (EWA) learning model* (Camerer and Ho 1999). This task calculates the attraction for cooperation parameter based on the previous attractions toward cooperation weighted by a discounting parameter that weights recent trials more heavily than the older one's sum to the current trial payment.

2.1.2 Hawk-Dove Game

The Hawk-Dove game (Maynard-Smith 1982) is a dyadic decision-making paradigm theorized to model status interactions and hierarchy emergence collective outcomes. According to the structure of the Hawk-Dove game, both players have incentives to establish a dominant-subordinate relationship (Hawk-Dove combination). Each participant may adopt a dominance (Hawk) or deference (Dove) strategy, and each player's strategy has implications for the distribution of resources between the two players. If both players adopt a dove strategy (labeled as A), both players win 2 €. By contrast, if both players choose the hawk strategy (labeled as B), both players win 0 €. Finally, if someone chooses the hawk strategy and the other one the dove strategy, the one who adopted the hawk's strategy gains 4 €, and the one who adopted the dove strategy wins 1 €. Then, choosing more times, the hawk strategy implies being more dominant.

Reinforcement learning computational models were not extended in the hawk and dove game. However, this game is also a 2×2 game like Prisoner's Dilemma, with feedback and two persons involved. The only difference between both games is the contingencies that reward competitive or cooperative behaviors more. For this reason, it should be possible to apply similar reinforcement learning computational models to this task.

2.1.3 Ultimatum Game

The Ultimatum Game (Güth et al. 1982) is a task where a participant (responder) accepts or rejects fair/unfair offers from a common amount of money shared with another participant (proposal). Responder knows the original amount of money and the repartition proposed by the proposal. If the respondent agrees, both participants win the money proposed by the proposal. Otherwise, nobody wins money. This game is usually used to measure the equity and fairness sense of the responder. One version of the Ultimatum game comprised 32 trials, with a high (100 €) and low (20 €) amount of money. The offers will be 0%, 10%, 20%, 30%, 40%, 50%, 60%, and 100% of the total amount to be divided. The outcomes are the total rejections from the 0–30% unfair offers and the 40–100% fair offers for each proposal and amount of money. This task evaluates the sense of fairness in the responder and the altruism or selfishness in the proposal.

A computational model has recently been developed for a version of this task, the UG Delta model (Gu et al. 2015), where participants only assume the role of responders and never proposals. This model yields two parameters: envy (α) and inverse-temperature (τ). The higher the envy parameter, the greater sensitivity to norm prediction error, that is, the participant's unwillingness to accept an offer below the "internal norm" or "internal reference value" (Gu et al. 2015). The inverse-temperature parameter reflects "how deterministically individuals' choices are made with respect to the strength (subjective value) of the alternative choices" (Ahn et al. 2017, p. 29). High and low inverse temperatures represent more deterministic and more random choices, respectively (Ahn et al. 2017).

2.1.4 Trust Game

The Trust Game (Berg 1995) is a dyadic task where a participant plays the role of an investor and the other plays the role of administrator. The investor should decide how much money from a total want to invest, give to the administrator, and how much to keep for himself. The quantity of money sent to the administrator is multiplied by a random factor before arriving. Then, the administrator should decide how much money should keep each one. This task evaluates the trust of the others in the investor role and the reciprocity in the administrator.

Past literature applied classical reinforcement learning models as the *Experience weighted attraction (EWA) learning model* (Camerer and Ho 1999) to the trust game, showing that learning across the procedure was different for each role due to the asymmetric positions of each one (Meidinger and Terracol 2012). However, recently, Haiyan (2019) proposed a more exciting model that accounts for the learning effect of both the investor and the administrator based on the Rescorla-Wagner anticipatory error rule (Rescorla and Wagner 1972) and takes into account this asymmetry. Moreover, this model also gives a temperature parameter determining the tendency to repeat previously rewarded interactions with a partner (exploit) versus trying alternate actions that might result in more significant payoffs (explore).

2.2 Decision-Making Style and Competence

Decision-making had been classically evaluated using tasks that involve cognitive resources. Nevertheless, many researchers are beginning to evaluate decision-making from individuals' different perspectives recently. In this sense, several self-rated questionnaires had been designed to evaluate individual differences in decision-making; concretely, decision-making styles and decision-making competence. Although no computational models can be extracted in this kind of questionnaire, the constructs evaluated with these instruments are helpful when combined with cognitive decision-making tasks.

2.2.1 Decision-Making Styles

Decision-making styles have been defined as "*the learned habitual response pattern exhibited by an individual when confronted with a decision. It is not a personality trait, but a habit-based propensity to react in a certain way in a specific decision context (p. 820)*" (Scott and Bruce 1995). Thus, decision-making style is the usual way of making decisions (Driver 1979; Harren 1979). This kind of construct can be conceptualized as a "surface" individual difference because is more malleable and adaptive depending on the situation (Curry 1983) than a stable "core" personality trait. Researchers have tested the utility of decision-making styles in the prediction of some critical decisions such as choosing a satisfying job (Crossley and Highhouse 2005), choosing an excellent major college (Galotti et al. 2006), or choosing a career with a future good person-job fit (Singh and Greenhaus 2004; Gati et al. 2010).

There are several scales to evaluate decision-making styles. Some of these scales are the Decision-Making Style Inventory (DSI; Nygren 2000), which is a 45 items inventory that evaluates analytical, intuitive, and regret-avoidant factors; the Melbourne Decision Making Questionnaire (M-DMQ; Mann et al. 1997), a 22 items scale that evaluates vigilance, hypervigilance, buck-passing, and procrastination styles; the Decision Styles Scale (DSS; Hamilton et al. 2016), a ten items inventory to evaluate rational or intuitive decision making, and finally, the Decision Styles Questionnaire (DSQ; Leykin and Derubeis 2010), a 43 items scale that evaluates anxiety, avoidance, brooding, dependent, vigilant, intuition, and spontaneity styles).

However, the most used is the General Decision Making Style questionnaire (GDMS; Scott and Bruce 1995), an instrument of 25 items and five scales that are: (1) rational style, people with this style follows a logical approach to decisions by searching some information and alternatives and a carefully thought out; (2) intuitive style, in this style, people make decisions depending on their feelings; (3) dependent style, here, people decide in the function of other people advice and guidance; (4) avoidant style, this style is characterized by procrastinating decisions-making; and (5) spontaneous style, a style characterized by the need to make decisions as quickly as possible. There exist different GDMS adaptations to some languages: Swedish (Thunholm 2004), Italian (Gambetti et al. 2008; Baiocco et al. 2009), Dutch (Curşeu and Schruijer 2012), Slovak (Bavol'ar and Orosova 2015), French (Girard et al. 2016), Spanish (Alacreu-Crespo et al. 2019) and an English adaptation for patients clinical decision making (Fischer et al. 2015).

2.2.2 Decision-Making Competences

It is not easy to define how well someone makes decisions or is productive or competent in decision-making research. However, decision-making competence is a set of constructs designed to assess how good are individuals to make decisions. The criteria to judge a good decision are based on the decision process or the external outcomes. The task most used to evaluate decision-making competence is the Adult-Decision Making Competence (A-DMC; De Bruin et al. 2007), a battery of 87 items distributed in 6 different decision problems designed to evaluate six different decision skills are needed to be normatively competent in decision-making.

These skills are: (1) Resistance to framing, assess whether choices are affected by irrelevant differences in the problem description, for example, if options are described in terms of rewards or punishments; (2) Applying decision rules, or how well people can use described decision rules; (3) Consistency in risk perception, i.e., assess how well people understand probability rules in a decision; (4) Recognizing social norms, that is to assess if participant understands social groups of peers; (5) Under/overconfidence, i.e., asses if the participant is calibrated in terms of recognizing the extent of their knowledge; and 6) Resistance to sunk costs, it is the ability to ignore prior investments when making decisions. The questionnaire is adapted to evaluate decision competence in pre-adolescents (Weller et al. 2012), youth (Y-DMC; Parker and Fischhoff 2005), and older adults (OA-DMC; Finucane and Gullion 2010). An alternative to DMC is the Decision Outcome Inventory (DOI; De Bruin et al. 2007), a questionnaire evaluating competence to reach satisfactory outcomes in the past or avoid adverse decision outcomes.

3 Decision-Making Based on Neurocognitive Models

By nature, decision-making is a complex cognitive skill that involves weighing different alternatives to choose the "best" course of action based on the relative value of their potential consequences (Balleine 2007). If quotation marks are used, it is because this issue raises a broad debate on whether there exists an optimal decision or, rather, the quality of each decision depends on the context in which it is evaluated, as well as on the criteria used in the evaluation (Evans 2014; Raab and Gigerenzer 2015; Felin et al. 2017; Chater et al. 2018). As Simon's scissors analogy already alluded, the quality of our decisions "is shaped by scissors whose two blades are the structure of task environments and the computational capabilities of the actor" (Simon 1990, p. 7). The same choice and the underlying cognitive processes involved in it could be rational or irrational, adaptive or maladaptive, depending on the context (Raab and Gigerenzer 2015; Haksöz et al. 2018). A decisional context can range along a continuum of uncertainty, from no uncertainty at all (certainty) to complete ambiguity, depending on the number of alternatives to choose from and the knowledge of the potential consequences of the choice (Volz and Gigerenzer 2012).

Decisional tasks based on contexts with low uncertainty, also known as risk tasks, propose simple decisions with few alternatives and where the probability of occurrence of each potential consequence is known (Bechara and Damasio 2005a, b; Starcke and Brand 2012). Here, it could be helpful to weigh the alternatives and order them according to their relative values, following a rational choice process, such as the one proposed by the classical Theory of Games (von Neumann and

Morgenstern 1944). Following the normative criterion of rationality, the best decision would be to choose the alternative with the highest subjective value (Starcke and Brand 2012). These tasks assess the subjects' ability to adjust to the rationality criterion or whether, on the contrary, they decide influenced by cognitive biases such as loss aversion or framing effect (explained later). In parallel, they also provide information on whether people take a risk when deciding. The main risk tasks that will be described in the following section come from the economic field and are the Mixed Gamble Task (Tom et al. 2007), the Risky Choice Framing Task (De Martino et al. 2006), and the Cambridge Gambling Task (Rogers et al. 1999).

On the other side, in complex contexts with a higher degree of uncertainty (known as ambiguous tasks), as occurs in industrial contexts, it could not be feasible to follow reasonable procedures, and many decisions must be made relying on our intuition or our experiences (Shiv et al. 2005; Raab and Gigerenzer 2015). Here, cognitive processes, such as working memory, reinforcement learning, and reversal learning (Bechara and Damasio 2005a, b; Dougherty et al. 2005a, b; Starcke and Brand 2012). In these contexts, given that there would not necessarily be a "best" decision or, if it exists, it can be complicated to find, alternative criteria to rationality are raised. For example, it can be assessed the adaptivity of decisions, the risk taken, or impulsivity (Haselton et al. 2009; Santos and Rosati 2015); but also other aspects focused on the decisional process rather than on the outcome, such as the ability of participants to learn which alternatives are favorable based on the feedback obtained from successive choices (Shiv et al. 2005; Fridberg et al. 2010; Starcke and Brand 2012). New trends in the decision-making field suggest the need to assess the results and the decisional processes to adequately address the complexity of this cognitive ability (Keys and Schwartz 2007; Brugnach et al. 2011). The most used ambiguous tasks in the study of decision-making are the Iowa Gambling Task (Bechara et al. 1994) and the Balloon Analogue Risk Task (Lejuez et al. 2002).

The risk and ambiguity tasks mentioned will be described below. It should be noted that these tasks, initially, only allowed to obtain some primary and general decisional indicators (e.g., the Iowa Gambling Task yielded a global index of the quality of the decision); however, nowadays, we count with several computational models based on Bayesian logic that allow us to extract more specific parameters; that is, it is possible to obtain information about mechanisms underlying the global decision-making process. Thanks to these models, we can draw more accurate conclusions about how this cognitive ability works.

3.1 Risk Tasks

3.1.1 Mixed Gamble Task

In the Mixed Gamble Task (MGT; Tom et al. 2007), each trial entails a bet with one of the combinations randomly extracted from a losses and gains matrix until all the combinations are completed. Depending on the version, this matrix can range from

8 × 8 (Chandrasekhar Pammi et al. 2015) to 16 × 16 (Tom et al. 2007) losses and gains, respectively. Following the gamble ranges used by Tom et al. (2007) in the original task, gains could range from €100 to €380 in €40 increments and losses from €50 to €190 in €20 increments. There is a 50% chance of gaining in each trial and a 50% chance of losing. Participants must decide whether to accept or reject the bet. They are instructed that €200 is their initial amount, and each bet must be made with that reference. Betting results are not presented immediately; however, they must choose carefully in each trial since, in the end, four bets will be randomly picked and played heads or tails, affecting the initial amount.

Usually, logistic regressions are performed with each participant using possible gains and losses as independent variables and acceptance or rejection as a dependent. Thus, β of gains and β of losses are obtained, being able to apply the formula of Tom et al. (2007): $\lambda = \frac{-\beta_{loss}}{\beta_{gain}}$, to calculate λ parameter, which represents loss aversion ($\lambda \geq 0.5$ signals the presence of this bias). Loss aversion, one of the main pillars of the Prospect Theory (Kahneman and Tversky 1979), is a cognitive bias whereby losses have a greater psychological impact than gains and, when present, lead to decisions far from the criterion of rationality (Kahneman et al. 1991; Molins and Serrano 2020). Thus, someone with high loss aversion will base his decisions on avoiding any loss rather than choosing the optimal alternative. Therefore, the higher the value of loss aversion, the less rational decisions are made. However, this parameter λ of loss aversion assumes in its calculation that the utility function (i.e., how possible gains and losses are valued) is linear, which distances its interpretation from the original parameter proposed in Prospect Theory.

Fortunately, several computational models have been developed and allow us to assume the curvature of the original function. The most commonly used is the Prospect-Theory model (Sokol-Hessner et al. 2009). Two parameters are derived from this model: λ (loss aversion coefficient) and μ (the logit parameter). $\lambda = 1$ indicates that gains and losses were valued equally; however, when $\lambda > 1$, losses are overvalued relative to gains (loss aversion). The logit parameter (μ) represents the amount of "randomness" in the subject's choices or, in other words, consistency over options. Higher parameter levels would mean that participants rely more on "rule-based" decision-making or rational processes (Sokol-Hessner et al. 2009).

3.1.2 Risky Choice Framing Task

The Risky Choice Framing Task (RCFT; De Martino et al. 2006) follows a paradigm similar to MGT, posing several bets with potential gains and losses. However, this time, bets can be framed in a context that, although mathematically equivalent, is offered in a positive or negative form. This allows us to check whether people make the same decisions regardless of the presentation (following the rationality criterion) or decide differently depending on how the information is framed, incurring in the well-known Framing Effect (De Martino et al. 2006; Ring 2015). Task trials can vary, but the computational version of the task usually consisted of a bet list in which the participants are asked to choose between two economical options. Firstly, a message appears indicating the initial amount of money (€20, €25, €40, €50, €75, €80 and €100). Next, they must choose between a "sure" or a "gamble" (risky) option.

The "sure" options are set out in a positive ("You keep €50") and in a negative frame ("You lose €30"). The "gamble" option proposes a probability of winning or losing a certain amount of money (20%, 40%, 60%, and 80%). For example: "(A) You keep/lose €30; (B) Gamble, knowing that there is a 60% chance of keeping everything and a 40% chance of losing everything". Two possible ways to analyze the RCFT are available: obtaining the percentage of bet acceptance in each frame and calculating the difference between gambling in loss and win frames (the size of Framing Effect). To our knowledge, a computational model applicable to this task has not yet been developed. However, given the similarities with MGT, it might be feasible to adopt a model for RCFT that would allow us to extract the Framing Effect value, the loss aversion value, and the betting consistency for each of the two frames (positive and negative).

3.1.3 Cambridge Gambling Task

In the Cambridge Gambling Task (CGT; Rogers et al. 1999), a yellow token is hidden in one of ten boxes. Some of the boxes are red, and others are blue. The ratio between red and blue boxes ranges from one red (nine blue) to nine red (one blue) boxes. The participant must predict the box's color hiding the token, and then they must bet a proportion of their accumulated points based on the certainty of their decision. Importantly, the presentation order is varied across conditions, where ascending and descending blocks present the lowest (5%) and highest (95%) bet first, respectively (Romeu et al. 2020).

Traditionally, performance on the CGT is assessed through several behavioral measures that capture different facets of decision making, including (1) quality of decision making, the percentage of trials where a participant chooses the color with more boxes; (2) impulsivity, the difference in average betting ratios chosen across ascending and descending conditions but only counting the optimal trials (i.e., where the participant chose the color that had the greater number of boxes); (3) risk-taking, the average betting ratio only on those trials where participants choose the optimal color; (4) deliberation time, the time between the beginning of the trial and the bet choice; (5) risk adjustment, the tendency for participants to bet more when the odds are in their favor; and (6) overall proportion bet, the average betting ratio chosen across all trials, including non-optimal trials and trials in which the proportion of red and blue boxes are the same.

Recently, a cognitive computational model has been developed, allowing for stronger statistical inferences and a better understanding of CGT decision-making (Romeu et al. 2020). The Cumulative model (Romeu et al. 2020) is also based on the principles of the Prospect Theory (Kahneman and Tversky 1979) and can extract five parameters. First, α represents the subjective probabilities for the color choice. The color could be "distorting" the objective possibilities of the token being under a red versus the blue box. Higher values for α indicate underweighting of low and overweighting of high probabilities, which leads to more optimal color choices. A value of $\alpha = 1$ indicates objective probability weighting. The second parameter is c, a color bias parameter, where values closer to 1 show a bias for red, which could distort the objective weighting probabilities for the color choice. The third is the loss aversion parameter (ρ), which shows again how sensitive participants are to losses relative to gains. Specifically, the model sets $\rho = 1$ for gains and freely estimated ρ for losses, which allows for to capture variations in loss sensitivity that can lead to risk-seeking ($\rho < 1$) or risk-averse ($\rho > 1$) behavior. The fourth is the impulsivity parameter (β), which captures the tendency to select immediate over delayed bets. The higher β, the higher impulsivity. Finally, the variability/noise parameter (γ) indicates if participants are making more deterministic or random choices concerning their model-predicted expected value for each option. The lower the value of γ, the higher randomness.

3.2 Ambiguity Tasks

3.2.1 The Iowa Gambling Task

The Iowa Gambling Task (IGT; Bechara et al. 1994) is a decision-making task that assesses risk-taking decision-making in conditions of ambiguity uncertainty. Participants receive the instructions of gaining as much money as possible starting with 2000 €. Participants must choose between four decks: two disadvantageous decks (Decks A and B) that provided immediate higher gains but greater future losses (long-term loss), and two advantageous decks (Decks C and D) that provided immediate lower gains but smaller future losses (long-term win).

Each deck contains 40 cards and provides different winnings or losses, giving feedback to the participant after each choice (modifying the amount of money won or lost). Participants will complete 100 trials with feedback after each trial. The primary dependent variable (IG index) will be the mean difference between the number of good deck choices and the number of disadvantageous deck choices (i.e., CD − AB). The more positive values indicate the more conservative decisions and the better understanding of the decision context. Generally, IG is analyzed every 20 items, and a learning curve is constructed. In this sense, when this task is applied, participants have no clue as to the outcome when choosing between one deck or the other, so the decisional context has been one of ambiguity.

However, the feedback provided by the task during the 100 trials promotes that participants can learn, in the first few trials, which decks are the best (Maia and McClelland 2004). Thus, the uncertainty of the task becomes risky from trial 41 onwards, given that the probability of future gains or losses could be learned from the feedback of the first 40 trials (Bechara and Damasio 2005a, b; Buelow et al. 2013). Likewise, in decks A and C, five cards contain losses for every ten choices, while in decks B and D, it is only 1. Based on this characteristic is possible to analyze the sensitivity to failures with the following formula (i.e., AC − BD).

Several computational models could be applied to the IGT to identify the different cognitive processes involved and improve the comprehension of the specific neurocognitive characteristics underlying decision-making. The first cognitive model proposed for IGT was Expectancy Valence Learning (EVL; Busemeyer and Stout 2002), based on reinforcement learning rules, was widely used to detect differences in clinical populations. However, two evolved models were created to capture decision-making behaviors more accurately. On the one hand, the Prospect Valence Learning (PVL; Ahn et al. 2008, 2011) is a revised and improved version of the EVL model with a better fit and more reliable parameters. The PVL model extracts four theorized parameters from the IGT: feedback sensitivity, loss aversion, learning/memory, and choice consistency.

On the other hand, the Value-Plus-Perseverance model (Worthy et al. 2013) is also based on reinforcement learning but isolates the tendencies to persevere. The VPP extracts eight parameters: learning rate, outcome sensitivity, response consistency, loss aversion, gain impact, loss impact, decay rate, and reinforcement learning weight. Finally, Haines et al. (2018) recently proposed the Outcome-Representation Learning (ORL) model, a novel reinforcement learning model that explicitly accounts for the effects of expected value, gain–loss frequency, choice perseveration, and reversal-learning processes. Five parameters summarize these processes: reward learning, punishment learning, forgetfulness, win perseverance, and deck perseverance. The ORL model outperformed past learning reinforcement models (such as the Prospect Valence Learning and Value-Plus-Perseverance models) in prediction accuracy and parameter recovery (Haines et al. 2018). These models can be extracted using the hBayesDM package in R (Ahn et al. 2017).

3.2.2 Balloon Analogue Risk Task

The Balloon Analogue Risk Task (BART; Lejuez et al. 2002) assesses risky decisions in conditions of ambiguity uncertainty. The task is to inflate a balloon that will pop randomly at some point. Each time the participant pump air into the balloon can earn 5 cents. The participant can stop and accumulate the winnings; if the balloon bursts, the participant loses all money. There are three types of balloons, blue, yellow, and orange, which generally will burst before or after, depending on the color. The primary outcome is the adjusted BART score, the average number of pumps for unexploded balloons, the most pumps the riskiest decision-making. Although BART provides feedback throughout the development of the task, its simplicity (only two options: blow up the balloon or pick up the money) and randomness do not allow correct learning of the task rules, and it is difficult to arrive at conditions of risk uncertainty.

Wallsten et al. (2005) first proposed several computational models for the BART based on the well-known EVL model from IGT. The model with the most accuracy was the 4-parameter model and consisted of four parameters: prior belief of balloon not bursting, learning, risk-taking and consistency. However, researchers showed that this model is not reliable because learning parameters reduce the recovery of the other parameters (Pleskac 2008; van Ravenzwaaij et al. 2011). This model was updated and reduced into a 2-parameter model (van Ravenzwaaij et al. 2011) that evaluates only a risk parameter and a consistency parameter. Nevertheless, this model has the strict assumption that participant does not learn during the BART. To address this limitation, recently, a new model, the Exponential-Weight Mean–Variance Model (EWMV; Park et al. 2021), was presented for BART. This model uses an exponential weight rule that considers loss aversion and impulsivity and has a better fit and excellent parameter recovery than the other models. The EWMV extracts five parameters: prior belief of burst, updating exponent, risk preference, inverse temperature (consistency), and loss aversion.

4 Practical Implications and Strategies to Implement These Measures

As we have seen in the previous sections, decision-making is a complex process that involves numerous variables and assessments that must be considered to evaluate it correctly and draw valid conclusions. Thus, we can divide between social decision-making, a priori, more distant from industrial contexts, and cognitive decision-making, closer to the classical concept of decision-making.

Although social decision-making can be seen as alien to industrial processes, we believe that it is crucial to evaluate the efficiency of work teams or even within inter- and intra-organizational negotiation processes. Thus, knowing the decision-making styles or knowing the type of decision-making (and the individual reaction to it) can help to predict the behavior of workers and other company staff to obtain the greatest ergonomic benefit in economic, emotional, cognitive, and social terms. All these would contribute to a better adaptation of the organization to change and to the processes that lead to decision-making (practically all of them).

Regarding cognitive decision-making, we consider that it is essential to consider its evaluation from the models presented before its study in ecological contexts. Thus, knowing how workers (and other employees) make decisions can help select personnel according to the risks or ambiguous contexts they will face in specific jobs. Specifically, the aspect of ambiguity and risk should be highlighted. The former is increasingly present in complex industrial contexts and requires adequate management of this ambiguity to make appropriate decisions that are adjusted to the changing context, which entails the maximum economic and psychosocial benefit. On the other hand, the possibility of risk situations (fires, uncontrolled processes, accidents) makes it essential to know how workers can behave in such cases and thus instruct and implement measures to reduce the negative consequences that may arise.

From an applied point of view, these decision-making measures should mainly be implemented during recruitment processes to select the most optimal candidates to handle uncertain or risky situations and thus ensure a more adaptive and efficient behavior. This would also be appropriate in the case of social decision-making tests, which should be implemented for jobs that require regular social interactions and negotiation processes. However, considering that decision-making is a trainable process, we assume that training should be encouraged for all those workers who may be working in jobs with the characteristics mentioned above. Therefore, our proposal aims to unite basic cognitive science with applied ergonomics. Basic cognitive science is making great progress in understanding decision-making and its relationship to behavior by focusing on the underlying processes (learning, reinforcement) from which applied cognitive ergonomics could clearly benefit, using scientifically proven measures to understand how workers process information when making decisions. This would exponentially improve decision-making and predictive capacity knowledge in complex and/or risky situations.

5 Conclusion

This chapter presents different ways of measuring social and cognitive decision-making, showing how various computer-based tasks can help us understand how people make decisions. In addition, we have seen how the underlying cognitive processes are being explored in depth through computational models based on the Bayesian perspective, which is allowing us to scrutinize the basic core processes of decision making that in the future will help us to influence the way we instruct workers to make decisions not only more efficient but adaptable to environmental changing circumstances. In conclusion, decision-making is an essential process, and knowing it deeply will lead to a better understanding and prediction of human behavior, especially in working contexts where decisions are critical, mainly in some processes under ambiguity or risk. Thus, we propose cognitive ergonomists from applied fields to include basic tasks to evaluate decision-making to have basic knowledge of workers' psychological processes to adapt workers to tasks more efficiently. In addition, from the basic science, it would be interesting to know how basic models of decision-making match with applied models to improve both.

References

Ahn WY, Busemeyer JR, Wagenmakers EJ, Stout JC (2008) Comparison of decision learning models using the generalization criterion method. In: Cognitive Science, pp. 1376–1402

Ahn, W.-Y., Haines, N., Zhang, L.: Revealing neurocomputational mechanisms of reinforcement learning and decision-making with the hBayesDM package. Comput. Psychiatry (2017). https://doi.org/10.1162/CPSY_a_00002

Ahn, W.-Y., Krawitz, A., Kim, W., et al.: A model-based fMRI analysis with hierarchical Bayesian parameter estimation. J. Neurosci. Psychol. Econ. **4**, 95–110 (2011). https://doi.org/10.1037/a0020684

Alacreu-Crespo A, Fuentes MC, Abad-Tortosa D et al (2019) Spanish validation of general decision-making style scale: sex invariance, sex differences and relationships with personality and coping styles. Judgm Decis Mak

Baiocco, R., Laghi, F., D'Alessio, M.: Decision-making style among adolescents: relationship with sensation seeking and locus of control. J. Adolesc. **32**, 963–976 (2009). https://doi.org/10.1016/j.adolescence.2008.08.003

Balleine, B.W.: The neural basis of choice and decision making. J. Neurosci. **27**, 8159–8160 (2007). https://doi.org/10.1523/JNEUROSCI.1939-07.2007

Bavol'ar, J., Orosova, O.: Decision-making styles and their associations with decision-making competencies and mental health. Judgm. Decis. Mak. **10**, 115–122 (2015)

Bechara, A., Damasio, A.R.: The somatic marker hypothesis: a neural theory of economic decision. Games Econ. Behav. **52**, 336–372 (2005a). https://doi.org/10.1016/j.geb.2004.06.010

Bechara, A., Damasio, A.R.: The somatic marker hypothesis: a neural theory of economic decision. Games Econ. Behav. **52**, 336–372 (2005b)

Bechara, A., Damasio, A.R., Damasio, H., Anderson, S.W.: Insensitivity to future consequences following damage to human prefrontal cortex. Cognition **50**, 7–15 (1994). https://doi.org/10.1016/0010-0277(94)90018-3

Berg, J.: Trust, reciprocity, and social history. Games Econ. Behav. **10**, 122–142 (1995). https://doi.org/10.1006/game.1995.1027

Brugnach, M., Dewulf, A., Henriksen, H.J., van der Keur, P.: More is not always better: coping with ambiguity in natural resources management. J. Environ. Manage. **92**, 78–84 (2011). https://doi.org/10.1016/j.jenvman.2010.08.029

Buelow, M.T., Okdie, B.M., Blaine, A.L.: Seeing the forest through the trees: improving decision making on the Iowa gambling task by shifting focus from short- to long-term outcomes. Front. Psychol. **4**, 773 (2013). https://doi.org/10.3389/fpsyg.2013.00773

Busemeyer, J.R., Stout, J.C.: A contribution of cognitive decision models to clinical assessment: decomposing performance on the Bechara gambling task. Psychol. Assess. **14**, 253–262 (2002). https://doi.org/10.1037//1040-3590.14.3.253

Camerer, C., Ho, T.H.: Experience-weighted attraction learning in normal form games. Econometrica (1999). https://doi.org/10.1111/1468-0262.00054

Chandrasekhar Pammi, V.S., Pillai Geethabhavan Rajesh, P., Kesavadas, C., et al.: Neural loss aversion differences between depression patients and healthy individuals: a functional MRI investigation. Neuroradiol J **28**, 97–105 (2015). https://doi.org/10.1177/1971400915576670

Chater, N., Felin, T., Funder, D.C., et al.: Mind, rationality, and cognition: an interdisciplinary debate. Psychon. Bull. Rev. **25**, 793–826 (2018). https://doi.org/10.3758/s13423-017-1333-5

Crossley, C.D., Highhouse, S.: Relation of job search and choice process with subsequent satisfaction. J. Econ. Psychol. **26**, 255–268 (2005). https://doi.org/10.1016/j.joep.2004.04.001

Curry, L.: An organization of learning styles theory and constructs. Educ. Res. Inf. Cent., 2–28 (1983)

Curşeu, P.L., Schruijer, S.G.L.: Decision styles and rationality: an analysis of the predictive validity of the general decision-making style inventory. Educ. Psychol. Meas. **72**, 1053–1062 (2012). https://doi.org/10.1177/0013164412448066

De Bruin, W.B., Parker, A.M., Fischhoff, B.: Individual differences in adult decision-making competence. J. Pers. Soc. Psychol. **92**, 938–956 (2007). https://doi.org/10.1037/0022-3514.92.5.938

De Dreu, C.K.W., Kret, M.E.: Oxytocin conditions intergroup relations through upregulated in-group empathy, cooperation, conformity, and defense. Biol. Psychiatry **79**, 165–173 (2016)

De Martino, B., Kumaran, D., Seymour, B., Dolan, R.J.: Frames, biases and rational decision-making in the human brain. Science (80-) **313**, 684–687 (2006). https://doi.org/10.1126/science.1128356

Dougherty, D.M., Mathias, C.W., Marsh, D.M.: Laboratory measures of impulsivity. In: Aggression, pp. 263–282. CRC Press (2005a)

Dougherty, D.M., Mathias, C.W., Marsh, D.M., Jagar, A.A.: Laboratory behavioral measures of impulsivity. Behav. Res. Methods **37**, 82–90 (2005b). https://doi.org/10.3758/BF03206401
Driver, M.J.: Individual decision making and creativity. In: Kerr, S. (ed.) Organizational Behavior, pp. 59–91. Grid Publishing Inc., Columbus, OH (1979)
Evans, J.S.B.T.: Rationality and the illusion of choice. Front. Psychol. **5**, 1–4 (2014). https://doi.org/10.3389/fpsyg.2014.00104
Felin, T., Koenderink, J., Krueger, J.I.: Rationality, perception, and the all-seeing eye. Psychon. Bull. Rev. **24**, 1040–1059 (2017). https://doi.org/10.3758/s13423-016-1198-z
Finucane, M.L., Gullion, C.M.: Developing a tool for measuring the decision-making competence of older adults. Psychol. Aging (2010). https://doi.org/10.1037/a0019106
Fischer, S., Soyez, K., Gurtner, S.: Adapting Scott and Bruce's general decision-making style inventory to patient decision making in provider choice. Med. Decis. Mak. **35**, 525–532 (2015). https://doi.org/10.1177/0272989X15575518
Fridberg, D.J., Queller, S., Ahn, W.Y., et al.: Cognitive mechanisms underlying risky decision-making in chronic cannabis users. J. Math. Psychol. **54**, 28–38 (2010). https://doi.org/10.1016/j.jmp.2009.10.002
Gächter, S., Johnson, E.J., Herrmann, A.: Individual-level loss aversion in riskless and risky choices (2007)
Galotti, K.M., Ciner, E., Altenbaumer, H.E., et al.: Decision-making styles in a real-life decision: choosing a college major. Pers. Individ. Diff. **41**, 629–639 (2006). https://doi.org/10.1016/j.paid.2006.03.003
Gambetti, E., Fabbri, M., Bensi, L., Tonetti, L.: A contribution to the Italian validation of the general decision-making style inventory. Pers. Individ. Diff. **44**, 842–852 (2008). https://doi.org/10.1016/j.paid.2007.10.017
Gati, I., Landman, S., Davidovitch, S., et al.: From career decision-making styles to career decision-making profiles: a multidimensional approach. J. Vocat. Behav. **76**, 277–291 (2010). https://doi.org/10.1016/j.jvb.2009.11.001
Girard, A.J., Reeve, C.L., Bonaccio, S.: Assessing decision-making style in French-speaking populations: translation and validation of the general decision-making style questionnaire. Rev. Eur. Psychol. Appliquée/eur. Rev. Appl. Psychol. **66**, 325–333 (2016). https://doi.org/10.1016/j.erap.2016.08.001
Gu, X., Wang, X., Hula, X., et al.: Necessary, yet dissociable contributions of the insular and ventromedial prefrontal cortices to norm adaptation: Computational and lesion evidence in humans. J Neurosci **35**, 467–473 (2015). https://doi.org/10.1523/JNEUROSCI.2906-14.2015
Güth, W., Schmittberger, R., Schwarze, B.: An experimental analysis of ultimatum bargaining. J. Econ. Behav. Organ. **3**, 367–388 (1982). https://doi.org/10.1016/0167-2681(82)90011-7
Haines, N., Vassileva, J., Ahn, W.Y.: The outcome-representation learning model: a novel reinforcement learning model of the Iowa gambling task. Cogn. Sci. (2018). https://doi.org/10.1111/cogs.12688
Haiyan, L.: Dynamic trust game model between venture capitalists and entrepreneurs based on reinforcement learning theory. Cluster Comput. (2019). https://doi.org/10.1007/s10586-017-1666-x
Haksöz, Ç., Katsikopoulos, K., Gigerenzer, G.: Less can be more: how to make operations more flexible and robust with fewer resources. Chaos **28** (2018). https://doi.org/10.1063/1.5024259
Hamilton, K., Shih, S.I., Mohammed, S.: The development and validation of the rational and intuitive decision styles scale. J. Pers. Assess. **98**, 523–535 (2016). https://doi.org/10.1080/00223891.2015.1132426
Harren, V.A.: A model of career decision making for college students. J. Vocat. Behav. (1979). https://doi.org/10.1016/0001-8791(79)90065-4
Haselton, M.G., Bryant, G.A., Wilke, A., et al.: Adaptive rationality: an evolutionary perspective on cognitive bias. Soc. Cogn. **27**, 733–763 (2009). https://doi.org/10.1521/soco.2009.27.5.733
Kahneman, D., Knetsch, J.L., Thaler, R.H.: Anomalies: the endowment effect, loss aversion, and status quo bias. J. Econ. Perspect. **5**, 193–206 (1991). https://doi.org/10.1257/jep.5.1.193

Kahneman, D., Tversky, A.: Prospect theory: an analysis of decision under risk. Econometrica **47**, 263 (1979)

Keys, D.J., Schwartz, B.: "'Leaky"' rationality normative standards of rationality. Perspect. Psychol. Sci. **2**, 162–181 (2007)

Kurzban, R., Neuberg, S.: Managing ingroup and outgroup relationships. In: The Handbook of Evolutionary Psychology, pp. 653–675 (2015)

Lejuez, C.W., Read, J.P., Kahler, C.W., et al.: Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). J. Exp. Psychol. Appl. **8**, 75–84 (2002). https://doi.org/10.1037/1076-8989.8.2.75

Leykin, Y., Derubeis, R.J.: Decision-making styles and depressive symptomatology: development of the decision styles questionnaire. Judgm. Decis. Mak. (2010)

Maia, T.V., McClelland, J.L.: A reexamination of the evidence for the somatic marker hypothesis: what participants really know in the Iowa gambling task. Proc. Natl. Acad. Sci. **101**, 16075–16080 (2004). https://doi.org/10.1073/pnas.0406666101

Mann, L., Burnett, P., Radford, M., Ford, S.: The Melbourne decision making questionnaire: an instrument for measuring patterns for coping with decisional conflict. J. Behav. Decis. Mak. **10**, 1–19 (1997). https://doi.org/10.1002/(SICI)1099-0771(199703)10:1%3c1::AID-BDM242%3e3.0.CO;2-X

Maynard-Smith, J.: Evolution and the Theory of Games (1982)

Meidinger, C., Terracol, A.: Learning in the trust game. Rev. Philos. Écon. (2012). https://doi.org/10.3917/rpec.131.0155

Molins, F., Serrano, M.Á.: Heart rate variability after vigorous physical exercise is positively related to loss aversion. Anxiety Stress Coping, 1–12 (2020). https://doi.org/10.1080/10615806.2020.1865531

Nygren, T.E.: Development of a measure of decision making styles to predict performance in a dynamic J/DM task. In: 41st Psychonomic Society Meeting. New Orleans, LA (2000)

Park, H., Yang, J., Vassileva, J., Ahn, W.Y.: Development of a novel computational model for the Balloon Analogue Risk Task: the exponential-weight mean–variance model. J. Math. Psychol. (2021). https://doi.org/10.1016/j.jmp.2021.102532

Parker, A.M., Fischhoff, B.: Decision-making competence: external validation through an individual-differences approach. J. Behav. Decis. Mak. (2005). https://doi.org/10.1002/bdm.481

Pleskac, T.J.: Decision making and learning while taking sequential risks. J. Exp. Psychol. Learn. Mem. Cogn. (2008). https://doi.org/10.1037/0278-7393.34.1.167

Raab, M., Gigerenzer, G.: The power of simplicity: a fast-and-frugal heuristics approach to performance science. Front. Psychol. **6**, 1–6 (2015). https://doi.org/10.3389/fpsyg.2015.01672

Rapoport, A., Chammah, A.M.: Prisoner's dilemma: a study in conflict and cooperation (1965)

Rescorla, R.A., Wagner, A.R.: A theory of pavlovian conditioning: variations in the effectiveness of reinforcement and nonreinforcement. Classical Cond II Curr Res Theory (1972)

Ring, P.: The framing effect and skin conductance responses. Front. Behav. Neurosci. **9**, 1–7 (2015). https://doi.org/10.3389/fnbeh.2015.00188

Rogers, R.D., Everitt, B.J., Baldacchino, A., et al.: Dissociable deficits in the decision-making cognition of chronic amphetamine abusers, opiate abusers, patients with focal damage to prefrontal cortex, and tryptophan-depleted normal volunteers: evidence for monoaminergic mechanisms. Neuropsychopharmacology **20**, 322–339 (1999)

Romeu, R.J., Haines, N., Ahn, W.Y., et al.: A computational model of the Cambridge gambling task with applications to substance use disorders. Drug Alcohol. Depend. **206**, 107711 (2020). https://doi.org/10.1016/j.drugalcdep.2019.107711

Santos, L.R., Rosati, A.G.: The evolutionary roots of human decision making. Annu. Rev. Psychol. **66**, 321–347 (2015). https://doi.org/10.1146/annurev-psych-010814-015310

Scott, S.G., Bruce, R.A.: Decision-making style: the development and assessment of a new measure. Educ. Psychol. Meas. **55**, 818–831 (1995). https://doi.org/10.1177/0013164495055005017

Shiv, B., Loewenstein, G., Bechara, A., et al.: Investment behavior and the negative side of emotion. Psychol. Sci. **16**, 435–439 (2005). https://doi.org/10.1111/j.0956-7976.2005.01553.x

Simon, H.A.: Invariants of human behavior. Annu. Rev. Psychol. **41**, 1–20 (1990)
Singh, R., Greenhaus, J.H.: The relation between career decision-making strategies and person-job fit: a study of job changers. J. Vocat. Behav. **64**, 198–221 (2004). https://doi.org/10.1016/S0001-8791(03)00034-4
Sokol-Hessner, P., Hsu, M., Curley, N.G., et al.: Thinking like a trader selectively reduces individuals' loss aversion. Proc. Natl. Acad. Sci. **106**, 5035–5040 (2009). https://doi.org/10.1073/pnas.0806761106
Starcke, K., Brand, M.: Decision making under stress: a selective review. Neurosci. Biobehav. Rev. **36**, 1228–1248 (2012). https://doi.org/10.1016/j.neubiorev.2012.02.003
Thunholm, P.: Decision-making style: habit, style or both? Pers. Individ. Dif. **36**, 931–944 (2004). https://doi.org/10.1016/S0191-8869(03)00162-4
Tom, S.M., Fox, C.R., Trepel, C., Poldrack, R.A.: The neural basis of loss aversion in decision-making under risk—supporting Material. Science **315**, 515–518 (2007). https://doi.org/10.1126/science.1134239
van Ravenzwaaij, D., Dutilh, G., Wagenmakers, E.J.: Cognitive model decomposition of the BART: assessment and application. J. Math. Psychol. (2011). https://doi.org/10.1016/j.jmp.2010.08.010
Volz, K.G., Gigerenzer, G.: Cognitive processes in decisions under risk are not the same as in decisions under uncertainty. Front. Neurosci. **6**, 1–6 (2012). https://doi.org/10.3389/fnins.2012.00105
von Neumann, J., Morgenstern, O.: Theory of Games and Economic Behavior. Princeton University Press, Princeton (1944)
Wallsten, T.S., Pleskac, T.J., Lejuez, C.W.: Modeling behavior in a clinically diagnostic sequential risk-taking task. Psychol. Rev. (2005). https://doi.org/10.1037/0033-2959.112.4.862
Weller, J.A., Levin, I.P., Rose, J.P., Bossard, E.: Assessment of decision-making competence in preadolescence. J. Behav. Decis. Mak. (2012). https://doi.org/10.1002/bdm.744
Wilson, D.S., Wilson, E.O.: Rethinking the theoretical foundation of sociobiology. Q. Rev. Biol. **82**, 327–348 (2007). https://doi.org/10.1086/522809
Worthy, D.A., Pang, B., Byrne, K.A.: Decomposing the roles of perseveration and expected value representation in models of the Iowa gambling task. Front. Psychol. (2013). https://doi.org/10.3389/fpsyg.2013.00640

The Augmented Reality Technology. An Experimental Application in the Educational and Industrial Sector of Baja California, Mexico

Juan Gabriel López-Hernández, Roberto Carlos Valdes- Hernández, Rogelio Lopez-Rodríguez, Juan Carlos Quiroz-Sánchez, Omar Ramírez-Franco, Daniela Hernández-Ramos, and Gustavo Lopez-Badilla

Abstract The main aim of this investigation was the implementation of Augmented Reality Technology (ART) in an activity of the education sector in elementary schools, with a deficient infrastructure of Information and Communication Technologies (ICT) in the northwest's region of the Mexican Republic in the Mexicali and San Quintin cities. Also in this analysis evaluated the possibility of implementing the ART in industrial companies of Baja California State, Mexico and as a novel

J. G. López-Hernández · O. Ramírez-Franco
Department of Basic Sciences, Agricultural Technology Center School, # 146, Carretera Transpeninsular Km. 177, Vicente Guerrero, 22920 Valle de San Quintín, Baja California, Mexico
e-mail: juan.lopez@cbta146.edu.mx

O. Ramírez-Franco
e-mail: omar.ramirez@cbta146.edu.mx

R. C. Valdes- Hernández
Department of Technology, Faculty of Administrative Sciences, Autonomous University of Baja California, Blvd Río Nuevo, Eje Central y, Río Nuevo, 21330 Mexicali, Baja California, Mexico
e-mail: valdez.roberto@uabc.edu.mx

R. Lopez-Rodríguez
Department of Sciences, San Quintin Faculty of Engineering and Business, Autonomous University of Baja California, Carretera Transpeninsular Km 180.2, Ejido Padre Kino, San Quintin, Baja California, Mexico
e-mail: rogelio.lopez.rodriguez@uabc.edu.mx

J. C. Quiroz-Sánchez
Department of Sciences, Autonomous University of Baja California, Boulevar Benito Juárez S/N, Parcela 44, 21280 Mexicali, Baja California, Mexico
e-mail: quiroz.juan@uabc.edu.mx

D. Hernández-Ramos
Department of Education Sciences, Baja California Center for University Studies, Blvd. Sharp 3502, Benito Juárez, 22710 Rosarito, Baja California, Mexico
e-mail: dhernandezramos1@edubc.mx

G. Lopez-Badilla (✉)
UNEA Universidad, Cjon. Cuauhtémoc 336, 21230 AviaciónMexicali, Baja California, Mexico
e-mail: glopezbadilla@hotmail.com

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_10

way to develop distance training processes, considering the current limitations of the Covid 19 pandemic. Another limitation of the training activity is the lack of economic resources on some occasions to attend events in other cities or places of training. This scientific study was very relevant because this analysis verified that the use of the ART in the activities and the aspects of ICT mentioned made it possible to work and generate productive and representative results. As the deficiency and lack of ICT is an occurrence in some regions of Mexico and is a concern of government and industries of the persons in charge of educational and industrial operations, this investigation would be an alternative method to make educational courses at distance or personality with students. This can also apply to industrial workers with training courses at distance or personality to improve the yielding operative workers. They used in some healthy activities to understand any thematic the ART in training courses as the understanding the Covi19 in some public or private clinics or hospitals and generates the adequate tools to combat it.

Keywords ART · Educational and industry activity · PBL · Platforms · Mobile devices

1 Introduction

The investigation was of significant support for educational institutions in rural areas that are a little far from large cities, where the telecommunications technology limited, as the schools where they're made the investigation. The software used in this investigation was the Unity-Vuforia, with an algorithm installed on the cellular phones of the students, to see and understand a specific thematic of the subject of geometry, and with this. With this, it created students an environment model to elaborate on the continuous improvement in the classroom where they attend classes. With this type of technology, it placed some objects in strategic positions or zones of the classroom, and generating a change of size or colour of objects to change the classroom environment. Regarding the experimental case in the electronic industry made a training to some workers of manufacturing areas about a specific thematic of electronic components of an industrial equipment used in the industrial processes. This training resulted very beneficial, because workers understood very well the operation of an electronic system of an electronic equipment used to detect electrical failures in computers manufactured in the electronic industry, where made the other part of this investigation.

With this training process, workers helped to specialized people that support to maintain operating correctly the industrial equipment and machinery. These operative workers repaired the failures presented in an electronic system used in their area of work, because with the training course they learning about it quick. This helped to avoid f stop of the electronic systems evaluated and with this not stop the production lines, which was a very concern of managers and supervisors, being a pilot test in the industry of this region of Mexico. This analysis developed based on the feedback factor applied in industrial activities, as a relation of the capacitation process as the input signal and the productive yielding of workers as the output signal, considering the implementation of the ART, being like that made in students, with the educational yielding. The developed of this scientific study in the educational sector showed relevant results, as the improving of teach class in classrooms and students with more interest to learn in the three schools analyzed, occurring the same process in the industry evaluated. For this reason, considered that the application of Augmented Reality Technology (ART) in the educational and industry activities is of great importance. With this analysis in the industry can improve its production processes and productive yielding of workers and industrial equipment and machinery fast.

The evaluation in this investigation, of the application of the ART in schools were in three educational institutions of rural areas, where two of these educational institutions are in the Mexicali Valley, who's a large and industrialized city, but its rural area has many deficiencies in terms of telecommunications infrastructure and the other educational institution is from the town of San Quintin, near of Ensenada city, which is a city with industrial and fishing activities, and with the same problematic situation that the Mexicali Valley schools. These two cities of the Baja California State in the northwest of Mexico, and being a border area, there is an interrelation between industries, with a large industrial, commercial activity between both countries because of the Free Trade Agreement (FTA).

The investigation in two stages, being the first stage, an evaluation to implemented the Augmented Reality Technology in educational activity and the second stage was in an industrial activity mentioned above in both cases. With this experimental process, the students had a perception of how to analyze real-life situations focused on the method of Problem-Based Learning (PBL) (Mutasim et al. 2018). With the use of ART, scenarios generated to understand detail, all or most factors that intervene in an evaluated environment, without needing to be in said environment and can apply the continuous improvement to elaborate the functions, using all resources (human, materials and economic) of the most efficient way (Dong-Hee et al. 2013).

Respect of the educational activity is over 4000 schools in the Baja California State, from preschool to college, and being a pilot test what presented in this investigation, can apply in all educational institutions of this state and other states of of the Mexican Republic (SEP 2021). Respect to the industrial activity, are over 500 industries in this state the six cities (Ensenada, Mexicali, Rosarito, San Quintin, Tecate and Tijuana) (INDEX 2021), to apply the ART, as made in this scientific study. The main industrial operations are in aeronautics, biomedical, electronics, metalworking, textile and plastics manufacturing. In San Quintin, the majorly of industries are of agricultural and livestock operations because they considered this city a very extensive area for farming and fishing activities with a minor industry of electronics sector.

Then, for the first stage analyzes, it evaluated the infrastructure conditions in the three schools, where the services and facilities regarding information technology is deficient, even though the state of Baja California is one of the most prosperous in Mexico. Of the six cities that comprise the geographical area of this state (Ensenada,

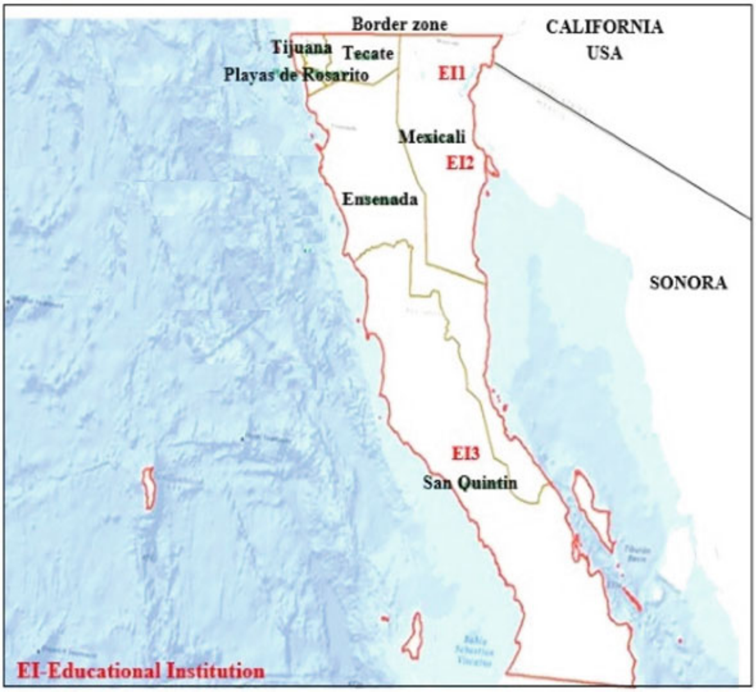


Fig. 1 Map of the Baja California State with educations institutions where made the investigation

Mexicali, Rosarito, San Quintin, Tecate and Tijuana, where presented in Fig. 1), the government has focused only in the cities of Ensenada, Mexicali and Tijuana with greats invested in infrastructure (GEBC 2021).

Figure 1 shows a map of the six cities of the Baja California State and the foreign zone with the California State of United States. In this map represented the three educational institutions where made the investigation, which is showed two schools in rural areas of the Mexicali Valley and one school in the San Quintin city, with scarced infrastructure about the information technologies. Mexicali is a great city that was founded in 1903 and San Quintin is a city that was declared the sixth municipality of Baja California in 2020, being a zone that belonged to the city of Ensenada founded since 1882.

Even though Mexicali has over 100 years after its founding, and it is an industrialized area, the rural area called Valle de Mexicali has many deficiencies, even in areas close to about 30 km from the industrialized area of the city.

The schools of the Valley of Mexicali, one of them in the Benito Juárez Town (EI1) is located 50 km away and the other in the Sonora Town (EI2) at 45 km from the industrialized area of Mexicali, where there is a great infrastructure regarding to the information and communication technologies. The educational institution (EI3) is in the city of San Quintin, which, being a young municipality and having been from the rural area of Ensenada, does not have sufficient information and communication technology infrastructure and not received support respect infrastructure of the ICT. In the two cities mentioned are foreign industries, principally from United States, Japan and Korean; having more manufacturing industries in Mexicali, (being considered as a large industrial city) where a large infrastructure investment has developed, especially in the urban area, but in rural zones are deficient and scarced infrastructure in the ICT.

Even being one state of the Mexican Republic with great economic prosperity, and contributing a large percentage of GDP to the country, the three remaining cities mentioned (Rosarito, San Quintin and Tecate), and the rural areas of the cities considered large industrial cities, suffer by the lack of ICT or low investment regarding the information technology (GEBC 2021). For this reason, there are not the tools for the adequate understanding of knowledge in school classrooms such as accessories and books, mainly; to develop educational activities.

Based on this, the investigation take more relevance, because in the three schools evaluated, the internet is intermittent and function little times, and it required to purchase a service in commercial convenience stores, with information data for communication and having the possibility of accessing to internet (López Hernández et al. 2016). But, in this type of service, the information data consumed quickly, and it is necessary to require another purchase of service (noting that you can have access to phone calls and the internet (social networks) and search for information), to continue having access to Internet. The application of ART with the Unity-Vuforia software does not consume a large amount of data (Reisoglu et al. 2017), but if the educational institution not have a good infrastructure in ICT, is necessary have constantly buying the service to have data and access the internet. And other aspect is that these schools do not have a library or have one, but with few books.

1.1 Importance of ICT in the Educational Sector

One of the important aspects in the educational sector is the use of the Information and Communication Technologies (ICT), with specialized computer programs, to develop administrative and educational activities (Kingsley 2017). For teaching classes, the ICT used in laboratories and classrooms with advanced technology to understand adequately the knowledge of each scholar subject. Using ICT in teaching–learning activities has generated great relevance because of the advantages that exist, such as the comprehensive learning of students and teachers. In base of information from the internet, teachers and students can create scenarios to determine the behavior of the activities that are developed in classrooms, without being outside of the classroom (Bagon et al. 2018). The adequate use of ICT in educational institutions, increase the levels of educational performance and with this it competitiveness, and also using strategic tools, it created harmonious environments between students and teachers. This can achieve immersion in the learning processes, through interactive games, and with activities that are fun, and may include contents, themes or messages of a school subject, calling to this ludic method (Caspary et al. 2015), in Table 1 showed the major advantages and disadvantages.

Table 1 shows information on the fundamental characteristics required for implementing ICT in educational activities, noting that expert computer personnel required

Table 1 Characteristics of implementation of ICT in the educational sector

Factors Involved personnel	Actions	Needs
Director, Administrative and Academic Responsible, and experts of the Computing Laboratory of Educational Institutions	Realization of a web page to keep to the administrative personnel, teachers and the student community informed with advance of scholar events	Schools need to have specialized computer personnel to train and support to administrative personnel, teachers and students; to take advantage of the event's information by the scholar's website and prepared for each event
Teachers, students and personnel experts in a thematic and experts of the Computing Laboratory of Educational Institutions	Use of communication tools such as email to send extra-class work such as tasks and research reports (progress and final) and topic forums that help increase the knowledge of students, with lectures by experts on a topic	Schools need to have specialized computer personnel to train and support to teachers and students, to take part in the forums to reforge the knowledge of teachers and students. Teachers must determine the personnel expert that will impart the forums to generate interest in students
Teachers, students and experts of the Computing Laboratory of Educational Institutions	Use of computer systems platforms to impart knowledge with extra-class activities, as well as the teaching of classes in periods of an event that may generate a serious situation of health, such as the COVID-19 pandemic that is currently presenting. In addition, it can send tasks and research papers with the platform and proportionated advice to students	Schools need to have specialized computer personnel to train and support to teachers and students, to take part in the virtual classes and the extraclase activities as proportionated advice to students. Teachers must be an organization of their activities to review daily tasks and investigation activities of students
Teachers, students and experts of the Computing Laboratory of Educational Institutions	Development of interactive and integrated educational environments to achieve harmonious and comprehensive activity, where all students take part together with the teachers of each school subject taught	An adequate information technology infrastructure required, so that everyone takes part virtually, as well as an optimal integration of the teachers of the student groups for the daily tasks or research works to be developed for certain periods of time

in all operations, to support in functions of people that work in offices and classrooms of schools. These specialized people have great relevance in using ICT in educational institutions, to improve any type of process where involved a computer systems in schools. In some times, schools do not have specialized personnel and activities not made properly, presenting a problematic situation that instead of supporting administrative, academic and student personnel, can generate great confusion and cause a lack of interest in students and teachers in the teaching–learning processes. Having all the elements as mentioned in Table 1, efficient results and optimal school performance of qualified students and teachers can show to increase the competitiveness of educational institutions.

1.2 Educational Institutions with Poor ICT

Sometimes exist educational institutions with poor infrastructure of ICT or not have, like schools mentioned in this investigation. The principal aim of the educational system in Mexico is to plan all kinds of solutions, with the funds, but sometimes not applies to all cities, because not reach the budget. For this reason not considered the realization of some interactive activities in schools as operations to teach class. This type of application called GWAP (Games with a Purpose), and called interactive teaching–learning games (Reis et al. 2010). When these applications reach the purpose for which they designed, it can work for a long time. According to studies by the Entertainment Software Association (ESA), users reach 200 million hours per year, of which an average of about ten hours per day is equivalent to five years playing each person 40 h a week during their entire life.

In other way, use of the cell phone in educational spaces restricted because they considered it a distraction. However, through educational technology can used cell phones as a tool to approach, develop, complement and evaluate educational activities, as each teacher deems appropriate (Istenic et al. 2014). In its planning activities, teachers can use especially some types of context using ICT, which are depends on each zone of the Mexican Republic.

For example, in one place that was made the investigation, as is San Quintin city, offers a wide variety of culture aspects with diverse indigenous peoples, according to the Mexican Institute of Indigenous Peoples (MIIP). For this, teachers debit do the planning of class, thinking about the poor infrastructure in educational institutions and consider about its culture using ICT if is possible. This is because this new city is a geographical area with 48 dialects of the 63 that are spoken throughout Mexico. Regarding the educational institutions in the Mexicali Valley, EI1 institution is in the Benito Juárez town, and EI2 in the Sonora town, its people is considered with diverse Mexican traditions, with persons of different states of the Mexican Republic (GEBC 2021). In both zones of the northwest of Mexico, where made the investigation, the major of people have poor information about ICT. With this experimental case in the educational sector, made a specific analysis, approaching the learning from practical situations, and involving teamworks and determination of solution alternatives, with the aim that these actions generate a positive effect on students' learning (INEE 2015).

1.3 Differences Between Virtual Reality and Augmented Re-Ality

These types of technologies are of great importance in using ICT, which even having parallel paths have different functions (Akçayır and Akçayır 2017). Virtual reality introduces a user to a virtual world, simulating a sensory experience through equipment with earphones, glasses and helmets (Baus et al. 2014). Augmented reality generates proper environments with proper elements, simulating activities with games, observing animations that not detected in reality. This type of technology uses electronic devices such as cell phones, tablets and computers, to generate the environments that they want to evaluate (Brown et al. 2016). Table 2 shows the major differences where the way of operation of each type of reality.

Table 2 Principal differences of virtual reality and augmented virtual

Virtual reality	Augmented reality
Develops a reality different from the existing one to evaluate the possibility of improving the original conditions Introduces the user to a new world by interacting with the environment	Change the existing reality to evaluate the possibility of improving the original conditions It takes the user to a world that does not exist, generating an interaction with the contour that surrounds it
In order to enter the virtual world in a sensory way, it used them besides wearing glasses and a helmet; headset and gloves used	It does not require elements such as those used in virtual reality, but only needs a cell phone, smartphone, tablet or computer, to feel in the environment to observe or evaluate
I limit it in its used to fun activities such as interactive games, because it cannot interact with the real world	It has less limitation, as it can used in various topics such as analysis and medical operations, decoration styles, sports activities, types and ways of interacting with information and a great variety of areas of the agricultural sector, It limited in its use to fun activities such as interactive games, because it cannot interact with the real world biomedicine, livestock, industry and commerce, by being able to interact with the real world
Requires items such as a headset, helmet, glasses and gloves; which can generate significant cost for your interaction process with your environment, and sometimes these costs, some users cannot perform	It does not require items with high costs, but a cell phone, smartphone, tablet or computer; being that its costs have decreased because of its large influx in the global market; and therefore, the user can interact with their environment and improve their experience in knowledge of a subject without elaborating on a high expense

Table 2 represents the major differences between virtual reality and augmented reality, where it observed that augmented reality has more advantages regarding its application and way of interacting with its environment (Brown et al. 2016).

In addition, the costs of using virtual reality are higher than using augmented reality with all the equipment to achieve interaction with your environment. The costs of cell phone equipment, smartphone, tablet and computer; have decreased notably because of the large number of products of this type that are sold worldwide and with this, it is easier to get these elements to develop activities in a new environment. Augmented reality sometimes uses some type of lens adapted to speculate about an environment that you want to evaluate (Akçayır and Akçayır 2017).

1.4 ART: General Knowledge

This technology refers to the visual perception of a physical scene through a cellular device, portable tablet or computer; through which it projected images in real time accompanied by previously pre-recorded objects, to build a specific purpose (Martins et al. 2015). The first concept about augmented reality is because of a Boeing Researcher working on his tedious boards by proposing special glasses and virtual boards on a generic real board, showing that generated an augmented vision in the user's reality.

The development and application of the ART in different fields has been gradual to technological advances in different computer equipment, mobile devices and educational policies at different school levels in each country, that are being integrated to emerging technologies in order to make it more flexible and dynamic (Teichner 2014). Another concept of ART is to increase the natural feedback for the operator with simulated ideas, besides being considered as a form of virtual reality where the device mounted on the participant's head is transparent, which allows a clear vision of reality.. Other experts in using ART conceptualize augmented reality as a system that fulfills three basic functions: a combination of real and virtual worlds, interaction in real time, and the precise 3D registration of virtual and real objects.

Using augmented reality in various areas (Marketing, Advertising, Architecture, Engineering, education and Medicine), has facilitated the incorporation of virtual reality in different real scenarios to a great extent to improve many functions with activities developed from real life (Merino et al. 2015). This is the reason for this investigation, proposed the use of the ART in education sector in our country. Only, sometimes in some urban and rural areas of certain areas of the Mexican Republic, as the region where made the scientific study, is a little difficult to have the possibility of having access to technology, so it is not possible to have advances in the educational field. This makes relevant the use of ART in this investigation, being in three phases of development (1) virtual reality activities before 2014, (2) activities from 2014 to 2016 and (3) contemplated from 2016 and towards the future trends of augmented reality in the educative area (Martín-Gutiérrez et al. 2010).

The developments of applications in augmented reality have focused mainly on the industry for sales areas, because of the ease and speed of illustrating information with texts, figures and graphics, using high-tech devices.

Besides the illustration of information in sales areas, there is also the use of the ART for the collection of information through scanning codes in order to make the activities with a better organization, order, besides the ease and fast, to get adequate required data. At the European level, in a comparative report between virtual reality and augmented reality from a technical and practical point of view, by a German development company, the mixed ART or diminished reality, combines real objects and information to superimpose reality in a virtual world (Bacca et al. 2014). Therefore, it is a technology that allows adding virtual entities such as images, video, multimedia, audio, text and others, which are superimposed in a real world, through the use of a mobile device such as a tablet or cell phone with the camera. With an application or software, interprets this images and the information read through visual or positioning markers to generate or activate the multimedia object enlarged on a screen. From the previous concepts, a definition of augmented reality in the education activities built, which is expressed as an augmented reality environment that combines the real world with information or superimposed tools to generate an interactive environment with educational objects, and achieve the expected learning in a kinesthetic way that allows reaching a metacognitive level in the planned topic (López et al. 2021a; b).

1.5 Characteristics of the Augmented Reality Technology

It has characterized the augmented reality technology since its inception by the superimposed or three-dimensional images start from the principle of stereoscopic vision, which are derived etymologically from the Greek words stereo and opsis (solid vision). This is a brain capacity that vision has since it comprises the two perceived cerebral hemispheres respectively for each eye and it visually transforms this phenomenon as a 3-dimensional image, since each eye perceives a different image for its position. This is how it perceives the distance of an object, which mathematically known as the 3rd axis or z axis using as a reference to the x and y axes (Cabrero-Almenara et al. 2019).

Implementing an educational lesson of augmented reality through mobile technology in schools in a rural area in Baja California, proposes alternatives of action before the use of the cell phone not as a distraction but for its use with emerging digital technologies to complement team needs computing facilities in schools. Using the cell phone in class can enhance the teaching–learning process through the use of augmented reality on mobile devices to design didactic lessons that contribute to the training of critical students, with sufficient skills and competencies to face different potential scenarios in their community through problem-based learning (Noll et al.

2014). It is this last purpose that education pursues through the different educational levels, to contribute to the training of professionals useful to the society and communities where they trained.

1.6 History of the ART

According to the history of this technology, 300 years before Christ (BC), this thematic had approached by the Mathematician Euclides, who derived from his studies, concluded that, once the two images perceived by the eyes, the brain fuses them into a single image. It can do this, adding a sense of depth or 3rd dimension (Alrashidi et al. 2016). Later almost, five centuries later after Christ (AC), the astrologist Claudio Ptolemy related physiological diplopia with binocularity and in this way justified that each eye perceives a different image because of the location and separation between them. Later, Alhacen a Muslim physicist in the 1000 years, took up these studies and related the sensation of depth with the perception that exists in binocularity, validating the studies carried out by Euclides three centuries AC. Leonardo DaVinci credited with creating the work in stereography (1503) in collaboration with the Florentine painter Jacopo Chimeneti da Empoli by reproducing a second version of La Gioconda (Mona Lisa) at the same distance, but with a slight lateral shift to create the 3-dimensional optical illusion, derived from binocularity (Bacca et al. 2014).

Then, in 1613, Francois de Aguillion, was the articulator and creator of the stereoscopic concept to define this phenomenon of visual solidity that is transformed by the brain after receiving the image through the optic nerve. In 1838, a prototype invented that allowed visualizing an object in three dimensions, beyond a flat shape, and this device called Stereoscope (Wheatstone, 1838), and in 1840 Thomas Alva Edison proposed the use of this equipment in movie theaters, to present visual aspects. In 1923, used this type of technology of this age, in movie theaters, with a movie called "The power of Love", being the first film to use a double strip in red and green anaglyph format (Martín-Gutiérrez et al. 2010). Also, used two colors to give the impression that it is three-dimensional, when presenting before a live audience using anaglyph glasses.

Later in 1930, an aerial simulator developed to simulate flight conditions in person and in time real, so that the training of the pilots was as close to reality. The scientist Link (Link, 1931 patented this development in the United States). In 1955, Morton Helling used the term virtual reality proposed from the 1930, and in 1958, Morton Helling fabricated the machine called Sensorama. In 1968, Ivan Sutherland created the helmet to be used in virtual reality activities, using graphs and CAD applications (Merino et al. 2015). In 1972, Singer was working about new materials, and with their in investigations developed a poly-chrome lens with a spherical mirror that projected images of the exterior of a cabin, helping to optimize the flight simulator, and achieving a better feeling of flight (S. J. Singer). Later in 1985, Lanier founded the company VPL Research, and fabricated new devices for medical uses, flight simulation, automotive and military activities (Jaron Lanier), and in 1990, after that the Philco Corporation took part in 1958, created a virtual reality headset. In 1992, the concept of augmented reality emerged as a new technology for computer systems.

Also, in1992, fabricated the first functional augmented reality immersive system, with a system that projected the vision of robotic arms onto the user's arms, and creating an augmented vision of reality (Louis Rosenberg). And also, considered the holography term, which was created by Dennis Gabor from 1938, being the precursor of the virtual or augmented reality. With this, it corrected it a reflected image from an electron microscope, which presented a visual distortion caused by its lenses. It later did this with other visual effects of actual images to correct these optical deformations (Cabrero-Almenara et al. 2019). Then in 2000 year, developed the ARQuake with the Quake computer, being the first outdoor game with augmented reality mobile devices, being presented at the International Symposium on Wearable Computers (Bruce H. Thomas). From this year on, it created a great variety of functions with the ART, until reaching our current era where augmented reality can applied through the internet. The information about the history of the augmented reality technology described in Table 3

1.7 The ART in Educational Activities

In the majorly of the activities, and especially in the educational area, there is the concept of competitive perspective, to get the expected levels of learning, and evaluate the educational performance of students, which is like the operational yielding of industrial workers of manufacturing areas (Aottithey achieved it improvements in what is being evaluated. With this method, in this scientific study, they achieved it a capture of knowledge in the students and with the use of augmented reality technology, greater than 80%. And with this, had the experience of being able to develop scenarios and evaluate them without the need to be in the places due to lack of economic resources or sometimes for being places of danger, or inaccessible places.

It developed this scientific study with the elaboration of workshops and dynamics of topics in mathematics, as the subject of geometry, to evaluate based on thematic areas and perimeters the organization of a classroom. It made this to determine the way to organize a classroom with its tools, books and spaces for each of the classes (Bazzaza et al. 2014).

The experimental process comprises carrying out activities in a visual, auditory or mixed way. Even though the use of ART has increased worldwide and in our country, it has been possible to give importance to this type of technology, which has gradually replaced virtual reality, the Secretaria de Educacion Publica (SEP) in Mexico, has not shown a greater interest in this technology, considering that the use of equipment such as cell phones, tablets and computers in a class-room is a distracting element. For this reason, this government institution determined that it is not appropriate to implement it.

Table 3 Historic events of the augment reality technology

Year	Event	Year	Event
300 A.C	Fabricated figures drawn with depth level (Euclides)	1955	The term virtual reality becomes more popular, generated in 1930, being used in the theater and suggested by Helling (Morton Helling)
150	Used the diplopia and the binocularity in figures (Claudio Ptolomeo)	1958	Helling makes his own machine called Sensorama in 3D (Morton Helling)
1000	Utilized the binocularity and the depth in figures (Alhacen)	1968	It created the virtual reality helmet with graphics developed by CAD computer (Ivan Sutherland)
1503	Reproduced a second version of La Gioconda (Mona Lisa), with a slight lateral shift to create the 3-dimensional optical (Leonardo Da Vinci and Jacopo Chimeneti da Empoli)	1972	Singer developed a polychrome lens with a spherical mirror that projected images of the exterior of a cabin (S. J. Singer)
1613	Used the concept of the stereoscope, as an equipment proposed in base of 3D images (Charles Francois Gonoud)	1985	New devices for medical uses, flight simulation, automotive and military activities (Jaron Lanier)
1838	Image enhancement with a new stereoscope (Sir Charles Wheaterspone)	1990	Created a virtual reality headset (Philco Corporation)
1840	Use of 3D images in movie theaters (Thomas Alva Edison)	1992	Was fabricated the first functional augmented reality immersive system (Louis Rosenberg)
1923	First feature film in 3D applied by photos arrived in the commercial theaters of Los Angeles(Harry K. Fairall)	2000	Was developed the ARQuake developed with the Quake computer, being the first outdoor game with augmented reality mobile devices (Bruce H. Thomas)
1930	Fabricated the Link Trainer in 3D, being known as the Blue box and Pilot Trainer, and used in flight simulators (Edwin Albert Link)		

By COVID-19, in this time, the use of ART considered as an emergent technology, because of the impartation of distance classes, where according to experts in this technology, it can be very relevant to increase performance educational level of students of any level. In addition, it originated a good interaction between the students and the teachers involved in this scientific study, and a very positive attitude of the students of support among them presented for the realization of the activities, getting opinions for the best solution and mainly as a team, which sometimes it is difficult (Travieso et al. 2018).

In teachers, this duality proposes inquiry scenarios about student situations, with pre-designed learning environments and flexible emerging technology tools that are combined with virtual reality (VR) or augmented reality (AR). Also, can do a balance of times for different levels of achievement and different tasks that vary between each type of group (Bellini et al. 2015). This made, focused in towards an ability to expand the diversity of educational tools, and relying on the use of support software, cell phones and the design of enriched learning environments within the constructive paradigm. And, proposed a logical and structured scheme for the development of skills and competencies of the Mexican school. This aimed to enrich both the achievement of students in the domain of skills (INEE 2015), as well as the knowledge and values proposed in the training programs of the SEP, and to determine the teaching–learning method according to the urban area and educational context.

Studies and developments of ART in the educational field suggest that the application of augmented reality in education favors a better mastery of the topics when using audiovisual media and/or fieldwork (Cheng et al. 2012). Other scientists consider that the use of augmented reality helps to reduce the level of complexity in the use and planning perceived by the students and teachers involved in this scientific study. Also, made a systematic study where they combined ART with problem-based learning to solve actual situations, also a systematic review in the opinion of students and teachers about the learning experiences they had (Chen et al. 2017).

1.8 Unit-Vuforia Software

This type of software can develop activities with augmented reality technology, creating environments that introduce the user to develop operations in a simulated manner (Lehui et al. 2015). This is to elaborate its functions, thinking that it is in an environment without leaving some place where it can make its analysis, considering the cost savings and generating no type of risk. It type of technology uses a system of computer with a vision to recognition, generating a great quantity of images as a register of information. This supports to informatics developers of software to make operations of orientation and position of objects that participle in type of activities that want to evaluate. Using the Unit-Vuforia software begins when downloading Unity 3D version 4.0.0 in a cell phone, computer or tablet (Cheng et al. 2014). Figure 2 shows an important development process of the Unity tool used in mobile devices and computers. In addition, it contemplated a textual analysis of the Unity components, in Fig. 3 with their explanation as in Fig. 2.

Figure 2 shows eight stages of the development of the Unity tool, explained below:

1. According to computer experts, it considered that it developed the first computer game in two dimensions (2D), and it called Arcade Frogs, being released in 1978, where the user could jump on the screen on a 2D computer. Subsequently, a video game with graphics called Moon Patrol belonging to the Arcade game developed in 1982. In 1992, it released the game Quake, being the first to use 3D objects for all game functions, and a significant step in video game technology. The 2.5D dimension type was first used in 1982 with the Arcade Moon Patrol

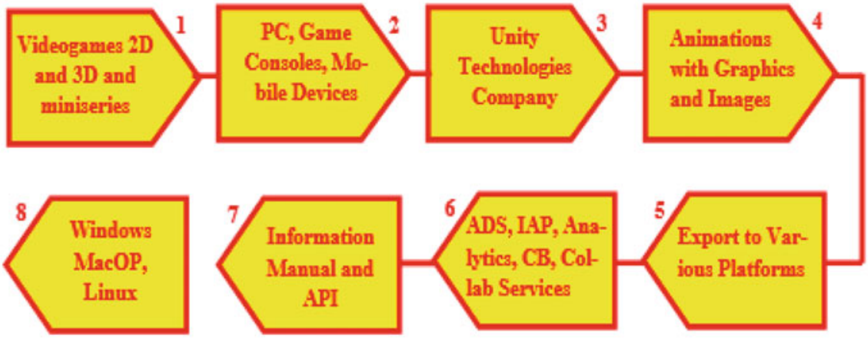


Fig. 2 Stages of development of unity

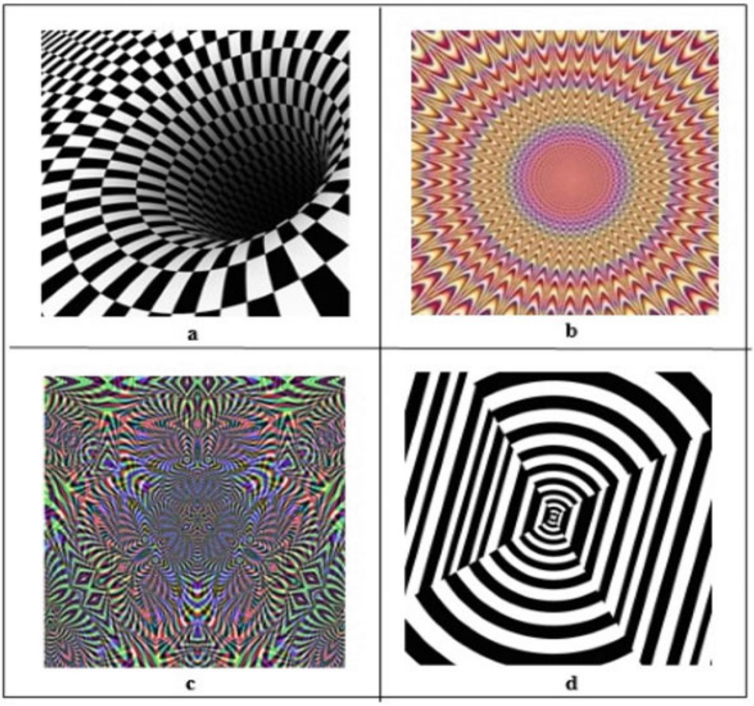
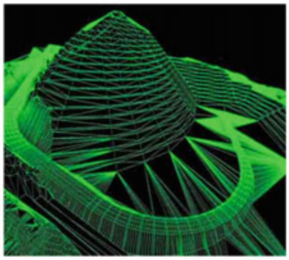


Fig. 3 Optical illusions generated on mobile devices and computers

game, illustrating 2D images that look like 3D (Mohd et al. 2016). The principal characteristics of dimensions of 2D, 2.5D and 3D represented in Table 4.

For the year 1995, the Japanese company Sega Corporation, commercialized its Saturn platform, with a 32-bit console, and games on compact discs CD, and not on cassettes as they previously handled giving way to games not only in consoles, but in

Table 4 Principal characteristics of projections with different dimensions

Characteristics Dimension	Concept	Application	Picture
2D	It defined as a series of projections of graphics and images in two dimensions	It applied in animation images with which; it generated the projections according to what it required in any activity	
2.5D	This type of dimension is intermediate between 2 and 3D, elaborating analysis with graphics and projections in two dimensions, but simulating that they visualize certain images as being in 3D without being so	They can use it in video games with a three-dimensional vision, but having the limitation of two dimensions (2 axes)	
3D	It represented graphics and 3D images in a three-dimensional way, generating projections such that the images or graphics are outside of what they represent, this being the Z axis	We used it in projections where images and graphics can elaborate or evaluated by being able to generate rotations between the same object	

computer, as a universal way. On June 23, 1996, the N64 console developed by the Nintendo Company in Kyoto, Japan launched, which was dedicated to the market of video games and card games regarding software and hardware. The N64 console comprised 64 bits, where on the first day of its release, 500,000 products sold (Von Der Heiden et al. 2019).

2. After World War II, in the 1950s, an era of development of new technologies began with large programmable computers, which stored a quantity of information mainly required by industries. This is how a new era in technology began, with the development of computer programs that generated entertainment, the first games of chess being. As the years passed, these types of games were reaching various parts of the world and improving their operation. According to

experts on this subject, the first video games arose in the 1960s, achieving technological advances every time more, without having limits in the development of video games (Cuendet et al. 2013). Technological advances have been so rapid that certain types of platforms, consoles and computer programs have ceased to operate to be obsolete and have moved to new ways of achieving maximum entertainment with video games (Bediou et al. 2018). This was regarding computers, and then at the first desktop game consoles that operated as part of entertainment activities, and were in the early 1970s by the Magnavox Company, with large structures. This company created by Ralph Baer in March 1971, being considered the father of video games on screens such as televisions and later on consoles and computers (Colder 2018).

Currently, the best cell phones to have access to video games entertainment are the Samsung Galaxy S21, Samsung Galaxy Note 20 Ultra, iPhone 12, Samsung Galaxy S20 Plus, Xiaomi 10 T Pro; where a great diversity of these mobile devices have video games (Carbonell et al. 2016). Only to achieve a better performance, competitive prices, dominant power in its graphics and images, and good quality screens should consider. The first indications of what is currently the electronic tablet date back to 1968, with the concept of a tablet that stores information being displayed in the movie Star Trek from the 1960s and in the 2001 movie Space Odyssey, as science fiction ideas. Based on this, the American computer scientist Alan Kay created a tablet called Notebook, to save textual information and images, having a battery that did not require constant charging. Alan Kay never imagined the great potential that this mobile device would have, which is widely used in various activities by children, adolescents, adults and some older adults (Beranuy et al. 2009).

For the year 1987, the Apple Computer company developed a futuristic tablet called Knowledge Navigator, with a friendly browser, so that the user could make the most of the functions of this tablet and responding to voice instructions. After this type of tablet, the same company manufactured two new models in 1993 called Newton and eMate 300, but only that because of the high costs for all users, it canceled their manufacture. It was until the beginning of the twenty-first century that the Microsoft Company released the Microsoft Tablet PC model, with its licenses at affordable costs for any user, and in 2001. Finally, the Nokia Company created the Nokia 510 web tablet model, improving the developed to the market by the Microsoft Company at the beginning of the year 2000 (Antley 2012).

3. In 2004, the Danish business people, David Helgason, Nicholas Francis, and Joachim Ante in Copenhagen, Denmark suffered a great setback in their company called Over The Edge Entertainment, when a video game called GooBall developed with the Mac platform, had a great failure. This led the three entrepreneurs to develop changes in their company, achieving the emergence of a new company, which continued with the approach of video game development, and they call it Unity Technology Company (Xie 2012). Although, the development of the GooBall game not has the expected success, it developed tools that would be useful for future video games. This was to promote new video games

with various types of unified platforms, achieving friendlier environments for programmers of this type of computer product.

The Mac platform was the first to design and work with the Unity tool in 2004, with two versions called Indie and Professional. It was so on May 30, 2005, which was considered the beginning of the new era of video games when observing the great potential of the Unity tool. In 2007, Unity Indie version 1.5 licenses had a great commercialization boom, reaching several countries, including Mexico. The costs for the Indie version had a cost from 300 to 1000 dollars, and the Professional version had a cost of 1500 dollars, with a greater amount of functions than the Indie version. With the manufacture of the iPhone in 2008, it was possible to have a platform for its application with the Indie version at a cost, and in 2009, the Android model appeared on mobile devices such as cell phones, resulting in the Indie version, and creating a new version, and being free, to open the field to anyone who wants to develop video games. This is how Unity widely accepted by programmers who developed video games, and it was in November 2012 that the company Unity Technologies created Unity 4.0, being a version compatible with DirectX 11 and Adobe Flash, being new animation tools called Mecanim, on the platform Linux.

1.9 Unity Tool

It is very useful in the development of video games, being a programmable operating engine that was integrated into several platforms in a friendly form to inform experts can elaborate on various video games in an easy and quick way. This tool can operate on platforms such as Windows, MacOS and Linux, to create video games and export it to over 25 platforms, having the ability to operate on consoles, computers and mobile devices such as cell phones or tablets. The main platforms to which your programming commands and instructions can export are PS3, PS4, Xbox One, PlayStation Vita, Wii U, Nintendo Switch, Nintendo 3DS (Mohd et al. 2016). This tool called video g engine or video game platform. One of its charandas well as video games. One application is in Augmented Reality Technology. Unity uses a visual editor and programming instructions encrypted to make various activities that achieve defined objectives. In the C # language that is used, it developed the operation commands to develop the visualizations required in each activity to be realized. This tool has the possibility of being coupled with various computer programs, with the greatest use in Table 5 being represented.

The multiple interconnectivity of the platforms mentioned in Table 5 allows to have objects and transferred between the mentioned tools and changed in the platform that is desired to improve its application. This makes the tools in Table 5 more powerful to get the maximum benefit and thus higher quality images and animations.

Table 5 Principal platforms coupled to unity

Factors / Platforms	Characteristics	Application
Blender	It is a computer program that produces modeling functions, lighting, animation and 3D graphics creation	One of its main applications is in animation design in television ads for marketing activities without using computer images, but with a great capacity for information storage as digital libraries
3ds Max	Create 3D graphics and animations developed by the company Autodesk Inc., being relevant because it uses the plugins (Application related to others to add new content)	It very used in television ads, video games, architectural designs or movies, generating computer images
Autodesk Maya	It can elaborate on 3D images by computers, as well as special effects and images with animations. It developed by the company Autodesk Inc	It used to make dynamic images with animations that are in constant movement
Softiiamge	It developed to create 3D images and special effects, with the use of reverse cinematic (for positioning images in specific coordinates)	It applied to the creation of computer animations for new movies, commercial advertisements and video games
Zbrush	It serves for the modeling process, images of sculpture and digital painting, whose goal is to create 3D objects in paintings or digital sculptures	It usually uses the 3D dimension, but sometimes projections can generated in the 2.5 dimension to create images that are in two dimensions and with a creative approach that seems to be in 3D, to better understand an evaluated image
Cinema 4D	It applied to develop 3D images, which can be compatible with Windows and Mac platforms	It very important in the elaboration of images with shadows sometimes determine the specific characteristics of an evaluated object
Adobe Photoshop	It applied as a photo editor, being created by the company Adobe Systems Incorporated	It primary use is in the retouching of photographs and graphics, normally known as a photography workshop
Adobe Fireworks	Considered as a vector graphic and bitmap editor	It applied to developers of internet pages to create interfaces and prototypes of internet pages

1.10 The ART Using the Unity

The Unity applied on various platforms for the development of games and interactive activities, being one of the primary tools used by increased reality technology. It based using art on this tool because it can develop interactive content in real time and environmentally friendly, for the development of video games or interactive activities.

According to the great potential that this programmable tool has, the ART adopted it as a specialized medium for the development of training activities and impartial classes in classrooms of educational institutions, essentially. Experts in using the ART are agreed that the application of this technology is fundamental for the increase in school performance of students from various educational levels (Travieso et al. 2018). With the knowledge of the potential of Unity and its interaction with various platforms, such as those mentioned, it could apply the ART in this research efficiently, achieving favorable results in educational activities in three educational institutions. Also, evaluated the possibility to apply this technology in an industrial company in the city of Mexicali. This was to get skills that supported to the responding quickly to problem situations without requiring specialized personnel in manufacturing areas of industrial companies (Alrashidi et al. 2016).

Artists, designers and programmers widely used the Unity platform to visualize their operations in real time and know the advantages and disadvantages of their work and thus improve their development proposals. For the development of this investigation applied the augmented reality technology, to know the origin of video games, which is the activity on which the ART based, describing the components and operation of video games from their beginnings to the present. The aim of using augmented reality technology in industries, was to have intelligent training processes as industry 4.0, with which the operating personnel learned in a training room of the industry where made the scientific study, to learn how to operate the process and can provide solutions in the presence of problematic situations with no specialized support person and propose continuous improvement (Martins et al. 2015).

4. The images are representations characterized by being in two ways:

   (a) It can be still images or dynamic images, which can present movements. Creating animated images called animation, and it comprises developing essentially dynamic images for various activities, reflecting a sensation of movement in a user. Currently in computer, there are various internet sites where you can get large amounts of images or cartoons, the most widely used being: Tenor, Google Images, GIF Bin, Giphy, ReactionGIFs, Gfycat, Tumblr, La casa del GIF. On a mobile device such as cell phones and tablets, to create an image or cartoon, there are various platforms such as Tumbler, Giphy, Google Images, If We Don't, Remember Me, Animated Albums and Gif Anime (Martín-Gutiérrez et al. 2010).
   (b) By following the instructions properly, it is easy to download images and cartoons on cell phones and platforms. Addition, there are computer editors such as Word, Excel and Power Point; in which animations with images, drawings and graphics with special effects can generate. In animated images, moving images are audiovisual media, expressing their advantages and disadvantages. Animation is an action that generates movement to drawings, graphics and inanimate objects through a sequence of drawings or photographs that, when ordered consecutively, spectacular movements achieved before our eyes, guiding us before a visual illusion. For mobile devices, there is an application called Wombo, with which

you can create various animated images, being available for Android and iPhone iOS, generating a function that makes the photos move, creating animations musicals.

There are ways to generate optical images, which are formed by a set of points where the rays that come from point sources of the object converge after their interaction with the optical system. It can achieve this on a cell phone, where it can do using Google Photos, being a default gallery application in the droid model. Figure 3 illustrates animation images with diverse expressions.

5. As mentioned, the Unity program can coupled, using APIs with graphics in DirectX, Metal, OpenGL and Vulkan, depending on the availability of the API (Application Programming Interface), on a particular platform, using a group of APIs with graphics with various types of publishers. It is here, where Unity can join with Vuforia, being a software development kit (SDK), with images in 2D, 2.5D and 3D, to have markers that are indicator format. Also, it can represent texts, images or graphics in editors to achieve positions that help properly organize the information in any editor (Beranuy et al. 2009). The Vuforia application has a marker that coupled to the Unity function, called VuMark, where there is locating devices in space, as well as occlusion detection through virtual buttons. In addition, a selection of images in running periods and the ability to create and reconstruct targets based on scheduling functions considered. To develop the applications with Unity-Vuforia on cell phones, is necessary first download the Unity 3D application with version 4.0.0, followed by the Vuforia SDK function for Unity and Android. With this you can create a new project, importing the Vuforia 2.31 platform at Unity.
6. In the development of images on cell phones, tablets and computers, there's is relevant functions generated in the Unity platform, explained below (Cabrero-Almenara et al. 2019):

   (a) ADS-Unity. It is a tool used to generate economic income for video game developers, with the generation of advertisements that are presented in video games. In certain games, there are game reward revenue generation ads for players if they reach various levels in the games. This type of tool is avail-able on Android and IOS cell phone systems.
   (b) IAP. With this function, is possible make purchases mainly on cell phones with the IOS system, Mac, Google Play and Windows. This is because within video games, there is an application to buy in a store with extra functions to make purchases. This virtual store being in the same company to understand and optimize the economy in each video game.
   (c) Analytics. It integrated this tool into the Unity platform, whose function is to provide information about each video game, besides the rewards of the level games, to create experiences for each player.
   (d) Cloud Built. It is a function used to expand video game operations and to generate functionality remotely, being operated with IOS and Android systems, configuring various gaming platforms for easy coupling.

(e) Collab. Supports saving, sharing and synchronizing Unity functions, to achieve optimal performance of video games, and depending on the location of each player, there may be an extra cost in each game.

7. For quick and easy understanding for the development of applications in Unity, there are various types of manuals with detailed information on each operation required for the creation of video game applications. In addition, it contemplated the API function, which is a function explained previously that can achieve an adequate coupling between platforms with the required interfaces (Brown et al. 2016). This is of great importance because in many parts of the world there is little effectiveness in the information technology infrastructure and there cannot be an interrelation between platforms and with this it is not possible to apply augmented reality technology. In addition, the informative manuals of the Vuforia application with the functions of Application Programming Interfaces (API) in C++, Java, Objective-C++, and the .NET, which are the programming languages coupled with the Unity platform. In this way, the SDK supports both native development for iOS, Android, and UWP while it also enables the development of ART applications in Unity that are easily portable to both platforms (Delić et al. 2014).
8. The Unity-Vuforia platform plans to be applied in the three main operating systems that are Windows, Mac OS and Linux. Each operating system has different processors, the main ones being Intel and AMD for Windows, as well as for MacOS and Linux, it can be compatible, but the Apple Company, some-times develops specific processors for these operating systems, operating on different platforms. Computer experts considered Linux may be the best operating system of the three mentioned, where it taken as a reference that the Mac system based on Unix. It based the Windows operating system on a specific programming language, being capable of running multiple applications, where Mac considered having greater stability, security and absence of viruses. In contrast, Linux is a free operating system, but it is more difficult to use (Xie 2012).

1.11 Programming Application of Unity-Vuforia

To the creation of images is necessary use the Unity 4.00 and Vuforia with the applications, developing a program as represented next (Chen et al. 2017):

```
using UnityEngine;
using Vuforia;
using System.Collections;
public class MyPrefabInstantiator: MonoBehaviour,
ITrackableEventHandler {
private TrackableBehaviour mTrackableBehaviour;
public Transform myModelPrefab;
// Use this for initialization
```

```
void Start ()
{
mTrackableBehaviour = GetCompo
nent < TrackableBehaviour > ();
if (mTrackableBehaviour) {
mTrackableBehav
iour.RegisterTrackableEventHandler(this);
}
}
// Update is called once per frame
void Update ()
{
}
public void OnTrackableStateChanged(
TrackableBehaviour.Status previousStatus,
TrackableBehaviour.Status newStatus)
{
if (newStatus = = TrackableBehaviour.Status.DETECTED ||
newStatus = = TrackableBehaviour.Status.TRACKED ||
newStatus = = TrackableBehav
iour.Status.EXTENDED_TRACKED)
{
OnTrackingFound();
}
}
private void OnTrackingFound()
{
if (myModelPrefab ! = null)
{
Transform myModelTrf = GameOb
ject.Instantiate(myModelPrefab) as Transform;
myModelTrf.parent = mTrackableBehaviour.transform;
myModelTrf.localPosition = new Vector3(0f, 0f, 0f);
myModelTrf.localRotation = Quaternion.identity;
myModelTrf.localScale = new Vector3(0.0005f,
0.0005f, 0.0005f);
myModelTrf.gameObject.active = true;
}
}
}
```

The program represented is an application to create figures, as the next images to develop into any type of activities in the inn daily life.

Fig. 4 Image created by the Unit–Vuforia application

1.12 Application of ART in Marketing Activities

As mentioned above, the first stage of the investigation comprised focusing on the educational sector with the application of augmented reality technology in classrooms. This was to evaluate some images that create an image with applications of Unity-Vuforia (Wu et al. 2013). Based on the development of images in Fig. 4, the main aim of the first stage of the investigation was to develop images like to shows in Fig. 4, where it simulated that the image is outside the screen of a Tablet, and created in the same way for a cell phone and laptop or desktop computer, using the Unity 4.0 and Vuforia applications. The applications developed by the expert researchers of these activities and later they used in the classrooms to be elaborating the environments with the students and understand the themes to develop continuous improvement with the tasks. This is a great step in the teaching's-learning improvement process in the educational sector and applied in the industry as an intelligent training operation such as Intelligent Industry, elaborating said operation of any manufacturing process, for the improvement of the skills of operational personnel (Sáenz et al. 2015) This is part of the second layer that is explained later in another section.

1.13 The ART in the Industry

The second stage of the investigation comprised evaluating a company in the electronics sector in the city of Mexicali, where a training course with ART made, which explains how it made immediately. This was to explain to the workers in the manufacturing areas how they operate the industrial equipment and machinery, which they are constantly using (Sanderink et al. 2018). This was necessary because in the electronic industry where the investigation made, it made activities at 24 h a day and from Monday to Friday without taking breaks from industrial equipment and machinery. In this industrial company, there are four shifts a week, being represented by shifts 1, 2, 3 and 4. The shifts are 12 h (day and night), working four days in a week (from Sunday to Wednesday), for shifts 1 and 2; and the other two 12-h shifts (day and night), working three days a week (Thursday to Saturday), for shifts 3 and 4. Subsequently, a change of days made in the four shifts, where in the shifts 1 and 2, they work three days a week (from Sunday to Tuesday) and in shifts 3 and 4 they work four days (from Wednesday to Saturday).

In this electronic industry in the city of Mexicali, where the scientific study made, semiconductor components used in cell phones manufactured and because of the high demand for this type of products, it is necessary to elaborate the production processes in these four shifts. In addition, this helps the industrial company to can accept more workers, being important for the Mexicali community. Therefore, as the equipment and industrial machinery are constantly working, there is the possibility of damage to any part or electronic device, causing failures and with it, malfunctions and sometimes the stoppage of any equipment or machine (Colder 2018). Because of this, delays generated between the manufacturing stages and in the client, which may cause in its minor effect, that the client generates a fine to the evaluated electronic industry or in its greater effect, that does not want the manufactured product, reaching cause economic losses.

To measure the level of three main variables that intervene in the operational yielding of workers (attitude, knowledge and experience), whose variables are qualitative, it evaluated all personnel in manufacturing areas; with the amount of products produced per day for a month. This was to consider which operational worker was suitable to train through augmented reality technology. Experts mentioned it developed the training in a room adapted for interactive activities, using Smartphone cell devices (Brown et al. 2016). In base in this, made an analysis of application of ART in industries, determining the type of industry as an electronics industry where made the second stage of the investigation and is in the Mexicali. In this are located five principal types of industries: electronics, biomedical, metallic, textile and, it hass howed a plastic in Table 6.

Table 6 shows the major industries established in the city of Mexicali, as well as the processes based on their volume and methods of operation in industrial activities. In addition, the products that are manufactured presented, where most of these manufactured products (80%) marketed in the state of California, United States and the rest (20%) of these products marketed in the northwest region of the Mexican Republic, essentially in the states of Baja California and Sonora. Regarding the process, volume explains below them as the first part of these:

(a) Lots. It is a process made with a large volume of manufactured products that are quickly marketed for a wide variety of customers.

Table 6 Principal industries located in Mexicali and its manufacturing factors

Manufacturing factors	Type of process		Products manufactured
Industries	Volume	Method	
Aerospace	Order	Continuous Flow	Aircraft Parts: Seat Covers, Autopilot Control Systems, Aircraft Cabin Structures, Aircraft Cabin Control System Voltage Sources
Biomedical	Batch, Order	Continuous Flow, Manufacturing Cell	Cervical Collars Defibrillators, Oxymeters, Pacemakers, Respiratory Masks
Electronics	Batch, Order	Continuous Flow, Manufacturing Cell	Calculators, Cell Phones, Computers, Electronic Sensors (Level, Piezoelectric, Pressure, Temperature, Transmitter–Receiver) Navigation Systems for Vehicles, Digital Cameras, Transmitter Recorders, Televisions, Video Game Consoles
Food and beverages	Batch, Order	Continuous Flow, U Form, G Form, Manufacturing Cell	Beers, Sauces, Sodas
Metallic	Batch, Order	Continuous Flow, T Form, Manufacturing Cell	Food Packaging Cans, Furniture Slides, Hinges, Screws, Sink and Dishwasher Keys, Nuts, Building Structures, Vehicle Bridge Structures
Plastics	Batch, Order	Continuous Flow, Manufacturing Cell	Antistress Dentures, Beverage Storage Bottles, Caps for Water Bottles and Jugs, Containers for Domestic and Office Activity, Garbage Collectors, Hoses for Medical Use, Irrigation Hoses, Kitchen Utensils, Plastics Gloves
Textile	Batch, Order	Continuous Flow, G Form, T form, T Form, Manufacturing Cell	Carpets, Clothing (Dresses, Pants, T-shirts), Cloth Gloves, School and Work Uniforms, Rugs, Tablecloths for Household Use

(b) By Order. It is a process elaborated by purchase orders of specific clients.

Based on the operating methods, they explained the following processes:

(a) Continuous Flow. elaborated linearly, manufacturing large quantities of manufactured products, using automated equipment and machinery in most cases, and in few occasions manual operations.
(b) Form G. Is developed in areas forming the shape of a G for products that require constant quality inspection, sometimes using automated equipment and machinery and also requiring manual operations.
(c) Form T. Is realized when some industrial operations made alongside the primary activities, using in most cases automated equipment and machinery and in few occasions manual operations elaborated on the sides attached to the lines of major production.
(d) Form U. Is elaborated when it is necessary to have a fluid process and carry out certain periodic inspections of the manufactured products, using automated equipment and machinery in most cases and in few occasions manual operations
(e) Manufacturing Cells. It made when certain activities with short production times require some manual operations.

1.14 Electronic Industry

This type of industry is of great importance in the global market, in the GDP (Gross domestic product) of the countries where this type of activity developed. In the Mexican Republic, 70% of national and foreign industries are of this type, or have some type of an industrial process that manufacture or use electronic devices in manufacturing areas and being used by industrial machines and equipment (López Badilla Gustavo et al. 2013), which have different electronic, electrical, electromechanical and electropneumatic equipments illustrated in Fig. 5.

These aforementioned components sometimes decrease their operating performance because of electrical failures, because of some type of situation. This worries the management and supervisory personnel, because productivity levels reduced and quality of manufactured products. This situation occurs in certain periods of manufacturing activities, because of the lack of operation in industrial processes, when an industrial equipment or machine stopped because of electrical failures or do not work properly. Based on this, it made an investigation, where it evaluated in a production line of an electronics industry in Mexicali, the way to elaborate the operations of the production process. This was to determine the operating personnel with the greatest number of qualities to develop activities in manufacturing areas.

The purpose of this analysis was to train with augmented reality technology, how industrial equipment and machinery operate and can support maintenance or manufacturing personnel specialized in solving problem situations. This proposal developed because sometimes the maintenance and manufacturing personnel are attending

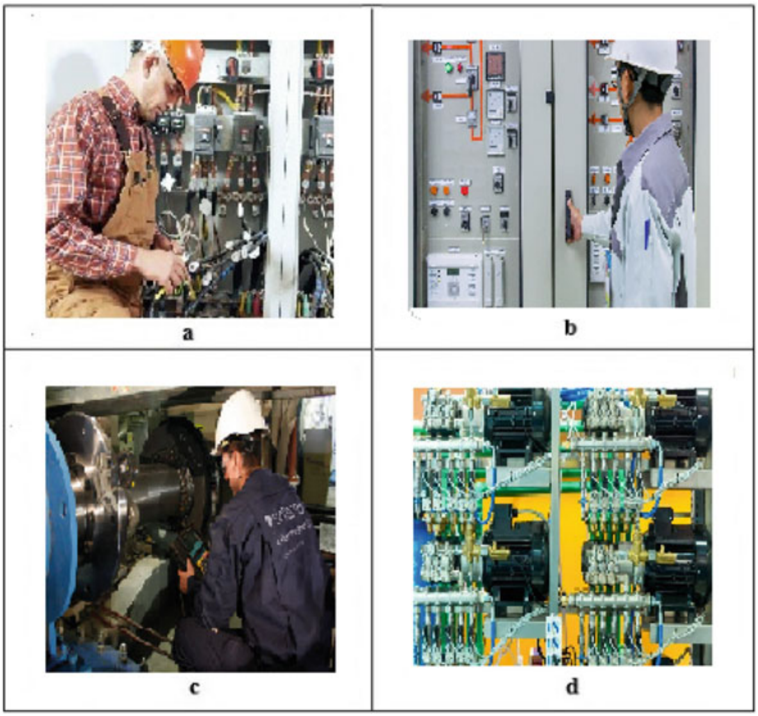


Fig. 5 Industrial equipment and machinery used in industries in Mexicali: **a** industrial electronic equipment and machinery, **b** industrial electric equipment and machinery. **c** industrial electromechanical equipment and machinery, **d** industrial pneumatic equipment and machinery

to various problematic situations and with this, the equipment and machinery remain without operating and it does not meet the production goals. In this way, the delivery to the customer is late and financial penalties arise or sometimes the customer no longer wants to make the purchase of the manufactured products. This generates economic losses to any electronics industry or other type of industries (Lopez Badilla et al. 2015).

1.15 Evaluation of ART Using Mobile Devices

The Eduteka platform created by the Gabriel Piedrahita Uribe Foundation (FGPU) in 2004 used and the SEP has drawn up an agreement with said foundation to be used in school activities. This platform comprises recreating images and 3D animations, videos and interactive activities. This combination of audiovisual elements awakens the curiosity and ingenuity of children and a more pleasant environment for students. comprises accessing a SEP address where it is available for Android, and once downloaded, it can recreate the increased multimedia content. The alternative of recreating images, texts, videos and other elements that are pertinent through augmented reality enrich the learning environments in the classroom, generating an interactive learning environment with high interactivity where curiosity triggers exploration in each student.

This exploration that occurs innately at an early age allows you to know your closest reality. It also provides additional motivation, which increases personal exploration learning. According to Hirokazu Kato, creator of the ARToolKit library, which supports the creation of ART applications, he considers that augmented reality is the best form of connection between the real world and digital content, and allows the user to reinforce the learning of educational content through its association with the real world. The elements of augmented reality provide more dynamic and attractive objects, from the visual, kinesthetic, competencies and cognitive approach with the support of emerging technologies and taking advantage of the public internet and cell phones that are increasing in schools, transforming it into a device supportive of learning activities rather than a hindrance and distraction from attention. ART has gained the attention of experts in recent years, and aims to be more effective for educators with different ways of approaching and applying it in classrooms. The design of these audiovisual media includes game-based learning. Next, in Table 7 shows the main applications of ART in cell phones (Sommerauer et al. 2018).

Table 7 Software developments in ART for cell pones

Factors	Types	Development areas	Factors	Types	Development areas
Quantity			Quantity		
1	Aumentaty Author	Technical drawing in axonometry	5	Aurasma	Option to create content as visual aids for interaction
2	Build AR	Build objects in real time	6	Layar Creator	Create augmented content through image scanning
3	AR Spot	Aimed at children to create audiovisual media	7	Hoppala	Allows you to establish a series of geolocated points of interest
4	Augment	Used to display 3D models in Android-IOs models	8	EspiRA	Allows teachers and students to create their own geolocated routes and visualizations

1.16 Educative Model Using the ART

Investigations in the ART in the educational activities have been important in the application of this type of technology with relevant results in the classrooms of educational institutions (Taketomi et al. 2014). Teachers for the development of environments have used the ART, especially with cell phones that subsequently lead to simulate these environments in computer systems for designing objects, figures, structures and buildings; essentially or in mock-ups to determine the factors that make up the activities to be evaluated. Based on this, the students in the three educational institutions and according to topics of the subject of analytical geometry dedicated to the formation of geometric figures. This done by the high school students, developing a model that simulated a classroom (López Hernández et al. 2017), to apply continuous improvement in the organization of tools and furniture and teaching optimally. Figure 6 shows the model.

The development of the model contemplated the major categories considered elaborating the application of ART, with aspects of planning, development, implementation and evaluation of educational activities (Hakan 2017; Radu 2014). The application of ART in this investigation determined according to the resources available at the time of developing the activities with the students (Travieso et al. 2018). The characteristics and variables that make up each category of the model, in the categories explained below:

1. Area. It is the first stage of the model, defining the place where the activity took place, whether in the classroom, laboratory or in the field (outside the classroom or school).

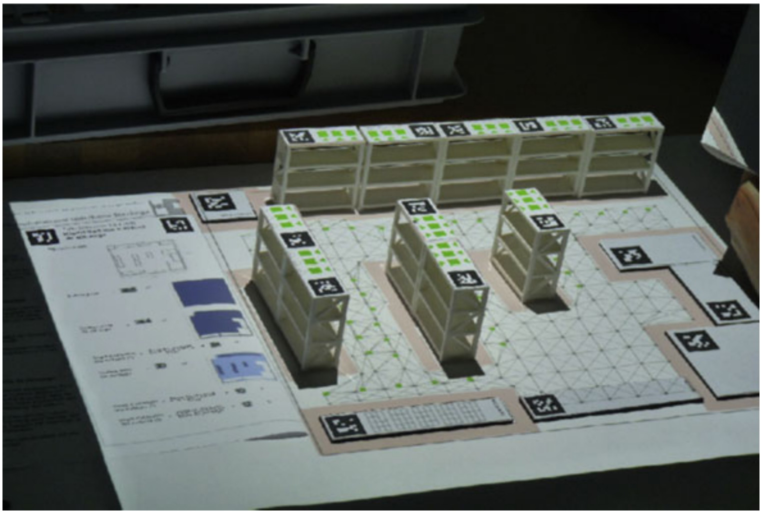


Fig. 6 Model that simulates a classroom based on the ART application. *Source* Information of the investigation

2. Supporting role. Represents the second step, which raises the way to elaborate on the activity made by the teacher or facilitator 2011 (SEP 2011). In this phase, the teacher explained to the students the most essential figures for the design of the classroom.
3. Mobile resources. It shows the third stage, where alternatives proposed to work with augmented reality technology, with mobile applications, platforms or programs, alternative mobile devices and adaptive portable devices.
4. Types of work scenarios. In 2013, it made a design of the environment or environment to use augmented reality in the classroom; with alternatives proposed to speed up the orchestration of the activity (Cuendet et al. 2013).
5. Goal-Oriented Learning Represents (GOLR), represents educational resources in place that can used within goal-oriented learning that are part of the constructivist educational paradigm or school. They considered these aspects for an effective augmented reality design either in teaching or learning. It made the study (Sommerauer et al. 2018).
6. Interactive educational resources. It shows the sixth section of the model, where various collaborative and interactive educational strategies observed, playful or based on problems.
7. Disciplines. This part of the model presents different terminal training disciplines where augmented reality has implemented, which is a process to be implemented in one area of these disciplines that are subdivided at the high school and high school levels. For this scientific study, augmented reality evaluated mathematics about analytical geometry (SEP 2017).
8. Analysis parameters. The last stage is the evaluation or measurement of the perception of the student and teachers involved in the activity, to observe different aspects to evaluate to monitor the learning or effect of the implementation in different learning channels.

1.17 Approach to Problem-Based Learning in Development

In this investigation, evaluated the method of problem-based learning, which consists in the elaboration of tasks in teams and teach to students to solve any type of problematic situations of the real world to gain constant acknowledgments (Radu et al. 2015; Radu 2014). They apply this method in base on four stages:

1. Development of the didactic activity. Encourages student learning in various topics.
2. Scenario of a problem. It involves the students so that they feel that a problematic situation can be a challenge for them and find a quick solution.
3. Initial statement of the problem. It prepared according to the characteristics of a topic of interest that is analyzed, to describe the problematic situation.
4. List the factors of importance that are required. This done to determine the aspects that are most required, to know the fastest way, with which to get what is necessary and give a solution to problem situations (SEP 2011).

1.18 Software Requirements to Apply ART

One of the important aspects in using ART is to determine the software to allow the optimal functioning of the application, with the most common operating systems for cell phones such as Android, IOs and Microsoft, being the most frequent the Android system. For this research, the application Unity (3.2.3) and Vuforia (3.2.5) used, which requires at least a version of Android 5.0 to articulate augmented reality on mobile phones or Smartphones, using the MobiAppRA2D program to create the computer programs. With a capacity not greater than 50 MegaBytes. It derived the name MobiAppRA2D from the phrases Mobi: Furniture, Application: Application, AR: Augmented Reality and 2D, for its markers or recognition patterns designed in 2D (Purnama et al. 2014).

1.19 Hardware Requirements to Apply ART

Another relevant aspect in the application of ART is the hardware to allow the application to work correctly. They took advantage of the wireless Internet network in the schools that operated intermittently. In addition, it used two cell phones with additional data as connection points to share the Internet so that the students could download the application. In this scientific study, the Unity development platform allowed the generation of compatible applications on Android and IOs and was compatible with Vuforia to generate the environments with ART (Palmarini et al. 2017). However, a crucial part of this research was the focus on bookmarks, developed with the Pixlr application, to achieve the best recognition from Vuforia (Neven et al. 2017).

1.20 Cultural Aspects

In the cultural sphere, the community of Mexicali Valley, which is a city inhabited mostly by people from the states of Sonora and Sinaloa, as well as a group in a lower percentage of states in the center and south of the Mexican Republic, this happens because of the high temperatures in the Mexicali Valley. With this, the cultural level of this population, mainly the one with the highest percentage of people who inhabit this zone of Mexico, who are closer to the border with the United States, oriented to an open mind with a focus on the constant use of technology (INEGI 2016). The population with a lower percentage that lives in Mexicali Valley is from the center and south of the country. It is a little more resistant to the use of technology because of its traditional customs. In the San Quintin city, there is a very diverse variability and cultural richness, highlighting its native customs of different ethnicities and dialects, with migrant groups that originally come from or are descendants of central and southern Mexico (GEBC 2021). it dedicate this type of people and their children to agricultural and fishing activities, where their dialect and traditions limit access to different technological tools. This evaluation made to know if there would be resistance to the use of ART, being in San Quintin, where there were problematic situations of resistance to the use of this technology, lack of infrastructure and lack of mobile devices because of the socioeconomic level of the community. The population in Mexicali Valley presented a little less resistant to the use of ART and a greater availability of mobile devices (SEP 2017).

2 Methodology

This investigation is exploratory as an experimental case, considering that this analysis can be the basis for future evaluations of the application of augmented reality in the educational sector of the northwest region developed in different schools in Ensenada and Mexicali. The research is in the field with the evaluation of the students' school performance by applying pedagogical tests with instruments for the perception of experimental variables such as personal skills, mastery and the relationship with the daily life of the topic addressed in a classroom using augmented reality (Radu et al. 2015). This investigation comprised six stages, considering cultural, economic, political, social, technical (specialized personnel with knowledge of augmented reality) and technological aspects:

(a) Analysis of theoretical information. At this stage, it carried a literary review out to analyze the theoretical background of augmented reality and its impact on real-life activities, according to the themes evaluated, to achieve the objectives proposed in this research. It synthesized the review in 3 categories, before 2014, from 2014 to 2016, and future trends of augmented reality in the educational area.
(b) Selection of subjects. Assessment of cultural, economic, political, social, technological aspects of the southern region of the state of Baja California, focused on the Mexicali Valley and San Quintin city, to develop an efficient methodological design and to get the optimal results shown by the relevance of the application of augmented reality in the educational sector of this region of our country.
(c) Design of instruments. Evaluation of the application of augmented reality to achieve a metacognitive domain, where the aim is to improve the educational performance of high school students in the northwest of the Mexican Republic and with the offer of being applied in other areas of the country. In the educational sector, many countries, including Mexico, have used it, mainly in educational institutions where the required technology is available..
(d) Design of a new educational model with the ART. made in a classroom with the mathematics subject and thematic of analytical geometry, developed in three

secondary-level groups using ART with technological tools required with cell phones under the supervision of a class tutor.

(e) Evaluation of the application of ART. made a proposal with the ART, based on the aforementioned class theme (application of analytical geometry in the distribution of furniture by educational subject) referring to a current situation to propose solutions through learning based on problems, being as a prototype model class, based on the resources available, considering the cultural, economic, political, social aspects technological of the Valley of Mexicali and the urban area, an educational activity recreated using augmented reality with markers to evaluate the variables and categories in which the model is subdivided.

(f) Analysis of numerical data. Compiling numerical information made in the model's process class, to analyze the functionality of ART in the teaching–learning It reflected this with the productivity and quality indices of the manufactured products, to carry out the intelligent training process to get an optimal performance of the operating personnel and of industrial equipment and machinery.

3 Results

The educational institutions where the research made, both those of the Mexicali Valley in the (Benito Juárez Town and Sonora Town), are rural, such as San Quintin, which was declared the sixth municipality in the state only in 2020 from Baja California, Mexico; and because of its characteristics of lack of infrastructure in certain activities and especially in information technologies, they considered it in this scientific study as a rural area. The levels of marginalization in these educational institutions in rural areas are very common in the rural regions of the Mexican Republic.

3.1 Analysis of Scholar Yielding

In the areas of the Mexican Republic where the investigation made, marginalization has an impact, generating an effect on the educational performance of high school students, according to results got from an analysis prepared by researchers from the five municipalities of the Baja California state. According to a report from the SEP-Mexico, from the year 2015, in the state of Baja California, there are 280 high school preparatory educational institutions without having a technical specialty, as there are technical professional high schools that have and accounted for apart from the type of schools where the research conducted. Based on these data, it carried an evaluation out as part of this scientific study in 60 high school level schools from 2015 to 2019 (20% of the total).

Table 8 Analysis of scholar yielding of students of high school of cities in Baja California

City	Ensenada		Mexicali		Rosarito		Tecate		Tijuana	
Year	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
2015	31	60	32	64	X	62	X	60	X	64
2016	32	61	33	66	X	62	X	61	X	66
2017	32	63	34	67	X	63	X	61	X	67
2018	33	64	35	67	X	63	X	62	X	68
2019	34	64	35	68	X	64	X	63	X	70

[a]The new municipality of San Quintin as the sixth municipality in the state of Baja California, not considered because someone demographically made it up in 2020 and there was no data as an urban area

[b]The areas considered were rural and urban

[c]San Quintin considered a rural area of Ensenada before being declared the sixth city of Baja California

X. It not considered because most of the population is in urban area

The evaluation comprised visiting the 60 schools in the aforementioned five-year period, on average 12 schools per year and one school per month, being elaborated with a with an authorization from the SEP. With the period of one month of the evaluation, relevant data got to determine the percentages of school performance of high school students, shown in Table 8, from rural and urban areas, being observed for each municipality in the state of Baja California. According to the SEP in the state of Baja California, school performance levels show that in the urban area there is an average school performance of 65% and in rural areas of 35% in areas of mathematics, science, Spanish and English.

Table 8 represents the percentage indexes of school performance of high school students, where it observed that only the Mexicali and Tijuana cities overpass the average of the indexes of Baja California State in rural and urban zones from 2016 to 2019. It was because this state the most percentage of investment in infrastructure, especially in information technologies, applied in Mexicali and Tijuana, being considered the most important cities of Baja California State. It should note that the state index is below the national average of the Mexican Republic, which is 60% in urban areas and 40% in rural areas.

3.2 The ART Applications in Scholar Activities

One of the most outstanding advantages of using ART is that the information, images, videos and other added elements superimposed in a proper environment, which facilitates the quick and easy understanding of the knowledge of the students in short periods of time. The applications (software) developed elaborate operations with elements that form a multimedia database and that stored in remote platforms, which allows that only a temporary internet connection needed, with a signal from devices

Table 9 Evaluation of knowledge of students about mobile device functions of cities in Baja California

Year	Cities									
	Ensenada		Mexicali		Rosarito		Tecate		Tijuana	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
2015	18	74	26	76	X	72	X	71	X	74
2016	20	76	38	77	X	74	X	73	X	76
2017	21	77	31	78	X	77	X	76	X	79
2018	22	78	34	80	X	79	X	79	X	82
2019	24	80	36	83	X	82	X	81	X	84

[a]The new municipality of San Quintin as the sixth municipality in the state of Baja California, not considered because someone demographically made it up in 2020 and there were no data as an urban area

[b]The areas considered were rural and urban

[c]San Quintin considered a rural area of Ensenada before being declared the sixth city of Baja California

X. It not considered because most of the population is in urban area

with mobile data or a signal wireless, to recreate augmented elements through multimedia on tablets, cell phones and computers. This way of developing classroom environments in educational activities in the Mexican Republic has not considered, thinking that it is a distraction for students because of cell phone use in a classroom, but this research found the opposite, being of great importance in areas where the infrastructure regarding information technology is deficient. As the research carried out from 2015 to 2019, a questionnaire measuring instrument applied to know the level of knowledge of the students of the aforementioned educational institutions, about at least 50% off the main functions of the aforementioned mobile devices previously, to determine the ART application process and developing the applications for understanding the knowledge of the subject of analytical geometry taken as a reference in this scientific study. Table 9 shows the information got of the analysis.

Table 9 shows that students in urban areas have greater knowledge in at least 50% of those of mobile devices, being the communication functions such as Facebook, WhatsApp and Twitter, and also the information search mainly on the Google platform the most used. The percentages start from 71% in the city of Tecate to 84% in Tijuana, being Mexicali and Tijuana where students have higher percentages with 83 and 84%. Regarding cities with rural areas, percentages were got from 18% in Ensenada to 36% in Mexicali.

3.3 Development of the Educational Model with ART

Once the evaluation of the students who took part and the knowledge factor of mobile devices, especially cell phones, developed, a model developed that shown in Fig. 7

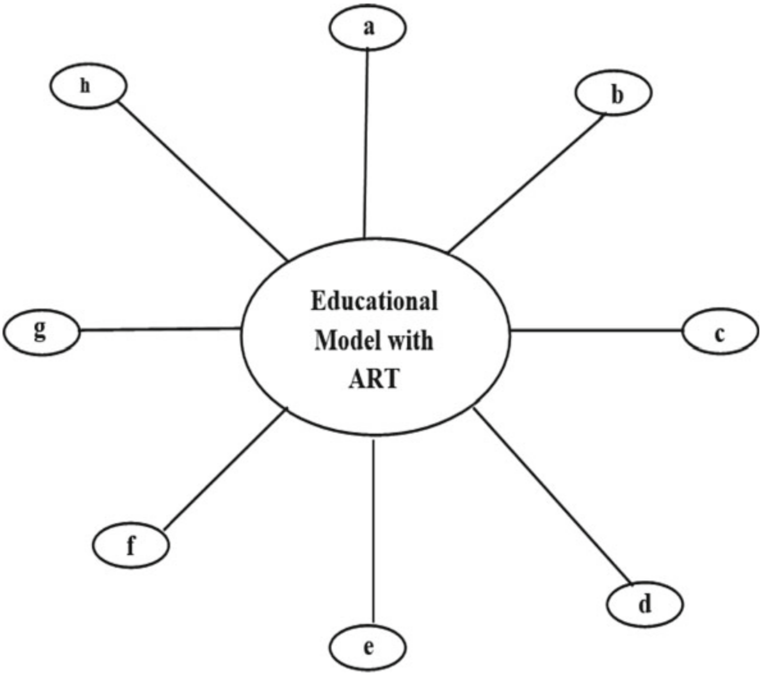


Fig. 7 Model developed with the application of ART in educational activities

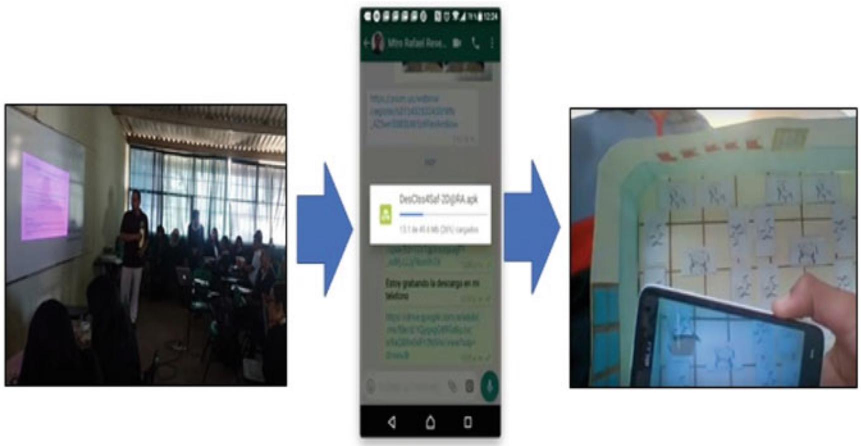
and complemented with Table 10 of the information required for the development of model. Subsequently, the model implemented in the three educational institutions mentioned above, to evaluate the results got in scenarios, also analyzing the limitations presented as the cell phones used, where in some the application could not instal (Borroto et al. 2015). The process comprised explaining to the director of each educational institution how to apply the model of this study with augmented reality to improve the teaching of classes.

3.4 Applying the ART in Educational Activities

At this stage of the scientific study, different distribution of school furniture proposed with the students, and it provided links to download the application, as well as markers, cards, scissors, and markers. They also asked to have considerations of civil protection and of colleagues with special needs or different capacities at the time of preparing the organization of the classroom with the environment elaborated with the ART, and to share their experiences as brainstorming, widely used in the industry. Below are three stages of the ART application process in a classroom in Fig. 8, with a teacher explaining the steps to follow in the first photograph. Then an

Table 10 Factors of Educational Model with ART

Operation Nomenclature	Factors	Characteristics
A	Area	Indoors and outdoors
B	Support Role	Free, directed, face-to-face
C	Resources	Mobile Applications (Aurasma, AR Sport, Build AR, Augmented), Computer Programs with ART (Processing, Scratch, Unity, Unreal, Vuforia), Mobile Devices (Cell Phone, Computer, Tablet,) Portable Devices (Viewers with Cell Phone, Viewers Mountable to Lenses, ART Lenses, HMD with Lenses) and Tools (Numerical Calculation, Logistic Strategies, Wifi Signal, Visual Markers, Virtual Support)
D	Scenarios	Ordinary Video, Images, Audio, Field GPS, Virtual Reality (2D, 2.5D, 3D, Animated, Environmental)
E	Goal-oriented learning	Simulated Worlds, Role Play, Discussions, Cooperative Learning, Self-Directed
F	Interactive educational	Collaborative Learning, E-Portfolio, Games with Purpose, Serious Games, Problem Based
G	Disciplines	Architecture, Education, Engineering, Marketing, Mathematics, Medicine
H	Analysis of parameters	Multiple representations (Auditory, Visual Text, Visual 2D, Visual 2.5D, Visual 3d, Kinesthetic), Multiple Alignment (Spatial, Temporal), Body Support (Mobile Spatial, Physical Sensation, Ideas with Metaphors), Directed Attention, Interactive Simulation (In Visual Form, Multi-User Access, Collaborative)



a b c

Fig. 8 Process of the application of ART in an educational institution: **a** teacher in a classroom, **b** ART platform and **c** stages of the application of ART image of the computer ART application illustrated as a platform and finally the third illustration shows the activities to be developed in a classroom and on a cell phone.

3.5 Development Environments

In the three educational institutions where the investigation made, it observed that the local internet network is intermittent and that the computer equipment, as well as the software programs differ between the different schools, so it was necessary to use the telephones Cell phones students contributed with mobile data, where they used with low capacity and did not generate a high expense for the purchase of mobile data in supermarkets. It was possible to take advantage of the software and hardware capabilities of these mobile devices, with mobile data on each computer, with an increase in its capacities and a decrease in its costs. Figure 9 shows a diagram of the ART with the animation program MobiAppRA2D, to develop the objects that made up the images in both 2D and 3D. This figure presents with the animation program, the identification of the objects to be recorded in a section of the ART platform, and the objects to be presented in the classroom environment.

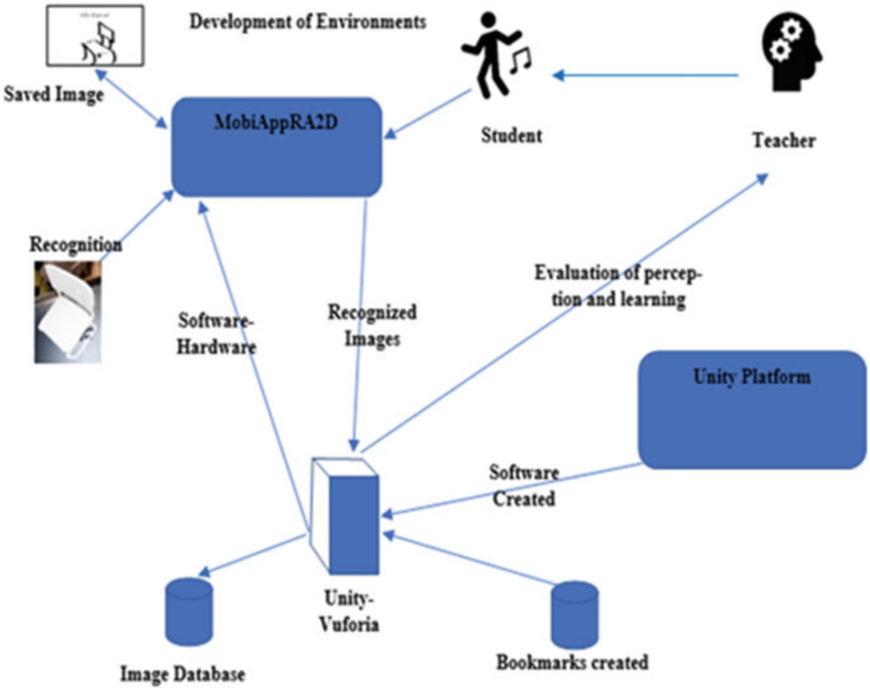


Fig. 9 Stages of development of images with Unity–Vuforia

The example in the diagram illustrates a chair that is recorded on the platform and organized within a classroom. This developed by the students with the teacher, in the Unity platform linking it with the Vuforia application, where the instructions developed as software created, as well as the markers to relate the software to the hardware of mobile devices, generated by the animation program MobiAppRA2D. With this program, the recognition of the objects elaborated to send the recorded images to a database that is stored in a section of the ART Unity platform, to be used and form the environments in the classroom's organization with tools and furniture optimally. The teacher must evaluate the perception and learning of the students to properly oriented.

3.6 Pattern Images as Bookmarkers

Initially, 2D power point markers used, which in combination with Aurasma were functional. However, when using the combination of the Unity/Vuforia platforms, visual recognition in Vuforia was very low and unstable, and that is why we were working with other software alternatives to generate bookmarks until when using the Pixlr application, achieving a more recognition stable and high recognition. Once each marker had validated, they searched the image associated with each marker within Unity to be enlarged with the cell phone application. The created markers and the enlarged images were as follows. Figure 10 shows the key markers developed in this scientific study.

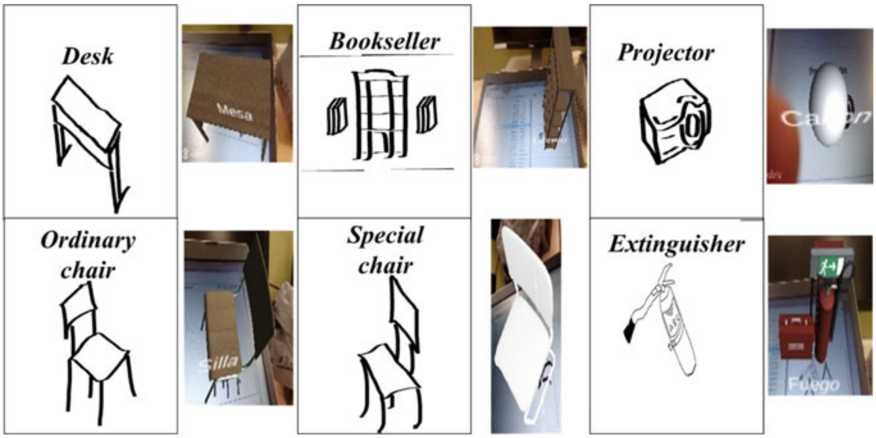


Fig. 10 Bookmarks created with the Unity

4 Unity-Android Platform

It linked the Unity platform with the Android operating system to create an APK package as an application to download and run the Unity application and associated applications, such as Vuforia and Pixlr on cell phones. In addition, the C-Sharp or C# code used as programming code for beginners and the procedure to develop the application went through different phases, developing 11 applications in order to debug in functionality and quality until reaching the application final. Next, name breaks each prototype of the program down in Fig. 19, showing the stages of development of the software with their instructions for the 11 applications. This section will present elements such as the development environment, as well as the minimum requirements for software and hardware; followed by a description of how the markers developed; continuing with the characteristics of the platform and ending with the user interaction process. The Unity platform links with Android to create an APK package as an application to download and run on Android phones. It uses the C-Sharp or C # code as programming code for beginners and the procedure to develop the application went through different phases, developing 11 applications in order to debug in functionality and quality until reaching the final application. Figure 11, name breaks each prototype of the program down.

4.1 Program Used in the Scholar Activity with 2MobAppRA2D

In the school activity, it developed a program with the 2MobAppRA2D application, which presents a section of the total program illustrated in Fig. 12, presenting the operating instructions. The total program covers four full pages.

Fig. 11 Sequence of prototypes worked until achieving operability in 2MobiAppRA2D

MobiAppRA-2DMarkVf: Bloc de notas

Archivo Edición Formato Ver Ayuda

```
      <option name="hasDebugSymbols" value="false" />
    </NativeLibrary>
    <NativeLibrary>
      <option name="sharedObjectFilePaths">
        <list>
          <option value="$MODULE_DIR$/lib/x86/libmono.so" />
          <option value="$MODULE_DIR$/lib/armeabi-v7a/libmono.so" />
        </list>
      </option>
      <option name="name" value="libmono.so" />
      <option name="debuggableSharedObjectFilesByAbi">
        <map />
      </option>
      <option name="pathMappings">
        <map />
      </option>
      <option name="hasDebugSymbols" value="false" />
    </NativeLibrary>
    <NativeLibrary>
      <option name="sharedObjectFilePaths">
        <list>
```

Fig. 12 Instructions of program 2MobAppRA2D used in scholar activity

The program shows the instructions of a section of the total program, showing the start of operations using the cell phone with Android system, presenting itself in the language of the 2MobAppRA2D platform.

4.2 Analysis of Numerical Data

An analysis made to determine the level of knowledge of the main functions of mobile devices, especially cell phones, the percentage information got in Table 11 represented, observing that in rural areas there is less knowledge in using the functions of cell phones and in urban areas the knowledge of this evaluated factor is greater. In the sections of the table where the letter X appears, it does not consider it as a rural area because the population in its highest percentage is in the urban area, such as the cities of Rosarito, Tecate and Tijuana. In the cities of Ensenada and Mexicali, if the rural area considered, where in Ensenada, the area of San Quintin declared a city in 2020, in this analysis considered as a rural area of Ensenada.

Table 11 Evaluation of knowledge of students about mobile devices functions in cities of Baja California

Year	Cities									
	Ensenada	Mexicali	Rosarito	Tecate	Tijuana					
	R	U	R	U	R	U	R	U	R	U
2015	18	74	26	76	X	72	X	71	X	74
2016	20	76	38	77	X	74	X	73	X	76
2017	21	77	31	78	X	77	X	76	X	79
2018	22	78	34	80	X	79	X	79	X	82
2019	24	80	36	83	X	82	X	81	X	84

[a]The new municipality of San Quintin as the sixth municipality in the state of Baja California, not considered because someone demographically made up in 2020 and there was no data as an urban area

[b]The areas considered were rural (R) and urban (U)

[c]San Quintin considered a rural area of Ensenada before being declared the sixth city of Baja California

X. It not considered because most of the population is in urban area

4.3 ART Evaluation in the Industry

An evaluation of the use of ART made in an industrial activity of an electronics company in the city of Mexicali, dedicated to manufacturing laptops. The aim of this part of the research was for ART to can generate training courses for certain operating personnel in manufacturing areas, of the main electronic, electrical, electromechanical and electro-pneumatic systems of industrial equipment and machinery; so that when a problematic situation arises in their workplace, the workers who are in the industrial processes, will support the maintenance personnel, to have an immediate solution to prevent the production line from stopping and thus prevent them from being generated an under level of productivity and quality, which is of great concern to managers and supervisory personnel. An experimental test developed with the operating personnel with the most experience in their activity, their work activity in a production line of the aforementioned industry, of a training course with ART, where the operation of the main electronic systems explained in detail, electrical, electromechanical and electropneumatic of the equipment and industrial machinery required for the manufacturing processes, observing that the workers of industrial processes had a quick and easy uptake of these systems. In this way, it generated knowledge that, together with the experience of the operating personnel, elaborated an immediate solution to problematic situations that were presented to them. This was relevant because the production flow in the evaluated manufacturing line did not stop.

The application of ART in this industrial company, comprised making known through environments with objects and figures of the operation of electronic, electrical, electromechanical and electro-pneumatic systems of equipment and industrial

Table 12 Analysis of productivity and quality levels with the application of ART in industry (2020)

Factors	Workers with trained with ART		Workers without trained with ART	
Months	Productivity, %	Quality, %	Productivity, %	Quality, %
January	68	66	65	63
February	70	69	66	64
March	71	70	66	66
April	73	70	66	67
May	73	73	68	68
June	75	74	68	68
July	76	75	69	69
August	76	75	69	69
September	78	77	70	70
October	80	79	70	70
November	82	81	70	71
December	83	84	70	71

machinery, quickly visualizing the way of its operation, as an inside view of these systems. This is how it was possible to learn about the mechanisms that make up these systems and how they work together to detect any type of anomaly that could cause malfunctions that cause operational errors and generate defective products or even stop the production flow, causing late deliveries to the customer. Table 12 shows the information from a comparative analysis of the capacity of the operating personnel for immediate solutions with ART training and workers in manufacturing areas without training and the productive performance reflected in the productivity and quality indexes. The period of analysis was in the 2020 year.

As can see in Table 12, workers in manufacturing areas with ART training generated better productive performance reflected in the percentage indexes of productivity and quality, starting in January 2020 with 68 and 66% up to 83 and 84% of the productivity and quality indices respectively in December of the same year. In workers without ART training, there were productivity and quality indices that started at 65 and 65% up to 70 and 71% of the productivity and quality indices respectively, showing that this type of worker is not suitable. to provide an immediate solution to problematic situations that arise in the production lines, so it is advisable to prepare the training with ART, to increase the productivity and quality indexes to the maximum. It made the program used in this section of the investigation similar that the scholar activity, only changing the type of objects and figures.

5 Conclusions

The development of this scientific study generated a significant complexity when implemented in the rural zones mentioned above, with limited information and communications technology conditions. The participation of students and teachers of the three educational institutions mentioned above was very relevant, applying the ART. This work made in base of the articulating and structuring an augmented reality model in the educational field, from which a didactic intervention designed, with a cell phone application on the Unity and Vuforia platform for cell phones of the Android operating system, and instruments for the survey of information of opinion and perception of students and teachers in the different stages of ART implementation. When working on the elaboration of the structure of the schematic educational model of augmented reality in education, the process was simpler and faster, and allowed to contemplate different stages, variables and necessary processes, to plan the activity throughout teaching–learning, until culminating with the evaluation and feedback part by the different actors immersed in the implementation. To develop a class plan, the social, structural, technical context of the immediate context and characteristics of the students considered; It was with this purpose that the diagnostic survey made in each group to channel that deviation of attention that favors the use of cell phones. In this way, the use of augmented reality with problem-based learning was used to involve students in proposing solutions to situations in their immediate context, analysis and prevention that allow the formation of active and participatory citizens of the teaching–learning process.

As well as the teachers, considered the class plan simple and the option of using cell phones in a regular class, being planned according to the distinct elements of the model. In the application's design, the size was less than 50 MB, so as not to saturate the memory of the mobile devices used. In addition, it designed a version of the mobile application on the Unity platform until reaching the final one in order to lower the size and that the markers show an adequate recognition by the cell phone cameras. It achieved this by working with Pixlr to design the markers for Unity-Vuforia to achieve an acceptable recognition. During the implementation, not all the students had a mobile device for the augmented reality activity, which meant that the students had to be integrated into groups of four and six members, covering the requirement of at least one cell phone per team. Because of the irregularity of the signal as it is a public network in schools, data shared with the help of two base cell phones, and it observed that it was difficult for them to download and install the application on the cell phone, therefore, They shared data, link via Bluetooth and USB cable to transmit and download the application. The area of education, training and education is having a very significant boom in augmented reality implementations, such as Augeo, mARble, iARBook and the developments that are listed in the analysis of the projects carried out and their effects on learning represented. These studies refer to interactive applications of mobile devices within architecture, education, engineering, medicine, advertising and marketing mainly. In Mexico, the Eduteka platform developed whose access is provided by the SEP. Thanks to advances in telephony and the application of emerging educational technologies in the classroom, it also took it advantage that there are more and more Internet users that, combined with educational technologies, can empower the learner. The augmented reality model proposed for the development of this study developed based on the investigation made by experts in computer science, where various evaluations developed to determine how to be applied in the educational sector for the teaching of classes. This inspired both teachers and students to make it an interesting proposition and to motivate students to develop their innovative ideas. With the branches evaluated and mentioned above. The important aspects that supported getting relevant information and that were decisive to observe the behavior of augmented reality in the educational area determined, with the aim determined in the classroom.

The development of the study was of great importance to generate an inspiration in the teachers and students in developing the activities with great interest and applying their ideas as a team comprehensively to understand the concepts of a specific topic easily and quickly and awaken innovative thoughts that may be part of an entrepreneur's process in the future. The evaluation of information as a background to the research comprised analyzing the use of augmented reality technology in areas other than the educational sector with relevant affects, generating interest and easy accessibility for any type of process and in any area. In the application's analysis, it observed how augmented reality is a technology that supports the activities of the education sector, because it is a source of inspiration for teachers and students to be in a constant learning process and evaluating techniques of optimal teaching. Using this technology in the immediate future will generate relevant results in the taking part students, because the students showed great interest in carrying out the activity with cardboard and markers, besides proposing additional elements on the distribution of the furniture suggested by them., This activity empowered the students by generating preventive awareness about risk situations and evictions from the classroom and school.

References

Akçayır, M., Akçayır, G.: Advantages and challenges associated with augmented reality for education: a systematic review of the literature. Educ. Res. Rev. **20**(1), 1–11 (2017), Consulted in: https://www.sciencedirect.com/science/article/abs/pii/S1747938X16300616

Alrashidi, M., Alzahrani, A., Gardner, M., Callaghan, V.: A pedagogical virtual machine for assembling mobile robot using augmented reality. In: Proceedings of the 7th Augmented Human International Conference 2016, pp. 43:1–43:2. New York, NY, USA, ACM (2016). https://doi.org/10.1145/2875194.2875229

Antley, J.: Going beyond the textual in history. J. Digital Human., Spring 2012, **1**(2), 23–32 (2012), http://journalofdigitalhumanities.org/1-2/going-beyond-the-textual-in-history-by-jeremy-antley/

Aottiwerch, N., Kokaew, U.: Design computer-assisted learning in an online Augmented Reality environment based on Shneiderman's eight Golden Rules, 2017 14th International Joint Conference on Computer Science and Software Engineering (JCSSE), Computer Science and Software

Engineering (JCSSE), 2017 14th International Joint Conference (2017), Consulted in: https://doi.org/10.1109/JCSSE.2017.8025926

Bacca, J., Baldiris, S., Fabregat, R., Graf, S.: Augmented reality trends in education: a systematic review of research and applications. J. Educ. Technol. Soc. **17**(1), 33–45 (2014)

Bagon, S., Gacnik, M., Starcic, A.: Information communication technology use among students in inclusive classrooms. Int. J. Emerg. Technol. Learn. (IJET), **1**(1), 56–72 (2018), Consulted in: https://online-journals.org/inde10.php/i-jet/article/view/8051

Baus, O., Bouchard, S.: Moving from virtual reality exposure-based therapy to augmented reality exposure-based therapy: a review. Frontiers Hum. Neurosci. **1**(1), 1–12 (2014), Consulted in: https://www.frontiersin.org/articles/https://doi.org/10.3389/fnhum.2014.00112/full

Bazzaza, M., Delail, B., Zemerly, M., Ng, J.: iARBook: an immersive augmented reality system for education. In: 2014 International Conference on Teaching, Assessment and Learning (TALE), pp. 495–498 (2014). https://doi.org/10.1109/TALE.2014.7062576

Bediou, B., Adams, D., Mayer, R., Tipton, E., Green, C., Bavelier, D.: Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. Psychol. Bull. **144**, 77–110 (2018). https://doi.org/10.1037/bul0000130

Bellini, H., Chen, W., Sugiyama, M., Shin, M., Shateel, A., Takayama, D.: Goldman Sachs VR & AR report 2015 (2015), https://es.slideshare.net/VRyzhonkov/goldman-sachs-vr-ar-report-2015?from_action=save

Beranuy, M., Oberst, U., Carbonell, X., Chamarro, A.: Problematic internet and mobile phone use and clinical symptoms in college students: the role of emotional intelligence. Comput. Human Behavior, **25**(1), 182–187 (2009), https://www.sciencedirect.com/science/article/abs/pii/S0747563209000351

Borroto, C., Hidalgo, R.: El uso del celular, un problema para el profesor en el aula o un medio de comunicación convertido en medio de enseñanza?, 29(4), 682–684 (2015)

Brown, A., Green, T.: Virtual reality: low-cost tools and resources for the classroom. TechTrends **60**(1), 517–519 (2016), Consuled in: https://link.springer.com/article/https://doi.org/10.1007/s11528-016-0102-z

Cabrero-Almenara, J., Barroso-Osuna, J., Llorente-Cejudo, C., Fernández-Martinez: Educational uses of Augmented Reality (AR): experiences in educational science. Sustainability, **11**(18), 4990 (2019), Consulted in: https://www.mdpi.com/2071-1050/11/18/4990

Carbonell, X., Guardiola, E., Fuster, H., Gil, F., Panova, T.: Trends in scientific literature on addiction to the internet, video games, and cell phones from 2006 to 2010. Int. J. Prevent. Med., **7**(63), 23–37 (2016), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4837796/

Caspary, M., Booth, D.: The global impact of the proliferation of ICT: a multinational study. In: 8th International Conference ICT for language learning, Pixel, November 12–13 2015, pp. 261–264. Florence, Italy (2015)

Cheng, X., Zhang, L.: Implementation of mobile augmented reality based on Vuforia and Rawajali. In: 2014 IEEE 5th International Conference on Software Engineering and Service Science, Beijing, China (2014). https://doi.org/10.1109/ICSESS.2014.6933713

Chen, Y., Zhou, D., Wang, Y., Yu, J.: Application of augmented reality for early childhood english teaching. In: 2017 International Symposium on Educational Technology (ISET), Educational Technology (ISET), 2017 International Symposium (2017), https://doi.org/10.1109/ISET.2017.34

Cheng, K.-H., Tsai, C.: Affordances of augmented reality in science learning: suggestions for future research. J. Sci. Educ. Technol. **22**(4), 449–462 (2012). https://doi.org/10.1007/s10956-012-9405-9

Colder, C., Van Rooij, A., Spruijit-Metz, D., Kvedar, J., Griffiths, M., Carabas, Y.: Commercial video games as therapy: a new research agenda to unlock the potential of a global pastime. Frontier Psychiatry (2018). https://doi.org/10.3389/fpsyt.2017.00300

Cuendet, S., Bonnard, Q., Do-Lenh, S., Dillenbourg, P.: Designing augmented reality for the classroom. Comput. Educ. **68**, 557–569 (2013). https://doi.org/10.1016/j.compedu.2013.02.015

Delić, A., Domančić, M., Vujević, P., Drljević, N., Botički, I.: AuGeo: A geolocation-based augmented reality application for vocational geodesy education. In: Proceedings ELMAR-2014, pp. 1–4 (2014). https://doi.org/10.1109/ELMAR.2014.6923372

Dong-Hee, S., Frank, B., Hyunseung, Ch.: Exploring the user experience of three-dimensional virtual learning environments. Behavior Inf. Technol. J., **32**(2), 203–214 (2013), consulted in: https://www.tandfonline.com/doi/abs/https://doi.org/10.1080/014492910.2011.606334

GEBC-Gobierno del Estado de Baja California: Información Geográfica del Estado de Baja California (2021), consultado en: https://www.bajacalifornia.gob.mx/Gobierno/Mapa_del_sitio

Hakan, A.: Current trends in Augmented Reality and Forecasts about the Future (2017). Research Gate. https://www.researchgate.net/publication/321762312_

INEE (Instituto Nacional para la Evaluación de la Educación): Informe Anual de Gestión 2015 (2015), consultado en: https://www.inee.edu.mx/wp-content/uploads/2018/12/InformeGesti%C3%B3n2015.pdf

INEGI: Principales resultados de la Encuesta Intercensal 2015 Baja California (Encuesta Intercensal 2015) (2016). http://internet.contenidos.inegi.org.mx/contenidos/Productos/prod_serv/contenidos/espanol/bvinegi/productos/nueva_estruc/inter_censal/estados2015/702825079673.pdf

Istenic, A., Bagon, S.: ICT-supported learning for inclusion of people with special needs: Review of seven educational technology journals, 1970–2011. British J. Educ. Technol., **45**(2), 202–230 (2014), consulted in: https://bera-journals.onlinelibrary.wiley.com/doi/https://doi.org/10.1111/bjet.12086

Kingsley, A.: Information Communication Technology (ICT) in the educational system of the third world countries as a pivotal to meet global best practice in teaching and development. Am. J. Comput. Inf. Technol., **1**(1), 1–10 (2017), consulted in: https://www.imedpub.com/articles/information-communication-technology-ict-in-the-educational-system-of-thethird-world-countries-as-a-pivotal-to-meet-global-best-pr.php?aid=21571

Lehui, H., Bin, G.: Research on the application of products based on unity 3D. In: Proceedings of the 2015 International Symposium on Computers and Informatics, January 1015, **1**(1), 34–42 (2015). https://doi.org/10.2991/isci-15.2015.160

López Hernández, J.G., Rodríguez Valenzuela, P., López Morteo, G.A.: Capitulo de Libro. La Realidad aumentada en el ámbito educativo. Análisis de experiencias y casos de estudio, 140–146 (2016); Prieto, M.E., Pech, S.J., Libro Completo. La tecnología como instrumento para potencias el aprendizaje, Amazon-EU SARL, UnADM, CIATA, UCLM, Comunidad Internacional Para el Avance de la Tecnología en el Aprendizaje. Libro publicado de la VIII Conferencia Conjunta Internacional sobre Tecnologías y Aprendizaje elaborado del 20 al 22 de Julio del 2016

López Badilla, G., Arreola Álvarez, R. A., Martínez Valdez, L.S., Mendieta Rodríguez, Y., García Rodríguez, M., Pérez Marmolejo, M.C., Rocha Crespo, J.L.: Corrosion of electronic devices of the electronics industry of Mexicali, B.C. México influenced by H_2S pollution. Revista Nova Scienta (2013), Consulted in: https://www.imbiomed.com.mx/articulo.php?id=90403

Lopez Badilla, G., Gómez, M.M.A., Gonzalez, H.M., Castillo, J. C.: Corrosion analysis in the electronics industry of mexicali influenced by atmospheric factors. Int. J. Recent Contributions Eng. Sci. IT (iJES), **4**(3), 63–65 (2015), Consulted in: https://onlinejour.journals.publicknowledgeproject.org/inde10.php/i-jes/article/view/4096/3335

López Hernández, J.G., López Morteo, G. A., Rodríguez Valenzuela, P.: Modelo de Realidad Aumentada, No. De Registro INDAUTOR: 03–2017–020711432200–01. México (2017)

López Hernández, J.G., López Morteo, G.A., Celina, A.: Realidad Aumentada como Alternativa Didáctica en Escuelas Públicas de Baja California, Mexico, Revistas Tecnológicas (In process) (2021a)

López Hernández, J.G., López Morteo, G.A., Celina, A.: Manual de Realidad Aumentada en Escuelas Rurales, No. De Registro INDAUTOR, In process, México (2021b)

Martín-Gutiérrez, J., Saorín, J.L., Contero, M., Alcañiz, M., Pérez-López, D.C., Ortega, M.: Design and validation of an augmented reality for spatial abilities development in engineering students. Comput. Graphics J., **34**(1), 7–19 (2010), consulted in: https://www.sciencedirect.com/science/article/abs/pii/S0097849309001514

Martins, V., Gomes, L., Guimarães, M.: BookChapter: challenges and possibilities of use of augmented reality in education. Full Book: Gervasi, O., Murgante, B., Misra, S., Gavrilova, M., Rocha, M., Torre, C., Apduhan, B. (eds.) Computational science and its applications, ICCSA, pp. 223–233. Springer International Publishing (2015), Consulting in: http://link.springer.com/chapter/https://doi.org/10.1007/978-3-319-21413-9_16
Merino, C., Pino, S., Meyer, E., Garrido, J., Gallardo, F.: Realidad Aumentada para el Diseño de Secuencias de Enseñanza-Aprendizaje en Química, Revista Educacion Química, **26**(2), 94, 99 (2015), consultado en: https://www.sciencedirect.com/science/article/pii/S0187893X15000051
Mohd, S., Mankar, V.: A review of 2d, 2.5d and 3d image visualization techniques. Int. J. Adv. Res. Comput. Eng. Technol., **3**(3), (2016), https://www.researchgate.net/publication/301328802_A_Review_on_2d_25d_and_3d_Image_visualization_Techniques
Ibrahim, M.E., Al-Shahrani, A.M., Abdalla, M.E., Abubaker, I.M., Mohamed, M.E.: The effectiveness of problem-based learning in acquisition of knowledge, soft skills during basic and preclinical sciences: medical students. Points of View, Acta Inf. Med. J., **26**(2), 119–124 (2018), consulted in: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6029903/
Neven, D., Lung-Hsiang, W., Ivica, B.: Where does my augmented reality learning experience (ARLE) belong? a student and teacher perspective to positioning ARLEs. TLT, **4**, 419 (2017). edsdbl. https://doi.org/10.1109/TLT.2017.2690426
Noll, C., Häussermann, B., Von Jan, U., Raap, U., Albrecht, U.: Demo: mobile augmented reality in medical education: an application for dermatology. In: Proceedings of the 2014 Workshop on Mobile Augmented Reality and Robotic Technology-based Systems, pp. 17–18. New York, NY, USA, ACM (2014). https://doi.org/10.1145/2609829.260983310
Palmarini, R., Erkoyuncu, J., Roy, R., Torabmostaedi, H.: A systematic review of augmented reality applications in maintenance (2017). http://search.ebscohost.com/login.aspx?direct=true&db=edsbas&AN=edsbas.13158A59&lang=es&site=eds-live
Purnama, J., Andrew, D., Galinium, M.: Geometry learning tool for elementary school using augmented reality. In: 2014 International Conference on Industrial Automation, Information and Communications Technology (IAICT), 145–148 (2014). https://doi.org/10.1109/IAICT.2014.6922112
Radu, I.: Augmented reality in education: a meta-review and cross-media analysis. Personal Ubiquitous Comput. **18**(6), 1533–1543 (2014). https://doi.org/10.1007/s00779-013-0747-y
Radu, I., Doherty, E., DiQuollo, K., McCarthy, B., Tiu, M.: Cyberchase shape quest: pushing geometry education boundaries with augmented reality. In: Proceedings of the 14th International Conference on Interaction Design and Children, 430–433 (2015). https://doi.org/10.1145/2771839.2771871
Reis, G., Cabral, L., Peres, E., Bessa, M., Valente, A., Morais, R., Soares, S., Baptista, J., Aires, A., Escola, J., Buas-Cruz, J., Reis, M.: Using information technology based exercises in primary mathematics teaching of children with cerebral palsy and mental retardation: a case study. Turkish Online J. Educ. Technol. (TOJET)-ERIC, **9**(3), 106–118 (2010), consulted in: https://eric.ed.gov/?id=EJ898019
Reisoglu, I., Topu, B., Yilmaz, R., Karakus, T., Goktas, Y.: 3D virtual learning environments in education: a meta-review. Asia Pacific Educ. Rev. **18**(1), 81–100 (2017), consulted in: https://link.springer.com/article/10.1007%2Fs12564-016-9467-0
Sáenz, M., Strunk, J., Maset, K., Seo, J., Malone, E.: FlexAR: anatomy education through kinetic tangible augmented reality. ACM SIGGRAPH 2015 Posters, 21:1–21:1 (2015). https://doi.org/10.1145/2787626.2792629
Sanderink, C., Baeten, S., Kooij, R., Doornik, D., De Witt, B., Schardijn, J., Leenhouts, J., Dias, R.: "Virtual reality—augmented reality: hype? or serious business? (2017 report; Bravant Development Agency (BOM), p. 34 (2018). www.bom.nl
SEP: Plan de Estudios 2011—Educación básica (p. 92). Secretaría de Educación Pública, Subsecretaría de Educación Básica, Dirección General de Desarrollo Curricular, Dirección General de Desarrollo de la Gestión e Innovación Educativa, Dirección General de Educación Indígena (2011)

SEP: Aprendizajes Clave para la educación integral—Matemáticas Secundaria. En Plan y programas de estudio, orientaciones didácticas y sugerencias de evaluación: Vol. LPM (1.ª ed., p. 272) (2017). https://www.planyprogramasdestudio.sep.gob.mx/descargables/biblioteca/secundaria/mate/1-LPM-sec-Matematicas.pdf

Sommerauer, P., Müller, O.: Augmented Reality for Teaching and Learning—A Literature Review on Theoretical and Empirical Foundations. Research Papers (2018). https://aisel.aisnet.org/ecis2018_rp/31

Southern, M. (2011). First 3D Movie: What Was The First 3D Movie. https://web.archive.org/web/20110602044014/; http://www.3d-tv-and-movies.com/first-3d-movie.html

Spring, D.: Gaming history: computer and video games as historical scholarship. Rethinking History-J. Theory Practice, **19**(2), 207–221 (2015), https://www.tandfonline.com/doi/full/https://doi.org/10.1080/13642529.2014.973714

Taketomi, T., Okada, K., Yamamoto, G., Miyazaki, J., Kato, H.: Camera pose estimation under dynamic intrinsic parameter change for augmented reality. Comput. Graphics, **44**, 11–19 (2014). edselp

Teichner, A.: Demo: mobile augmented reality in medical education: an application for dermatology. In: Proceedings of the 2014 Workshop on Mobile Augmented Reality and Robotic Technology-based Systems, pp. 17–18. New York, NY, USA, ACM (2014). https://doi.org/10.1145/2609829.2609833

Travieso, D., Ortiz, T.: Aprendizaje basado en problemas y enseñanza por proyectos: Alternativas diferentes para enseñar. Learning Based on Problems and Teaching by Projects: Different Alternatives for Teaching **37**(1), 125–133 (2018)

Von Der Heiden, M., Braun, B., Muller, K., Egloff, B.: The association between video gaming and psychological functioning. Frontiers Psychol. J. **5**(3), 45–56 (2019). https://doi.org/10.3389/fpsyg.2019.01731

Wu, H., Lee, S., Chang, H., Liang, J.: Current status, opportunities and challenges of augmented reality in education. Comput. Educ. **62**, 41–49 (2013). https://doi.org/10.1016/j.compedu.2012.10.024

Xie, J.: Research on key technologies base Unity3D game engine. Conference, Computer Science and Education (ICCSE) (2012), consulted in: https://www.researchgate.net/publication/261430664_Research_on_key_technologies_base_Unity3D_game_engine

Lean Automation Case Study: Down-Time Reduction in a Paper Unwinding Machine

David Sáenz-Zamarrón, Carlos González-Arredondo, and Nancy Ivette Arana-De-Las-Casas

Abstract Continuous improvement (Kaizen) is a branch of Lean Manufacturing methodology that aims to improve productivity and client satisfaction. In today's changing market, various conditions must be considered for a company to be competitive and improve its processes. Companies must do more with less, which sometimes involves the automation of old equipment, a practice known as Lean Automation (a combination of Lean production and automation technology). In this study, the unwinding process in roll unwinding machines was automated. It was done in response to a paper factory's need to implement technological improvements to provide them with competitive advantages resulting from greater process control. The unwinding machines faced a series of problems: they were obsolete due to being out of service for 30 years, and part refurbishment was no longer possible as the machines were no longer being built. Furthermore, they could only be operated in manual mode by different people. This led to the redesign and implementation of the reel braking control using the Turborex pneumatic brake. It replaced the original, which was manual, and fed a white bond printing and writing paper cutting machine. The tension of the sheet of paper to be cut was regulated, and the diameter calculator method was implemented in a Programmable Logic Controller using the TIA Portal software. This sheet circulated through the unwinding stations of the machine until it reached the cutting area. In the end, there was a decrease in quality defects such as wrinkles, bags, and sheets with greater or lower measures than programmed; and a reduction in dead time due to maintenance, all of which increased productivity.

Keywords Unwinding machine · Braking system · Lean manufacturing (LM) · Lean automation

D. Sáenz-Zamarrón (✉) · N. I. Arana-De-Las-Casas
Graduate Studies and Research Division, Tecnológico Nacional de México, Campus Cd. Cuauhtémoc, Av. Tecnológico #137, C.P. 31500 Cd. Cuauhtémoc, Chihuahua, México
e-mail: dsaenz@itcdcuauhtemoc.edu.mx

N. I. Arana-De-Las-Casas
e-mail: narana@itcdcuauhtemoc.edu.mx

C. González-Arredondo
PONDERCEL S.A de C.V., Centro Agroindustrial S/N, Anáhuac, Chihuahua C.P. 31600, México
e-mail: G17610004@itcdcuauhtemoc.edu.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_11

1 Introduction

Given the current technology growth and market demands, companies constantly need to increase their production capacity and modernize their manufacturing processes to supply high-quality products. A way to achieve the latter is to implement the Kaizen philosophy. In Japanese, Kaizen means continuous improvement and is one of the pillars of Lean Manufacturing (LM), whose objective is to improve products, processes, machines, and client satisfaction (Trent 2007).

In the case of the paper industry, factories need to be at the forefront in the use of technologies that can offer higher performance with less maintenance and dependence on operators so that they can improve the quality and reliability of their processes.

For a long time, the paper industry has seen a continuous improvement in automation, with the main goals of increasing productivity and reducing breakups in the process. Some examples of this are the system and method for unwinding soft, high-bulk tissue webs (Hanson et al. 2004a); the system and method for simultaneously rewinding multiple rolls of material (Hanson et al. 2004b); the method and device in a paper machine, coating machine, intermediate winder, rewind support of a slitter-winder, or any other web treatment device (Kinnunen et al. 2005); and the torn paper web capture system, which secures the paper across a paper roll as the roll is rotating (Rodríguez 2011).

On the other hand, the Lean Manufacturing philosophy is currently the most widely used way in which industries (including the paper industry) comply with client requirements. Thus, manufacturers attempting to apply lean principles to automated systems should begin with the usual Deming circle activities: Plan, Do Check, Action (PDCA) since these activities are involved in every quality performance (Mukhtar et al. 2020).

The latter process should lead to the automation of the LM philosophy: lean automation. This implies finding where technology should be used to improve the process (Vlachos et al. 2021; Ebinga 2020; Flinchbaugh and Carlino 2006), always looking for the appropriate amount of automation in a task, as well as reliable machine parts and the least expensive and complicated solutions (Duchinos and Massaro 2006).

Several studies have shown the advantages of implementing lean automation. Chanarungruengkij and Kaitwanidvilai (2018) applied lean automation to improve efficiency and productivity and reduce waste in a cable manufacturing process; on the other hand, Malik and Bilberg (2019) related lean automation theory to human–machine interaction, concluding with the need to combine the work of the best of humans and machines.

Ebinga (2020) stated the impact of lean automation on process performance in a case from the sugar industry in Kenya. Yamazaki et al. (2017) designed a material-handling method based on lean automation, which reduced waiting time, and Granlund et al. (2014) offered a summarized description of a characteristic lean automation development process as its possible consequences. Additionally, Kimball (2015) explored lean automation strategies for high volume, high complexity manufacturing systems.

Yamazaki et al. (2016) designed a lean automation method that they applied to an assembly system, reducing system costs. Later, Malik and Bilberg (2017) developed a systematic framework for the deployment of collaborative robots in existing assembly cells to enhance productivity while Shigematsu, et al. (2018) designed a lean automation method for optimizing the workstation layout to reduce movements and, thus, decrease the cost of equipment.

In this study, a paper cutting machine converts reels to extended cut reams of 500 sheets; it has built-in stations that oversee the unrolling of the newly produced paper reel in a controlled fashion and process it to obtain the finished product according to requirements.

Operating this machine requires that the operator be acutely aware of the unwinding tension forces in each station. At the slightest neglect, the material will hang due to low brake power and rip due to excess of the same braking force. Additionally, the cuts made show variations due to measurement variations, which may cause the product to change. Sometimes the material will get cut, bent, or marked from variations between sheets, thus generating waste and an unrecoverable production.

LM principles are all about continuous improvement, eliminating process waste, and having only value-adding activities (Tortorella, et al. 2019; Bittencourt and Alves 2019; Thangarajoo and Smith 2015a, b; Kolberg and Zûhlke 2015). Due to this, the importance of identifying quality problems such as those mentioned in the above paragraph is paramount.

Problems are also often identified in different areas, for example, differences in gauge, areas with differences in humidity, and wrinkles on the paper caused by tension problems in the machines that make the rolls (rewinders).

All these results from the braking tension force on the sheet of paper must be adequately regulated by the unwinding station so that the paper reaches the cutting area in the best possible condition. The cause for all the above is the age of the machine 30 years old, the wear and tear of its parts, and the limited technology with which it was designed.

The fundamental problem is the braking system in the unwinding stations of the paper cutting machine for writing and printing, and this features the following problems: it is obsolete, it is manually controlled, its mechanical and hydraulics parts are no longer available, its pumps leak, refurbishment is already quite expensive as the spare parts are no longer produced and thus cannot be obtained, its design is old and, thus, highly inefficient, and machine stoppages for reparations are frequent; in addition, sometimes the machining to repair wear on mechanical parts takes time, and the operator spends a lot of his/her working time adjusting the pressures to minimize defects.

Moreover, operating this machine as its manufacturer initially designed implied becoming familiar with a manual adjustment system with interrelated variables, whose optimal settings had to move continuously while unwinding, and the diameter of the coil decreased with variable production speeds. This makes machine operation highly dependent on the operator's experience, creating more inconsistencies since four people from different shifts and teams work in that position.

It has been demonstrated that to avoid rips and obtain a quality paper, it is crucial to keep a constant tension on the paper when it is being wound. Valenzuela (2003) proposed and evaluated a sheet tension estimation using only conventional motor and control signals present in new drive controllers, integrated into a process model observer.

Carrasco (2005) developed a tension estimator for a system consisting of two drums, an electric braking generator, and a production winder, based on unwinding and rewinding variables, without the use of load cell tension loops. Abd-Elraouf (2017) identified the need to achieve constant tension control between the multi coordinate drive of a winding machine as the primary requirement in many industrial paper production lines.

The paper cutting machine under study has four unwinding stations in which there is equipment for curb rolls; that braking force controls the tension force of the paper. The Valmet Strecker 2051 paper cutting machine and its stations can unwind up to 4 reels of bond paper (Pondercel 2015).

It was found that it was in the braking control system during the conversion of paper rolls to spread papers in the unwinding stations that defects in the paper originated, affecting the cut and, thus, the final product. The Deming Cycle (PDCA) showed that the root cause identified as the critical variable was the tension force, stabilizing the unwinding and cutting process.

By redesigning the automatic tension control system with brakes in the unwinding stations, the material can be kept at an adequate and constant laminar tension to rewinding, unwinding, cutting, punching, or punching printing tasks. It must also be able to always self-adjust the machine's speed without human intervention.

However, the market offers much more sophisticated machines with expensive integrated technologies that are difficult to adapt to obsolete machine sections; there are also system integrators and external engineering teams, which the company does not find profitable to acquire.

Thus, the internal proposal was to replace the manual braking system in the machine that converts rolls to cut spreads with a modern and precise control system based on Programmable Logic Controller (PLC), with its respective TIA Portal software, following the operation's philosophy.

LA stands for Lean Automation and is defined as a combination of lean production and automation technology; in recent years, it has seen an incredible boom due to the emergence of Industry 4.0 technologies (Shahin, et al. 2020; Tortorella, et al. 2020, 2019; Bittencourt and Alves 2019; Ma et al. 2017; Kolberg and Zûhlke 2015; Kolberg et al. 2016), also called Jidoka.

The new system will oversee the processing of input signals and create output signals for the final actuators during machine operation. It will be capable of automatically controlling the paper's tension force regardless of the rolls' condition, i.e., different diameters and widths and the speed of the machine, without the operator's experience being a point to consider.

This article shows the technical redesign to modernize the unwinding of rolls from a spreadsheet slitting machine, stacked into 500-sheet reams of bond paper for writing and printing for mostly continuous, security-based production.

The automatic tension control by brake is the modern and precise electronic system added to the machines to work with continuous laminated material such as paper. It can guarantee the uniformity of the products obtained in the unwinding process.

The implementation of this lean automation philosophy, seeking better quality and compliance with customer requirements, improved the total efficiency of the cutter by positively impacting productivity as it created lower downtime and less waste and rework, which positively impacted the company's goals.

The article is organized as follows: The Unwinder section defines relevant concepts and describes the technologies used to solve these problems, whereas the Method section covers the strategy used in this work. The Materials section offers information on the equipment and materials used during the improvement development. The authors explain the integration development, variables, programming software, and technical details in the System Integration part. Finally, the Results section describes what was achieved after the implementation of the job and includes a discussion on such results. The Conclusions part highlights the project's contributions.

2 Unwinder

Converting and slitting/rewinding operations require an unwind system. The slitting and rewinding systems are of paramount importance; however, the unwinding system isnot given the importance it deserves. Although it is often identified as a simple function, proper selection of an unwind system is critical to all converting productivity. Thus, implementing a controller for the unwinding zone for specific applications will ensure maximum performance and productivity (Augi 2020).

The paper guillotine consists of a sharp blade and squares that establish the paper's position. Although the mechanism of a paper guillotine is not complex, paper guillotines have evolved considerably, and with it, the technologies they use to cut; however, their parts continue to be essential (Idealsystems 2020a).

The first companies to see this machine's potential and concerned about improving it were Form and Krause in Germany; Furnival in England; and Oswego and Seybold in the USA (Idealsystems 2020b).

In the modern paper industry, large machines are used to cut large stacks of paper, cardboard, or materials with similar characteristics. Manufacturers such as Polar, Valmet, Strecker, and Will, all from Germany, make machines capable of cutting sheets up to 430 cm wide. Magnetic particle brakes provide excellent braking and smooth control for low-tension, low-horsepower applications.

Most conversion applications use air-cooled disc brakes, which are easy to maintain and require no external cooling. For higher tension horsepower applications, however, especially those operating at slower speeds, the heat dissipation in such brakes may not be adequate, thus requiring water-cooled disc brakes. The cooling water is automatically isolated to zero in such cases to prevent dew problems (Gilbert 2018).

Regarding the subject of friction, disc pneumatic brakes are used to control the tension in the unwinding of the coil as the final element. Today, there is a complete line of different powers, sizes, characteristics, and ideal configurations for corrugators, cutters of paper, and many other converting machines (EE 2020).

Tension is the force applied to a band of material in the direction of machine drag. The said band is a continuously formed cellulosic material that can be extended or compacted into rolls for later conversion to cut products or to other smaller rolls, depending on the need (Damour 2004).

The tension applied to a band can be described as the sensation of being pulled or dragged, which results from hanging a weight from the edge of the band. The tension in the belt will equal the weight in pounds. Thus, the PLI will be equal to the weight (or tension) in pounds divided by the width of the net in inches, Eq. (1).

$$\mathrm{PLI} = \mathrm{tension}/\mathrm{width} \tag{1}$$

The tension variable is critical for the paper industry because it is impossible to control material web without applying adequate force. The belt must be "in tension" with all machine tension rollers and driven rollers to ensure proper handling and control. If proper tension control is not applied, it will be impossible to unwind rolls in one process at the unwind station because wrinkles and even web breaks will occur due to telescopic coils and concave rolls.

When the tension is too high, the belts will stretch in the machine's direction and compress in the cross-machine direction. This narrowing of the web width can cause wrinkles to appear. The torque required to provide a certain level of tension to a web is the total tension measured across the web by the roll radius, as shown by Eq. (2).

$$\mathrm{torque} = \mathrm{tension} \times \mathrm{radius} \tag{2}$$

This means that the torque driving the unwind shaft must decrease in a linear relationship relative to the roll diameter since an unwind roll decreases in size through the running of the rolling machine to keep the tension constant (Damour 2004). The Technical Association for the Pulp and Paper Industry (TAPPI) and many other industry organizations publish estimated suitable tension levels and PLI's for several different types of belts and laminations.

However, it should be noted that these values are only guidelines and "best estimates" based on many years of combined experience in the industry. The actual best tension to execute a specific band and process will most likely vary from the guide, but it is a good starting point (Damour 2004).

3 Methodology

Controls via diameter measurement are considerably helpful for controlling tension on unwinding and rewinding. They control the tension by proportionally decreasing (unwinding) or increasing (rewinding) the torque to suit the change in roll diameter. These types of tension controls are used in the unwinding and rewinding tension zones.

The diameter calculator is a type of measurement control used for closed-loop applications. This type of control uses sensors on the unwind or rewind shaft and an idler or driven roller. Both sensors detect RPM, and they can be encoders or tachometers. The machine speed is constant and known.

Roll rewind and unwind speeds vary concerning roll diameter. The diameter can be calculated by comparing the known constant speed with the variable speed of the rewinding or unwinding roll. The sheet tension is adjusted to an optimum and constant level by controlling the sheet braking force (Damour 2004; Yuyama 2016).

When redesigning the converting machine, the first step was to understand the basic criteria of the original unwinding design. To do so, the following elements had to be determined: processed materials, classes (composite, extensible, non- tensile), range of base weight, thickness for each material, diameters and weights of the rolls, operating speed, tension (resistance to stretching of materials), center or core sizes and materials, length variations, internal diameters and their tolerances, external diameters, and the roll delivery system.

This project only implemented tension control in the roll unwinding area, using the method of the diameter calculator and the materials, measurements, and products produced by the machine.

3.1 Materials

3.1.1 Inductive Sensor

Inductive sensors are a particular class of sensors used to detect ferrous materials. They are widely used in industry, both for positioning applications and detecting the presence or absence of metallic objects in each context: detection of passage, jam, coding, and counting.

The selected sensor was refurbished and is commonly used; it had a high switching speed, a typical sensing distance of 1.5 mm, a thickness of 8 mm, belonged to the 24 VDC PNP type and was usually open, with a visible led light indicator to show that it was activated; also, it featured a built-in steel and PVC census surface and internal overload protection, among others.

3.1.2 Controller

The selected PLC for automation was a SIMATIC S7-300 from Siemens, suitable for universal automation. It is the best-selling controller of the Totally Integrated Automation (TIA) software and has numerous successful reference applications in the most diverse industrial sectors worldwide, for example, the pulp and paper industry.

3.1.3 Voltage to Pressure Converter

The equipment converts an input voltage signal into a pneumatic output (pressure) linearly proportional relationship. This versatile instrument was designed for control applications requiring high reliability and repeatability at an affordable cost. These units are used for applications that require the operation of valve actuators, pneumatic valve positioners, dampers and louver actuators, final controls, relays, air cylinders, web tensioners, clutches, and brakes.

Additionally, they feature the following main characteristics: An integral volume amplifier, a compact size, low air consumption, a reversible field, a flexible zero, span adjustments, standard process inputs, and a split range.

3.1.4 Control Actuator

The selected tx-180 air brake featured four internal discs of 180 mm diameter each, a maximum of 6 pistons, and a dual-vent cooling system. It was designed for standard applications and all sectors in paper-converting processes. It is ideal for rewinders, unwinders, and other high-speed applications up to 300 mt/min, 24 h/day (Renova 2020a).

Due to the low temperature dissipated by the pair of fans configured in push/pull, the voltage control of the process is improved at any line speed; the assembly remains cold even at low speeds, and slipping is avoided. In addition, pressure piston seals have a longer life and less dust; thus, wear and contamination within the brake are drastically reduced. Finally, the brake is 100% interchangeable and adaptable to all existing brakes on the market.

3.1.5 Pneumatics

One of the most important reasons to use air compression instead of electricity is safety. Electrical equipment poses a safety risk in applications where the equipment is overloaded. For example, electric shock or fire can damage property or injure personnel. On the other hand, compressed air and pneumatic tools can be used under many conditions on wet floors or in highly humid areas. Furthermore, pneumatic tools are cooler and have the advantage of variable speed and torque (Creus 2011).

A pneumatic hose is ideal for working with fluids at high pressure and with high repeatability of cycles. This is because its maximum working pressure is 250 PSI. The nylon pneumatic hose is the stiffest. Pneumatic connections, also known as pneumatic fitting, are components used in pneumatic systems to interconnect their elements, such as cylinders, valves, and maintenance units. Pneumatic fitting is mainly used for compressed air. Additionally, solenoid valves are used to control the flow of fluids. An electrical signal actuates them, and the action of a coil carries out the opening or closing of the valve.

3.1.6 E/P Servo Valve

They are electro-pneumatic elements that convert an electrical signal into compressed air with pressure directly proportional to the electrical signal received. The pneumatic output pressure is connected directly to the brake actuator, responsible for applying the braking force in the debulking station (Renova 2020b). It features the following: a compact design, voltage accuracy, a 24VDC power supply, reception of an analog signal from 0 to 10VDC, and an output pressure of 0–6 Bar.

3.1.7 Braking Actuator

To maintain the tension of the unwound material, an element is needed to act as a brake on the reel. The final control actuator does this work.

4 System Integration

All the braking system's elements that were no longer useful, including the security guard, were removed from the unwinding station since the new system's drives were found inside the set and were no longer a risk for the operator. The new model pneumatic brake actuator assembly was installed. Because each station had two actuators, one for each support arm, the total number of actuators was 8.

4.1 Unwinding Area Operating Stations

Each station's local controls for other functions such as raising, lowering, emergency stop circuits, and activating/deactivating brakes remained the same; they did not require intervention since the machine was primarily manual. These functions were direct electric drives that did not go through the controller.

4.2 Gyro Sensor

The sensor was used to detect revolutions in the unwinder. Thus, to calculate the diameter, we proceeded to make a hole in the structure of the rotation arrow support for its fixation, and then the metal plates that were added to the disk were cut and welded to the sensor to detect the rotation. Four inductive sensors of this type were installed for each unwinding station; finally, the sensing distance was calibrated.

4.3 Servo Valve

The servo valve's connection was the most critical maneuver to carry out inside the connection box of each unwinder. The servo is responsible for transforming the data obtained by the calculator into an electrical signal of diameters that the program is constantly calculating (Damour 2004). Its output is conducted to the servo to be transformed to the corresponding pressure. In this case, it had electrical connections on one side and pneumatic connections on the other.

Care was taken to ensure that it was securely attached as it is sensitive to vibrations that can affect its internal parts. After all, it is a precision device. Its characterization and calibration were carried out in the workshop, using an automatic valve actuator only for the final control element under test. Its operation was understood, and the fact that its output is linear to the behavior of the input signal was confirmed.

4.4 Electrical and Pneumatic Connections

This task required electrical wiring for the analog (servo valve) and digital signals (unwinder rotation sensor). Also, 12- and 14-gauge AWG wire was used along with 8 and 6 mm pneumatic lines and quick fittings; finally, a line filter unit was added to feed supply air to the servo valve to help manage condensed moisture in the lines.

4.5 Cutting Press Sensor

An aluminum support base was manufactured to fix the inductive sensor in its position as this sensor detects the cutting revolutions in the press. It had a slot for screw balancing. Another longer screw was applied to serve as the detection mark without carrying out modifications or applying welds or added weights to the press, which might create imbalance. This sensor was used by the PLC software so that the diameter calculator could perform its algorithm (Yuyama 2016).

4.6 Automatic and Manual Control

Two ways were designed to control the braking pressure in the unwinder assemblies: the automatic and the manual. The reason was that this specific cutting machine had been working with low productivity or recovery rolls, which are generally few and which had to be assembled on the machine with differences in diameter, width, and length. Thus, manual control was needed to work the cutter under such circumstances. Because of this, a potentiometer for manual adjustments was added to the design and was configured in the traditional electronic voltage divider since this was the input signal of the servo valve.

4.7 PLC Hardware and Software

The algorithm programming software and desktop testing were initially instrumented in a Siemens 400 PLC as it was in store to be replaced by another more giant machine. The logic operation of the diameter calculator began to be carried out in that PLC. The braking pressures towards the pneumatic servo valve were simulated, and galvanometers were connected as analog multimeters to observe and monitor the output voltage and the response obtained.

Later, the programming took place in a Siemens S7-300 PLC, the best option due to project cost. It was also more suitable since there was little space in the machine's electrical cabinet.

The SIMATIC Field PG programmer is the industrial notebook that best withstands even the most extreme industrial conditions (shocks, vibrations, or electromagnetic disturbances) and best automates all kinds of tasks through PROFIBUS and PROFINET connections. The program was carried out on PG1, and its backup was entirely recorded in a working directory.

The TIA Portal is state-of-the-art software developed by Siemens so that users can carry out the engineering, commissioning, operation, and monitoring of all automation and drive components through a single control platform. The portal integrates different industrial software applications for production processes in the same interface, greatly facilitating learning, interconnection, and operation without a wide variety of systems from different origins. V13 was installed on PG1.

Step 7 was the software component for the TIA Portal programming and configuration. In addition, the TIA Portal contained WinCC for designing and executing the process visualization in Runtime, with online help for WinCC and Step 7.

Step 7 provided a comfortable environment for developing, editing, and monitoring the program logic required to control the application, including tools to manage and configure all devices in the project, such as controllers and HMI devices.

Step 7 offered a comprehensive online help system to find the necessary information. It also provided standard programming languages, which allowed to development of the control program comfortably and efficiently. It also handled three types of language:

- KOP (ladder diagram), which is a graphical programming language. Its representation is like circuit diagrams.
- FUP (function diagram) is a programming language based on the graphical logic symbols used in Boolean algebra.
- SCL (Structured Control Language) is a high-level, text-based programming language. When creating a code block, the programming language that the block will use must be selected. The user program can use logic blocks created with any programming language.

4.8 Algorithm

The algorithm selected for this process was the diameter calculator described in Sect. 3, its fundamentals, measurement, and control. Its main advantage is the economy in the parts, but its main disadvantage is the complexity in programming, which will be described in the following sections.

4.9 Developed Software

The program software processes the input signals from rotation sensors to the PLC. The necessary data type conversions are carried out to be able to calculate the mathematical equations that allow conditioning, linearization, and generation of a control signal to the analog outputs, which will, in turn, be converted in each unwinder by the servo valve.

Next is a brief explanation of the segments of the program software that processed the input signals to the PLC:

(a) Program functions and data. Figure 1 shows the project screen, program structure, and function blocks. Figure 2 details the memory block, also called the DB1 database, which stores various parameters as input values of each unwinder that uses de-scaling functions.

(b) Counter Revolutions. The initial segments of the PLC program process the pulses coming through inductive sensors installed in the press and each decoiler. 1 Pulse = 1 Revolution.

When the input is detected, and the machine is working, it is counted by an adder block that stores the number of pulses in a WORD type mark. Figure 3 shows the

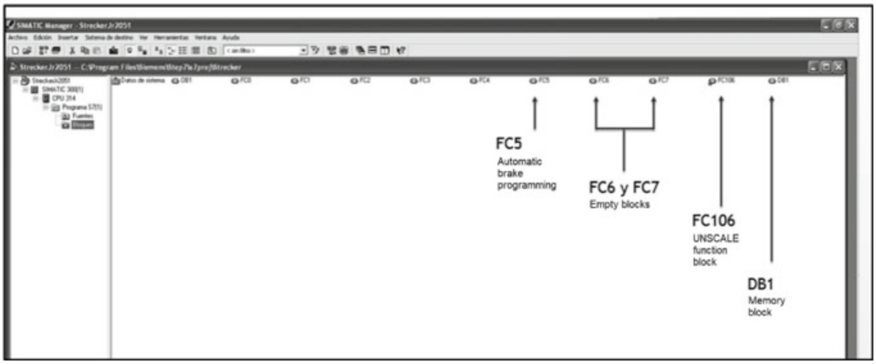
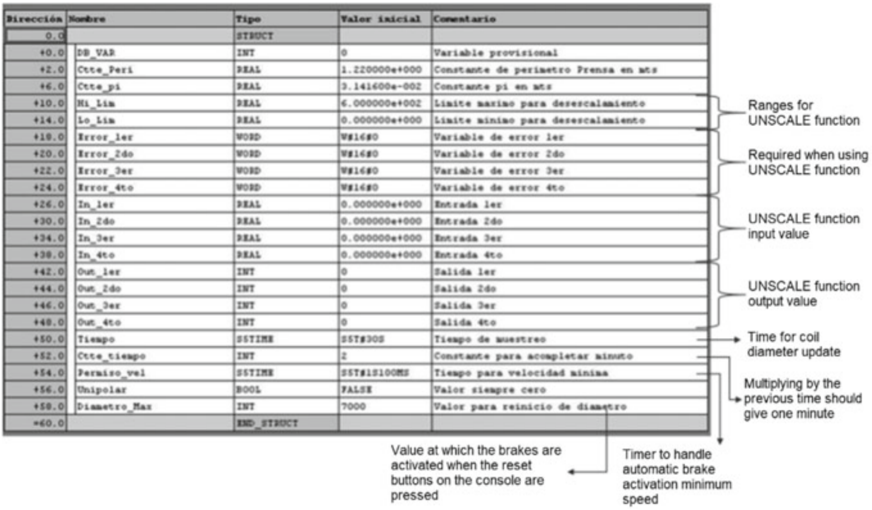


Fig. 1 General program structure



Dirección	Nombre	Tipo	Valor inicial	Comentario
0.0		STRUCT		
+0.0	DB_VAR	INT	0	Variable provisional
+2.0	Ctte_Peri	REAL	1.220000e+000	Constante de perimetro Prensa en mts
+6.0	Ctte_pi	REAL	3.141600e-002	Constante pi en mts
+10.0	Hi_Lim	REAL	6.000000e+002	Limite maximo para desescalamiento
+14.0	Lo_Lim	REAL	0.000000e+000	Limite minimo para desescalamiento
+18.0	Error_1er	WORD	W#16#0	Variable de error 1er
+20.0	Error_2do	WORD	W#16#0	Variable de error 2do
+22.0	Error_3er	WORD	W#16#0	Variable de error 3er
+24.0	Error_4to	WORD	W#16#0	Variable de error 4to
+26.0	In_1er	REAL	0.000000e+000	Entrada 1er
+30.0	In_2do	REAL	0.000000e+000	Entrada 2do
+34.0	In_3er	REAL	0.000000e+000	Entrada 3er
+38.0	In_4to	REAL	0.000000e+000	Entrada 4to
+42.0	Out_1er	INT	0	Salida 1er
+44.0	Out_2do	INT	0	Salida 2do
+46.0	Out_3er	INT	0	Salida 3er
+48.0	Out_4to	INT	0	Salida 4to
+50.0	Tiempo	S5TIME	S5T#30S	Tiempo de muestreo
+52.0	Ctte_tiempo	INT	2	Constante para acompletar minuto
+54.0	Permiso_vel	S5TIME	S5T#1S100MS	Tiempo para velocidad minima
+56.0	Unipolar	BOOL	FALSE	Valor siempre cero
+58.0	Diametro_Max	INT	7000	Valor para reinicio de diametro
=60.0		END_STRUCT		

Fig. 2 General database structure 1

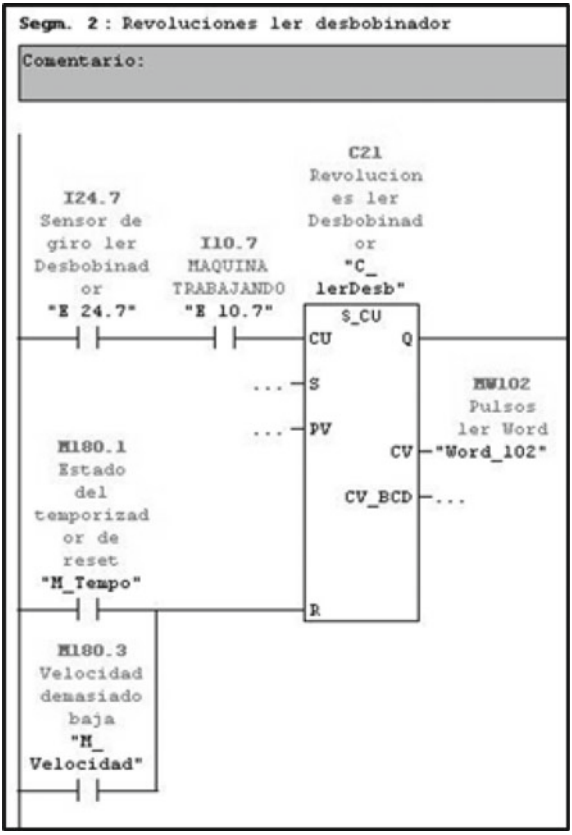
processing for unwinder 1. The data type of the marks was changed to be used later by mathematical functions.

Mark change Word to Int. It is also necessary to convert the data type word to int and assign them a memory variable for later processing. More data type conversions are required to perform mathematical operations. The conversion is carried out and saved in other brands for the press and unwinder 1.

(c) Calculation of RPMs in press and unwinders. A special entry containing the number multiplied by the pulse sampling time will result in 60 s.

As the sampling time is set in an internal timer of the PLC of 30 s, then the mentioned constant to complete the minute will be two because 30 s multiplied by a constant of

Fig. 3 Unwinder revolution adder 1



magnitude 2 allows us to obtain 60 s. That will become the time base, multiplying this constant by the pulses of the press and the unwinder 1 (see Figure 4), the number of turns that the section makes per minute respectively (RPMs), can be obtained.

It was converting the mark containing the RPM from INT to Real. The INT to Real data type conversion process must go first to DINT since we go from a word size to a double word. This applies to both the press and the unwanders.

(d) Calculation of Press Speed. The linear speed is calculated by multiplying the number of pulses per minute of the press by its perimeter, obtaining m/min.
(e) Coil Perimeter. The perimeter value is obtained by dividing the linear speed of the machine by the pulses per minute of each unwinder.
(f) Unwinder diameter calculation. The perimeter obtained for each unwinder is divided by the value of π (divided by 100). The value will be given in centimeters according to Eq. (3) (see Fig. 5).

$$\text{Diameter} = \text{perimeter}/\pi \tag{3}$$

Fig. 4 RPM calculation in unwinder 1

(g) Analog output de-scaling. Next, the de-scaling block is used to linearize the output signal used in the analog ports of the PLC (Fig. 6). The block is parameterized with a signal to start the calculation, when the sampling time is fulfilled, of an input of the diameter of the unwinders in meters, the operating range, and the output value.

(h) Philosophy for de-escalation. The unwinders require a braking pressure much lower than the maximum accessible (6 bars), approximately 2 bars.

The servo valve used works from 0 to10 V, equivalent to 0–6 bar. Thus, an approximate range between 0 to 2.5 V is required for the 0–2 bar. The largest coils used in the Strecker 2051 have a diameter of 59". Because a 2.5 V signal would be used for its correct braking, the range to be used is 0–600 cms.

(i) Range Modification. In this case, the pressure line acts in reverse because the rolls placed in the station enter with their maximum diameter and, thus, with the maximum braking pressure; as the pressure runs out, it will have to decrease to its minimum value. In other words, in the beginning, the braking pressure increases with large rolls, and as the roll unwinds, the pressure drops.

Analog output. This block is used to move the unscaled value to the analog output, also called peripheral, to where it is required.

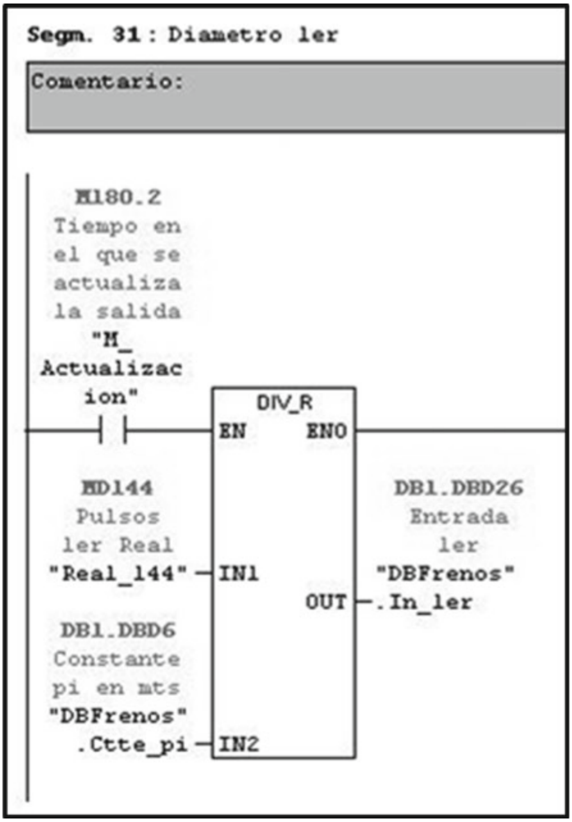


Fig. 5 Calculation of the diameter in unwinders

(j) Diameter reset button. The PLC does not install the new coils; instead, it holds the value of the last diameter read. This occurs because there is no sensor or selector to feed this information to the PLC since the machine did not require it when it was manual; however, it is now necessary.

A box with push-button type keypads was installed to force a manual diameter count reset for each unwinder individually. This machine can retrieve rolls with different diameters and widths. This way, the PLC is told that there is a new roll of a certain diameter, and it will calculate the new diameter since blocks are programmed to do this.

Suppose the new coils do not have a 59" diameter. In that case, they will initially have to be handled manually until the algorithm automatically calculates the new diameter, which takes approximately 30 s from a speed greater than 100 m/min.

(k) Timer for pulse accumulation. This timer marks the time by which the pulses of each revolution will be added in both the press and the unwinders (see Fig. 7).

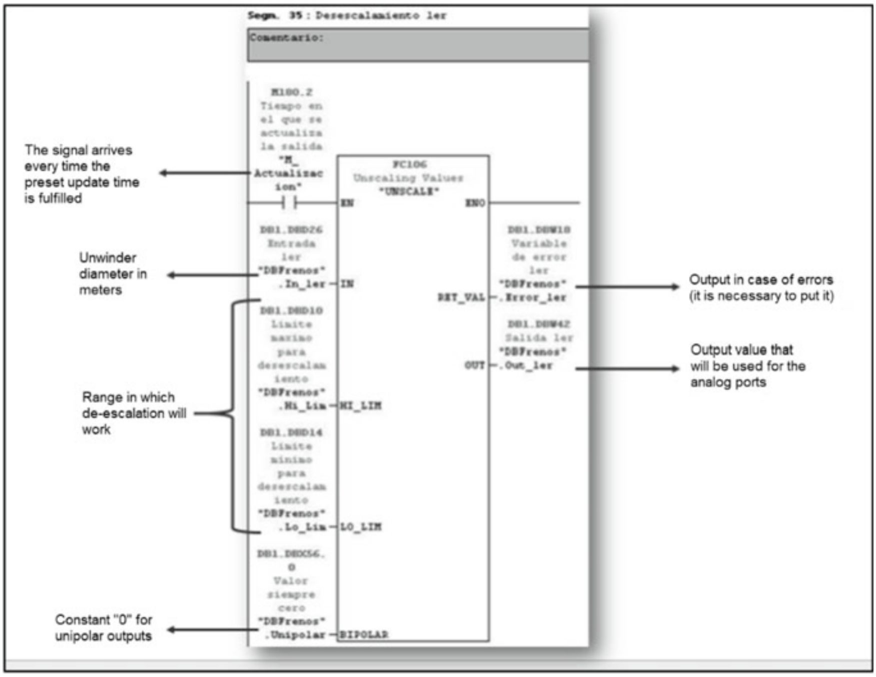


Fig. 6 Analog output of-scaling

Timer for block processing. A small interval between each pulse sampling is necessary to slow down process speed and give the function blocks the opportunity to do their processing before obtaining new values.

(l) Update Timer. While the time allocated for data processing is fulfilled, this block updates some function blocks and the analog outputs.

(m) Minimum Speed Timer. This timer changes state when the machine exceeds a specific speed assigned proportionally for the time of the same block. The pulses that arrive from the press keep it resetting its internal counter.

If pulses do not arrive at frequencies greater than the established time, the timer changes state, denying the permissions for various program blocks (Figure 8).

5 Results

The different LM tools involved in the Kaizen process, such as PDCA and Lean Automation, had the following results: after implementing the braking system update, tuning the systems, detailing significant adjustments, and conducting fine adjustments, the machine was released to begin work and measure the indicators being monitored.

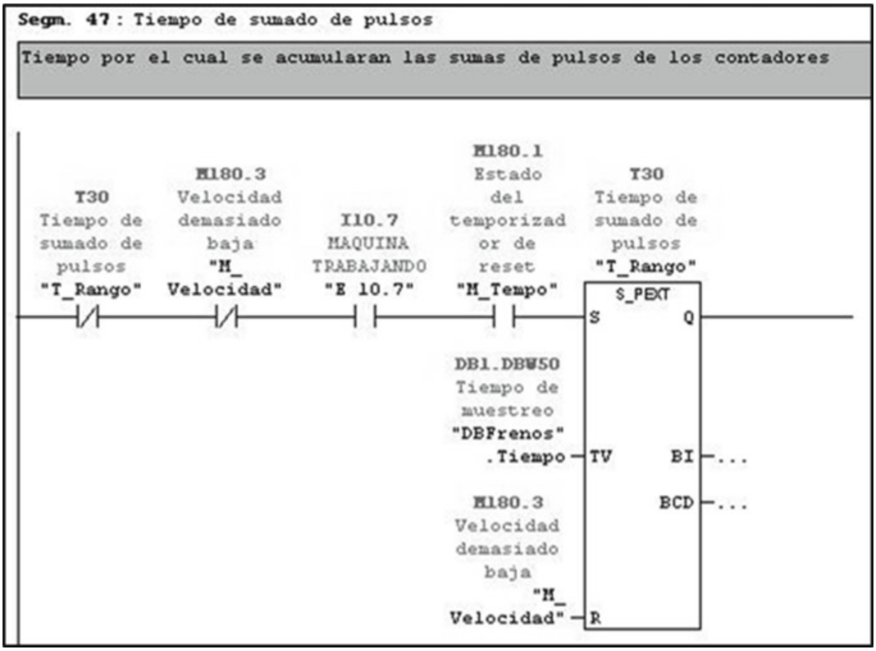


Fig. 7 Timer to accumulate pulses

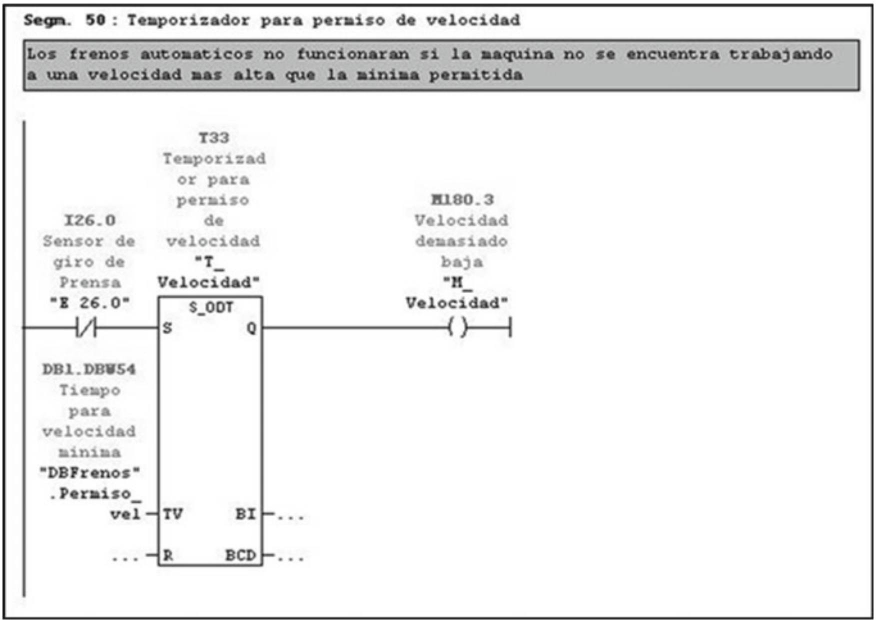


Fig. 8 Minimum speed timer

Performance was highly favorable, and the machine started, ran, and stopped without tearing the paper because of the improved tension control. Under normal operation, the maximum design speed was sometimes reached when the conditions were met.

Conditions like the cutting blades were well adjusted; in the unwinder, unbalanced rolls were placed, and rolls without quality defects were caused by rewinding. Also, it was reported that it worked much better, and when it was time to make a splice, it was done more easily. Furthermore, it was possible to operate the four unwinding stations automatically, and the reports of down-times due to failures or loaded repairs dropped notably.

When reviewing the daily logs for the times devoted to maintenance by specialty assigned by the operators, quantitative information was obtained, including comparing the year before and after the new system was implemented. The information was shown in down-time machine hours.

From such information, a graph of the behavior of the machine's down hours was created (Fig. 9). As can be seen, it was significantly reduced after a few months. It is worth mentioning that this cutter was strongly affected the year before (blue line) by low productivity rolls. However, it ended in a technical stoppage in the last four-month period due to low orders, lack of material, and other departmental details. However, it is still possible to see a decreasing trend in the down-time indicator.

Quantitative information on down-time, classified by machine section, was also obtained. The operators assigned times per hour to each zone when there was a stoppage, and the information for the years before (blue) and after (red) was processed. Then the data was analyzed and quantified for the section where the update was implemented, namely the four unwinders. A comparative graph of down-times was created for the unwinding section, showing that the objective of reducing times due to problems in that area was achieved (Fig. 10).

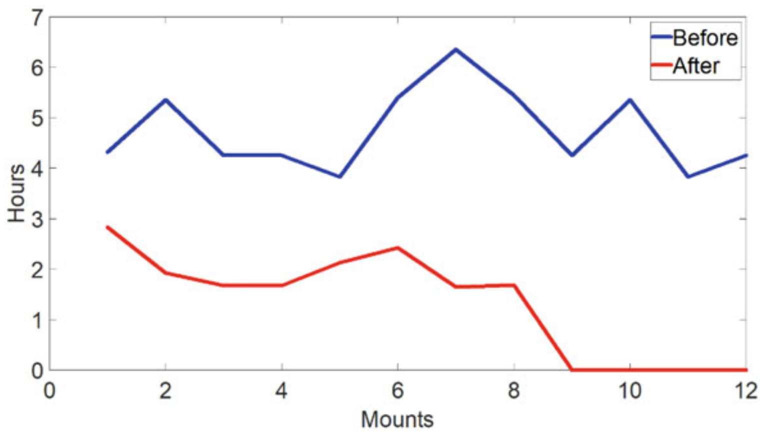


Fig. 9 Time comparison for instruments

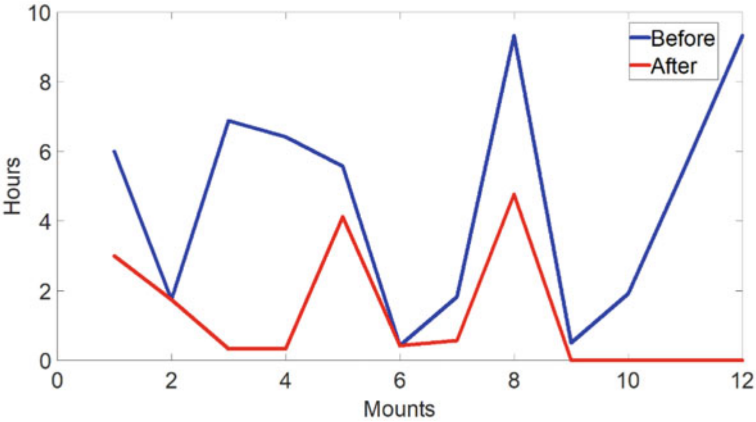


Fig. 10 Comparison of unwinding area times

This solution was implemented by and for engineers in the paper industry. It automated old equipment with state-of-the-art technology and the most appropriated methodology and programming software. Finally, it preserved the valuable characteristics of its operating mechanisms, kept project costs low, and improved its performance.

6 Conclusions

Lean automation is essential for companies with old machines and quality problems. Consequently, they look for a suitable automation solution to modernize their process, eliminating expensive and complicated solutions. In this case, an old brake system was replaced by a modern and precise mechanism, coupled with a PLC control system, thus achieving the general objective set out in this article.

The unwinding process was modernized and automated to increase a smooth operation and eliminate defects due to faulty operation. It was possible to prove that modernizing the braking system increases the performance of each unwinder because it avoids defects caused by faulty operation and inconsistencies in the obsolete elements of paper tension management.

On the maintenance side, it was perceived that the periods between services were lengthened due to the study and selection of materials, the availability of spare parts in the national market, the elimination of contamination by hazardous waste, more assertive diagnoses, and the decrease in the large parts wearing out.

As a result of the improved braking system, the operator was able to tend to other critical tasks in other areas, such as cutting or stacking by removing dirt caused by used brake pads and dust when changing braking technology.

Previous brakes had been found to overheat, thus reducing efficiency. With the new system's bi-directional ventilation design, airflow through the braking system increased without having to maximize a heat dissipation area, even at low speeds.

Such an airflow allowed the brake to dissipate heat more efficiently than others. Because these brakes are cold, they reduce wear, excessive noise (squeal), dust, and premature pad wear. The analysis of the operating philosophy, the diameter calculator technique, the materials obtained, and the operating needs led to creating the required software, a program for S7-300 PLC, in the Siemens Step7 language.

This software made it possible to optimize the paper unwinding and cutting process critical variables to avoid defects. There were significant savings in implementing this improvement as the company's instrument engineers' analysis, and system programming skills were used. They were specialized in Siemens PLC programming software, and they had the tools to carry out this activity without having to hire external services, which would have made the project more expensive.

A future project would be developing a connection between the PLC and the company's intranet to monitor production, speed, stoppages, and stoppage causes in real-time to generate automatic reports on a server computer, according to Industry 4.0.

Acknowledgements The authors thank PONDERCEL and TecNM for their support during the undertaking of this project.

References

Abd-Elraouf, M.A., El-Shenawy, A., Ashour, H.: Performance improvement of automatic tension control in multi coordinate drive systems for industrial paper winder. In: 2017 Nineteenth International Middle East Power Systems Conference (MEPCON), pp. 1163–1169. Cairo: IEEE (2017). https://doi.org/10.1109/MEPCON.2017.8301329

Augi: Desbobinado (2020) Retrieved from: https://www.augi.es/es/productos-aplicaciones/procesado-y-manipulado-de-papel-plastico-y-carton/desbobinado/

Bittencourt, V.L., Alves, A.C., Leao, C.P.: Lean thinking contributions for industry 4.0: a systematic literature review. IFAC Papers on Line **52**(13), 904–909 (2019)

Carrasco, R., Valenzuela, A.: Tension control of a two drum winder using paper tension estimation. IEEE Xplore, 169–179 (2005)

Chanarungruengkij, V., Kaitwanidvilai, S.: An application of lean automation: a case study of Thailand's control cable manufacturing. In: 2018 International Electrical Engineering Congress (iEECON), pp. 1–4 (2018). https://doi.org/10.1109/IEECON.2018.8712287

Creus, A.: Neumática e hidráulica. México. Alfa Omega, Editorial Marcombo (2011)

Damour, J.: The mechanics of tension control (2004) Retrieved from: http://www.pffc-online.com/mag/2889-paper-web-tension

Dulchinos, J., Massaro, P.: The time is right for labs to embrace the principles of industrial automation. Industrial Automation, 25–28 (2006)

EE: Frenos neumáticos para portarrollos (2020) Retrieved from: https://www.ee-co.com/mx/products/frenos-neumaticos-para-desembobinado

Ebinga, E.A.: Impact of Lean Automation on Process Performance in Sugar Industries in Kenya: Case of Mumias Sugar Company. (Publication No. F80/50496/2016). Doctoral Dissertation, University of Nairobi (2020)

Flinchbaugh, J., Carlino, A.: The Hitchhiker's guide to lean: lessons from the road. Soc. Manuf. Eng. (2006)

Gilbert, W.: Web tension control fundamentals (2018). Retrieved from: https://www.aimcal.org/uploads/4/6/6/9/46695933/gilbert_presentation.pdf

Granlund, A., Wiktorsson, M., Grahn, S., Friedler, N.: Lean automation development: applying lean principles to the automation development process. Proceedings form the 21st EurOMA Conference, pp. 20–25. Palermo, Italy (2014)

Hanson, J., Seymour, R., Daniels, M.E., Baggot, J., LeValley, R., Muksman, E., Greiner, J.: USA. Patent No. 6,719,240 B2 (2004a)

Hanson, J., Seymour, R., Daniels, M.E., Baggot, J., LeValley, R., Muksman, E., Welland.: USA. Patent No. 6,722,606 B2 (2004b)

Idealsystems: Guillotina de papel, el origen (2020a). Retrieved from: http://www.guillotinapapel.es/guillotina-de-papel-el-origen/

Idealsystems: Guillotinas Ideal (2020b). Retrieved from: http://www.guillotinasideal.es/guillotinas-ideal-ejemplos-por-cadatipo/

Kinnunen, J., Mikkonen, S., Linnonmaa, J.: Method and device in a paper machine, coating machine, intermediate winder, unwind stand of a slitter-winder, or in any other device for treatment of a web. USA (2005). Patent No. US 6,843,200 B2

Kolberg, D., Knobloch, J., Zuhlke, D.: Toward a Lean automation interface for workstations. Int. J. Prod. Res. **55**(10), 2845–2856 (2016). https://doi.org/10.1080/00207543.2016.1223384

Kolberg, D., Zûhlke, D.: Lean automation enabled by industry 4.0 technologies. IFAC-Paper on Line **48–3**, 1870–1875 (2015)

Kimball, P.E.: Lean Automation Strategies for High Volume, High Complexity, Manufacturing Systems. Thesis, Masachusetts Institute of Technology (2015)

Ma, J., Wang, Q., Zhao, Z.: SLAE-CPS: Smart Lean Automation Engine Enabled by Cyber-Physical Systems Technologies. Sensors **17** (2017). https://doi.org/10.3390/s17071500

Malik, A.A., Bilberg, A.: Framework to implement collaborative Robots in manual assembly: A lean automation approach. In: Proceedings of the 28th DAAAM International Symposium, pp. 1151–1160 (2017), https://doi.org/10.2507/28th.daam.proceedings.160

Malik, A.A., Bilberg, A.: Human centered Lean automation in assembly. Procedia CIRP **81**, 659–664 (2019). https://doi.org/10.1016/j.procir.2019.03.172

Mukhtarm, H., Siti, M.: Implementation of total quality management in developing santri charaters. Int. J. SE. Asia **1**(2), 1–12 (2020)

Pondercel: Manual Capacitación. Conocimientos básicos Strecker 2051. Cuauhtémoc. Pondercel S.A. de C.V. (2015)

Renova: Turborex pneumatic break (2020a). Retrieved from: https://www.renovainnovations.com/products/breaks/turborex

Renova: E/P Converter Transducer (2020b). Retrieved from: https://www.renovainnovations.com/products/control-system/ep-converter

Rodríguez, P.A.: Torn paper web capture system (2011). U.S.A. Patent No. 7,875,152 B2.

Shahin, M., Chen, F.F., Bouzary, H., Krishnalyer, K.: Integration of Lean practices and Industry 4.0 technologies: smart manufacturing for next-generation enterprises. Int. J. Adv. Manuf. Technol. **107**, 2927–2936 (2020). https://doi.org/10.1007/s00170-020-05124-0

Shigematsu, K., Yamazaki, Y., Kato, S., Kojima, F., Takata, S.: CIRP Ann—Manuf. Technol., **67**, 475–478 (2018)

Thangarajoo, Y., Smith, A.: Lean Thinking: an overview. Industrial Eng. Manage., 4–2 (2015a). https://doi.org/10.4172/2169-0316.1000159

Thangarajoo, Y., Smith, A.: Lean thinking: an overview. Ind. Eng. Manage **4**, 2 (2015b). https://doi.org/10.4172/2169-0316.1000159

Tortorella, G., Rossini, M., Costa, F., Staudacher, A., Sawhney, R.: A comparison on Industry 4.0 and Lean between manufacturers from emerging developed economies. Total Qual. Manage. Bus. Excellence (2019). https://doi.org/10.1080/14783363.2019.1696184

Tortorella, G., Sawhney, R., Jurburg, D., Carisio de Paula, I. Tlapa, D., Thurer, M.: Towards the proposition of a Lean Automation framework: Integrating Industry 4.0 into Lean Production. J. Manuf. Technol. Manage., **32**(3), 593–620 (2020)

Trent, R.: End-to-End Lean Management. Ft. Lauderdale, US; J. Ross. Publishing Inc., (2007)

Valenzuela, M.A., Bentley, J.M., Lorenz, R.D.: Sensorless tension control in paper machines. IEEE Trans. Industry Appl., **39**(2) (2003). https://doi.org/10.1109/TIA.2003.809449

Vlachos, I.P., Martinez, R., Zobolas, G., Repoussis, P., Glannakis, M.: Lean manufacturing systems in the area of industry 4.0: A Lean automation plan of AGVs/IoT integration. Prodction Planning Control (2021). https://doi.org/10.1080/09537287.2021.1917720

Yamasaki, Y., Shigematsu, K., Kato, S., Kojima, F., Onari, H., Takata, S.: Design method of material handling systems for lean automation-Integrating equipment for reducing wasted waiting time. CIRP. Ann. Manuf. Technol. **66**, 449–452 (2017)

Yamasaki, Y., Takata, S., Onari, H., Kojima, F., Kato, S.: Lean automation system responding to the changing market. Procedia CIRP **57**, 201–206 (2016)

Development, Testing, and Simulation of Antifungal Polyurethane Insoles for Footwear

Armando Mares-Castro and Jorge Domínguez-Domínguez

Abstract This chapter shows the design of an insole performed by developing, testing, and simulation using industrial software. The insole is composed of polyurethane (PU) reinforced with silver nanoparticles, said characteristic attributed to the material an antifungal property against fungi of the family Trychophyton, which are the cause of athlete's foot and ringworm. The study aims are to design the insole using two software, FreeCad® special for computer-aided design applications (CAD) and ANSYS® Workbench, to analyze mechanical properties using algorithms for scientific computation with the finite element method (FEA). In the latter, FEA techniques are used to verify the stress and deformation to which the insole is subjected in different use scenarios. From this research, satisfactory results were obtained in the material's performance in the insole due to the load exerted by people of different weights, both in the upright flat position and in the bent standing position. The study findings allowed to validate the efficiency of the insole and are profiled as a product that, in addition to its antifungal property, also has good mechanical properties as low residual deformation, representing an attractive and quality product for the user.

Keywords Antifungal insoles · Finite element analysis · Product development and simulation · Algorithms for scientific computation · Polyurethane

1 Introduction

Computational simulation and algorithms for scientific computation are widely used in companies in the product design phase to analyze, improve and predict the behavior

A. Mares-Castro (✉)
Department of Industrial Engineering, Tecnológico Nacional de México / ITS de Purísima del Rincón, Blvd. Del Valle #2301, Guardarrayas, Purísima del Rincón, Guanajuato 36413, México
e-mail: armando.mc@purisima.tecnm.mx

J. Domínguez-Domínguez
Department of Probability and Statistics. Centro de Investigación en Matemáticas, Unidad Aguascalientes, F. Bartolomé de Las Casas # 314, Aguascalientes, Aguascalientes 20259, México
e-mail: jorge@cimat.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_12

of processes in the industry. There is various software for the simulation of the performance of materials under various mechanical conditions. Several of the software used for product design requires the FEA, which will allow obtaining relevant answers to generate knowledge on different engineering problems.

In particular, developing a shoe insole to help the user solve different situations in a health context allows us to achieve a significant challenge in the manufacturing process. In this line, we apply two software, which will enable us to integrate this work into the framework of Industry 4.0. Thus, our objective in this chapter is to present a study for the development, testing, and simulation of mechanical properties in an insole of PU material reinforced with silver nanoparticles.

This product generates potential and essential market due to the potential benefits to an interested party. It is necessary to point out the critical requirements for designing an insole. In addition, we present the evaluation of the insole efficiency, and this focuses on the analysis of the stress and deformation to which the product may be subject.

To achieve this goal, we will use two computation materials, the ANSYS® Workbench software, with which the insole is examined using FEA. The other is the software FeeCAD®, which allows us to simulate the efficiency of the product as it will perform under normal conditions of use. This information will be helpful in the manufacturing process.

The work line to achieve the proposed goal is divided into presenting the characteristics of the product being designed, describing the manufacturing process of the PU insole, presenting the technical framework in which the study is developed, the methodology of the research, and the results generated in the development of this project.

Among the research findings, it is highlighted that the insole had good performance before the efforts to which it was subjected. The simulation carried through the FEA algorithms allowed us to know the deformation to which the insole is subjected when used by people of different weights. The material has good mechanical properties and memory, which translates into user comfort and material durability in the insole.

This chapter contains the following structure: Sect. 2 describes product characteristics to be designed, explaining the benefits that users can gain with sensitive feet. Users tend to acquire nail fungus and feet, and the features of the material are presented in a general way.

The process of developing the polyurethane insole at the industrial level is explained in detail in Sect. 3. The components of the mixture and the mould casting process, in which predefined input parameters are used to obtain the desired physical characteristics in the product, are indicated, which affect the mechanical properties that the insole will present, and which are the objective of the study.

The technical characteristics of the PU insole are discussed in Sect. 4. This section indicates the most important qualitative properties of the product and its impact on users' daily activities. The benefits of everyday use and dynamic activities are highlighted, as aspects of comfort, stability, and absorption of impacts, among others, must be considered.

Section 5 presents a literature review in modeling footwear insoles through FEA. The proposed process for evaluating the mechanical properties in the insole is highlighted, detailing the inputs and outputs of the insole. We highlight the existing contributions in state of the art, highlighting the findings in design, modeling, simulation, and tests in various scenarios and software specialized in FEA to evaluate technical characteristics in the insole.

The proposed research methodology is shown in Sect. 6. According to the model presented in Sect. 5, the phases for creating the 2D and 3D models are established from figures generated by a person's fingerprints. The modeling and meshing phases and the definition of FEA parameters are indicated, and finally, the performance of the tests in the simulator is detailed.

Section 7 analyses and discusses the research results, presenting the data obtained for the material's deformation applying different weights in the simulator. The effect of deformation on the material and its performance in regular use by the user is analyzed.

Finally, Sect. 8 presents the discussion and general conclusions of the study. The observed deformation in material and its effect on use, the benefits of the FEA technique in the insole modeling, and the ergonomic aspects are analyzed. It should be noted that PU material reinforced with nanoparticles has characteristics very similar to polyester PU for traditional insole, concluding that said modification does not affect its mechanical properties. In the same way, the scope and limitations of the research are highlighted, proposing future lines of research related to this research.

2 Characteristics of the Product to Be Designed

The feet are the part of the human body that presents a great effort to perform different daily activities, such as moving from one place to another and staying standing during some working day. Often, in the manufacture of footwear, designers do not consider the main characteristics of the feet to keep them healthy and in good condition, even if they influence a person's health. In this direction, a relevant project in industrial engineering is to elaborate a footwear insole such that a user has good comfort.

The evolution of footwear over time has allowed the incorporation of technologies that offer greater consumer comfort and produce less foot fatigue. Among the most widely used materials for insoles is PU foam, which has good physical properties such as low density, low water absorption, and good mechanical strength (Witkiewicz and Zielinski 2006).

One of the drawbacks of the continuous use of footwear is the generation of fungus, damage to the skin and nails. These conditions are known as ringworm and athlete's foot, familiar in young people with much physical activity, athletes, people with excessive sweating problems, and workers who must wear closed shoes for many hours during their working day.

Once the person has been affected by the activity of the fungus, it is not easy to cure, and constant care should be taken with the feet. It should be noted that a section of the population presents more risks in case of catching the disease. In the case of an individual who has some diabetes, their healing processes are even longer than that of an average person and require more rigorous care for the damage caused to the skin.

In the context of the above problems, this project worked with a PU material formulated for insole reinforced with silver nanoparticles. The literature has reported the latter for their inhibitory antifungal capacity and bactericidal effects in many antimicrobial activities.

Silver ions interact with the thiol groups of enzymes and proteins necessary for bacterial respiration and the transport of essential substances along the cell membrane. Within the cell, silver ions bind to the cell wall. Outside bacterial cells affecting them (Sadeghi et al. 2012), this biocidal capacity has also been analyzed in other microorganisms and bacteria (Pourjavadi and Soleyman 2011). However, the interest for the application case is its efficiency against fungi of the Trychophyton family, which are the leading cause of ringworm and athlete's foot.

Among the most used materials for insoles with therapeutic properties, we have Ethylene–vinyl acetate (EVA), Isoprene, Natural Rubber, Neoprene, PU, and Micro Cellular Rubber (MCR). PU's are polymers with urethane bonds, and the definition results in a wide variety of materials falling into their classification. Many PU's are used to create foam, including cushions for chairs and armchairs. In liquid form, PU is used as a paint or water sealant. Within its main properties, PU is a very flexible material that recovers its shape and is resistant to sweat, body oils, and detergents when stretched.

An attribute of interest is the capacity of the material for use with patients with plantar ulcers in diabetic patients and patients affected with Leprosy since they are damaged, which can lead to amputations. Therefore, studying the effect of the pressures planted (Paul et al. 2021).

In routine practice, patients with diabetes should be treated with special insoles to prevent ulcers, especially in neuropathic patients who lose sensation in their feet. An insole with appropriate support should help them to maximize the contact area and locally reduce high plant pressure and integral pressure over time when walking. If the prescribed insole is not shaped correctly and the foot structure cannot be balanced, the plantar soft tissues of the foot will be over-stressed and may develop ulcers with cumulative trauma disorders (Tsung et al. 2004).

During daily locomotive activities, the pressure of the plantar foot is the pressure field between the foot and the support surface. Information derived from such pressure measurements is crucial as it influences posture research and diagnosis of problems in the lower limbs, footwear design, sports biomechanics, and injury prevention (Abdul Razak et al. 2012). A variety of systems such as platform systems, in-shoe systems, plantar pressure sensors, among others, can be used for evaluation.

3 Polyurethane Insole Manufacturing Process

The chemistry of PU is based on isocyanate reactions with active hydrogen components. Isocyanates are compounds containing one or more of the highly reactive isocyanate groups (–N=C=O). This group reacts quickly with hydrogen atoms attached to atoms more electronegative than carbon (Beckerdite et al. 1997).

PU molded foam requires a cyclic process in which time is a crucial factor for productivity. A shot of the liquid polyol mixture is made, isocyanate, and catalyst on a mould with the shape you want the PU element to acquire (Mills 2007). PU systems for footwear can be based on polyether or polyester polyol, and these two systems have specific characteristics and depend on the required end-use.

Polyester systems are more reactive since they are solid at room temperature and must be heated before use (Karkalic et al. 2017). The system used for PU insoles is based on polyester polyol.

Figure 1 shows the manufacturing process of the PU insole. The high production process is commonly carried out on rotating machines with several moulds mounted on several supports. This system favors giving the curing time in the material when the engine turns.

Preparation of the injection machine includes reviewing the pipes for polyol and isocyanate and reviewing the process parameters. Initial tests to verify the quality of the foam supported by an indent meter and visual inspection of the material after skimmed to verify uniformity on its surface. The next step is to calibrate process parameters, such as the temperature of the material tanks, temperature of the moulds, the speed of firing, and the material flow must be checked, which will depend on the size of the insole to be processed. On some machines, parameters can be programmed according to the mould being worked, allowing different sizes and models to be worked during the working cycle. Some test shots of the mixture are made in small cups to observe the skimming quality and perform an indentation test to calibrate the equipment.

Applying the special release agent for PU material is necessary to prevent the material from sticking to the mould, breaking, or burning once the curing process is completed. The purpose of the process is to apply a resistant and semi-permanent film to the mould. Sometimes there are droplets of the release agent on the surface, which can generate bubbles in the insole, so it is necessary to clean the excess with tow or flannel before emptying the PU mixture into the mould.

Figure 2 shows the initial section of the PU insole manufacturing process. The position of the two tanks for polyol and isocyanate is observed, which are kept rotating the material heated to an internal temperature of 60 °C. The mixture of polyol and isocyanate is made in the trigger, in which we have a small mixing cone that rotates at a speed of 8000 rpm. The mix of polyol and isocyanate is made in the trigger, in which we have a small mixing cone that rotates at a rate of 8000 rpm.

Once the process parameters are calibrated, the mixture is poured into moulds by moving with the trigger to distribute the mix along with the mould; the foaming reaction begins about 20 s later.

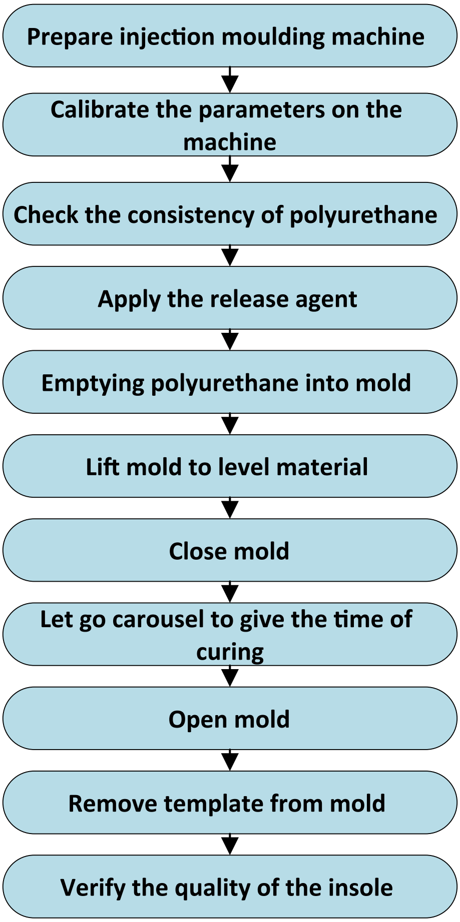


Fig. 1 Industrial PU insole manufacturing process

The curing process is usually carried out when moulds are moving from the closure of the mould from emptying to the moulding. The average curing time is 4 min in which the mould pressure and temperature interact with the polyol and isocyanate mixture. In this step, the material acquires the shape of the mould that contains it, the material is strengthened, and its elastic properties are maintained.

The removal process should be done carefully, as the insole is left with excess on the edges that tend to stick to the mould. If you want to remove the insole quickly and forcefully, you can break into the bites, which results in a waste of material. It is recommended to use wooden elements to support yourself when taking off the edges of the insole and removing it correctly from the mould.

Finally, an inspection of the insole should be carried out. Sometimes, there will be observable defects in the material, such as burns, bubbles, broken areas, excess material, lack of weight, wrong colour, raw, etc. It is recommended an inspection

Fig. 2 The initial phase of the PU insole manufacturing process

by attributes in which the above criteria are established for an adequate quality classification in the insole. The batch is carried out to move on to the following processes.

4 Technical Characteristics in the PU Insole

Among the technical characteristics presented by an elaborate PU insole, it is noted that it is a material of great adaptation because it can be used in various weight conditions in the person, humidity, temperature, physical condition of the foot, and the presence of diseases.

It has excellent absorption and shock absorption capacity, which helps the user in stress conditions on the material. Continuous daily use, use in sport's shoes, and carrying out activities in which cushioning is required, such as running, climbing, descending stairs, jumping, and walking, also affect the person's weight factor.

Low residual deformation, which implies that after the application of the loads and impacts, it is observed that the material presents good "memory" and can return to its original form to have a good life of use in the product. This study aims to simulate load conditions with different weights on the insole to evaluate the amount of deformation in the insole under regular use.

The PU insole gives maximum comfort to the user, which refers to the pleasure or comfort experienced by the insole due to the material conditions that provide them well-being or comfort. It is a critical aspect with people who have delicate feet or who need to be treated for a disease like diabetes and leprosy.—minimizing the friction between the foot and the footwear to avoid the appearance of blisters.

The maximum energy absorption in sports where jumps are frequently repeated is essential to the shock absorption capacity and the stabilization of the ankle to protect it from sprains. During the jump's landing, the energy from the impact against the ground is transmitted to the ankle and hip, so good cushioning will prevent injuries in these joints.

The PU insole presents optimal sweat management since it maintains its properties in the face of excessive foot sweating and high temperatures within the footwear. Therefore, it is also advisable to use it in sports activities and jobs in which work shoes or gardening boots should be used.

PU has good resistance to bacterial and fungal growth. The material used in this project is a PU reinforced with silver nanoparticles, which improves the resistance property, including a biocide agent that inhibits the growth of fungi that cause more damage to the foot, as is the case of the Trychophyton family.

5 Literature Review on FEA Insole Modeling

The analysis process followed in this research is illustrated in Fig. 3. The objective is to integrate the design and modeling phases into two software that represent the

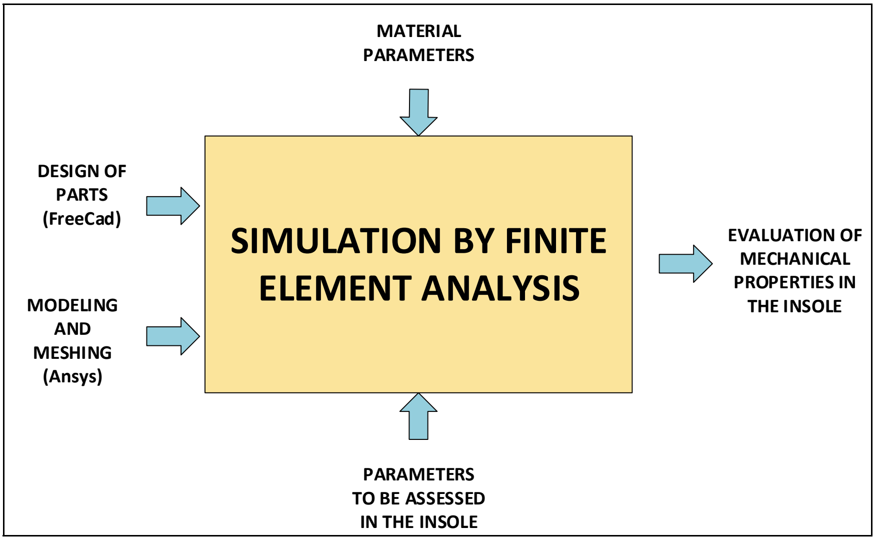


Fig. 3 Outline of the analytical process to be followed

initial inputs to generate the FEA simulation. The material parameters are required and the parameters to evaluate in the insole, rendering the desired output of the process, which is the evaluation of mechanical properties in the insole.

FEA techniques and the design of parts will simulate the deformation to which the material is subjected when used by users of different weights. The analysis will allow knowing the material's behavior in typical conditions of use, as it is when a person is standing and when the foot is bent. It is considered that this deformation that receives the material at the time of receiving the load helps the comfort and impact absorption conditions. In addition to that, the material will have low residual deformation after removing the loads acting on it.

Within state of the art for the simulation of the effect of the insole material on the plant pressure, Healy et al. (2011) published a study on the analysis of the characteristics of orthosis materials in the prevention of ulcers for people with diabetes. Tests were carried out with PU and EVA materials in ten healthy participants; pressure sensors were used inside the footwear.

Nouman et al. (2017) presented a similar study with a sample of 16 neuropathic diabetic patients with callosity and hallux valgus. The evaluation was performed with the total contact orthosis method. Within the research of plantar pressure and diabetic foot syndrome, Korada et al. (2020) submitted a systematic review on the topic.

Lin and Chen (2015) used 3D scanning techniques as a proposed change in the manufacturing system to evaluate ergonomic aspects in the design of women's footwear. Taha et al. (2016) applied FEA techniques in a human foot model to model dynamic behavior and internal load conditions during a neutral stand on flat ground, using Solid Works® and ANSYS®.

Shariatmadari (2009) performed an FEA modeling in high-density EVA material to analyze the interaction between the foot and the shoe with both models under the standard ASTM D575-91. The simulation was executed in the software ABAQUS®. Li et al. (2019) applied FEA techniques to construct footwear and footwear coupled model to run barefoot with the use of ABAQUS® software and a prediction model.

Cheung et al. (2009) presented a study on the current methods used in computer-aided engineering for shoe design in biomechanical studies for footwear, with foot and 3D footwear modeling applications using various software for FEA. Nouman et al. (2021) applied the FEA to analyze the effects of an insole to measure friction stress and contact pressure in the diabetic foot with neuropathy. The model was performed in the ANSYS® software.

Braun and Baritz (2017) presented an FEA modeling with ANSYS® for shoe insole components for foot and walking simulation. The insole analyzed is made up of several parts. Costea et al. (2012) used an FEA model with the DELCAM® software with a material combination procedure to obtain a sole and insole complex with different thicknesses.

Lee & Lee (2014) presented FEA modeling in a reinforced PU-based material for construction structures in the ABAQUS® software.

Luo et al. (2011) published research on FEA 3D modeling for a heel pad insole for reducing pedal tissue trauma.

Mahesh and Ramachandran (2018) applied FEA techniques to model a functionally graduated PU to create material by varying the properties of one material to another with a specific gradient in the application of diabetic footwear. The simulation was performed in the ANSYS® software.

Ghassemi et al. (2015) presented a proposal for creating a novel sole for reducing pressure in the diabetic neuropathic patient's foot using matter: silicone gel, foam plastazote, polyfoam, and EVA. The simulation was carried out in the software ABAQUS®.

6 Methodology

The research methodology is shown in Fig. 4. The process for modeling and simulation begins with the 2D trace for the base points in the insole. An insole is then scanned to integrate the strokes and nodes that detail the item. The next step was to develop the tests in the simulator. It is necessary to know an estimated area of contact of the foot with the material's surface at the time of stepping, which was done with the stroke of a person's foot on a tabloid.

The figure's outline was drawn on the FreeCAD® software integrating into the previous method of the insole to generate an area of the material with the shape of the foot and density of the material, which supports loads in the insole.

Once the model was obtained, creating Mesh in ANSYS® software according to the material's properties was performed. Finally, simulations were made with various weights of the person evaluating the efficiency of the insole before the load was received.

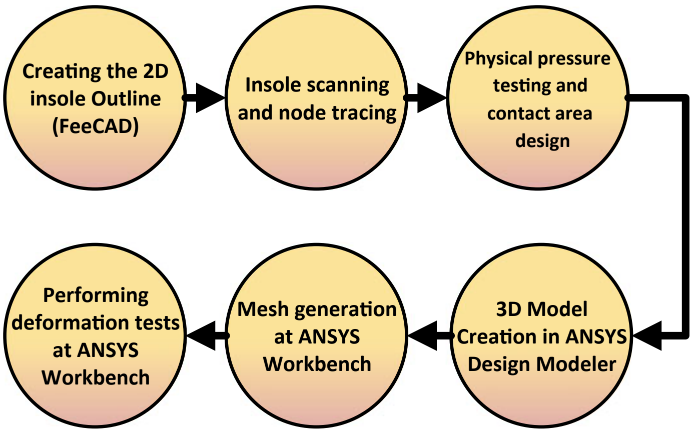


Fig. 4 Research methodology

FreeCAD presents a working environment like CATIA®, SolidWorks®, SolidEdge®, ArchiCAD® or Autodesk® Revit. The program uses parametric modeling techniques and is equipped with modular software architecture, and the software allows adding functionalities without the need to modify the system kernel.

Unlike traditional CAD software, FreeCAD is a parametric CAD that uses parameters to define its limits or actions. Under this approach, FreeCAD uses a parametric design. Each element is treated as an object determined by its spatial coordinates and parameters, being these graphs or functional.

The use of FreeCAD in the methodology is very favorable. It allows to properly model the area and outline of the insole in 2D, which can adequately replicate the details of the insole without the need to use a 3D scanner.

The ANSYS® DesignModeler application is designed to be used as a geometry editor for existing CAD models. The application is based on a solid modeling design with parametric features. The software allows you to intuitively start drawing 2D sketches, modeling 3D parts, or work with 3D CAD models previously made in other software for engineering preprocessing analysis.

Ansys® Workbench is a software platform that creates FEA analysis projects for different disciplines. Workbench allows the simulation in engineering to be displayed graphically, establishing the relationships between physical phenomena, including various variables.

The proposed methodology will make it possible to evaluate the deformation in the insole considering the contact area of the foot. By tread tests, the measurements of contact were obtained in two scenarios: when the person is standing and when the foot bends, simulating the most common positions of the foot on the insole.

The objective is to model the contact area of the foot on the insole material and apply the load exerted by people of different weights. The simulation results shall permit the evaluation of the deformation to which the insole is subjected in regular use.

6.1 Modeling the Insole in 2D

The traces of geometric elements related to the shape of the insole were made with the FreeCAD® Sketcher option to define an initial outline of the insole. Using the B-Spline tool by control points was outlined the sides of the insole, the software allows the tracking of arcs concerning the previously bent points, achieving the 2D model of the insole as shown in Fig. 5.

Insole modeling began with a box to measure the length and width of the insole. The top and bottom of the insole were drawn, arcs in the insole were defined with the help of circles. Finally, a detail was made to eliminate leftovers in design.

Using the B-Spline tool by control points, a stroke was made on the sides of the insole. The tool allows generating curvature concerning the points defined initially, completing the trace of the part in 2D.

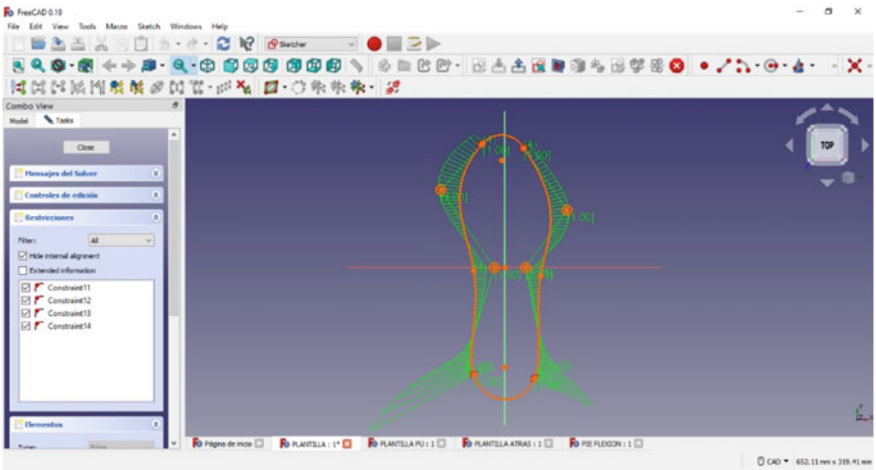


Fig. 5 Outline of the insole in 2D with FreeCAD® software

6.2 *Insole Scanning and Node Tracing*

For this procedure, one of the insoles obtained with the PU material reinforced with silver nanoparticles was used with a mould for the orthopedic insole used for the diabetic foot with a typical design. Once the insole was scanned, the image was imported into software CorelDraw® to obtain a layout close to the previous 2D design.

CorelDraw® software allows you to import the scanned image. Using nodes, you can trace the outline of the insole. The contour tracing phases and the details of the insole are observed from the outside area to the elements and attributes presented by the insole based on the mould used.

The node stroke allows the contour of the physical reference insole to be replicated appropriately. By using the format. svg proceeded to export the model to the FeeCAD program. The design generated in this phase is already closer to the previous 2D design.

Figure 6 illustrates the back of the insole. The drawing containing the insole physical has also been replicated and helped maintain its stability inside the shoe. With these steps, the modeling of the insole in 2D has been completed, and the base model has been constructed for its preparation for the modeling in 3D.

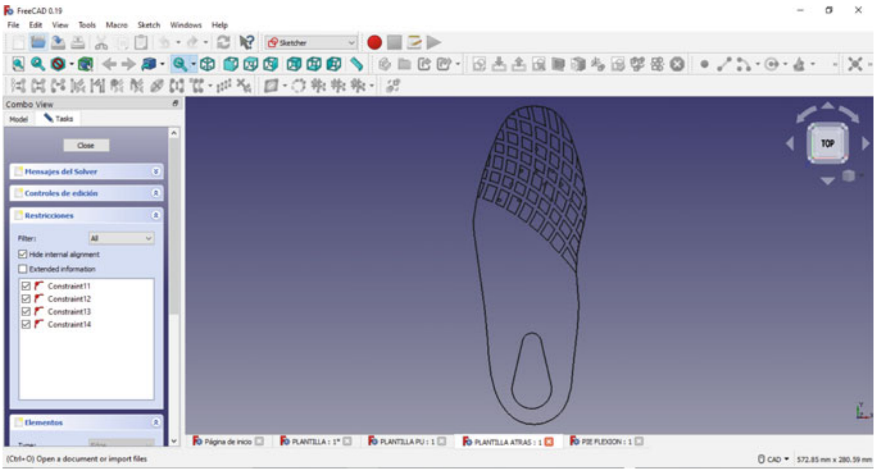


Fig. 6 Back part of the insole design

6.3 Physical Foot Pressure Tests

To model the contact area of the foot with the insole in a more precise and ergonomic way, we proceeded to draw the contact area of a person's foot by using black paint and a tabloid. The procedure's objective is to paint the sole on the paper to more accurately model the pressure generated by the foot on the insole. Figure 7 shows three plantar pressure tests.

The following materials were used to perform pressure tests in physics: black paint, tabloid paper Couche. We painted the sole with black paint to capture different pressures on paper with the foot. The purpose of obtaining the area of contact pressures is to use it for FEA modeling in deformation tests.

Fig. 7 Plantar pressure tests on the tabloid

Once we obtained the sample of the foot in standing position and the sample of the foot flexed, we realized the 2D models of contours in the software FreeCAD® with the same methodology with 2D modeling.

The 2D parts in the FreeCAD software were designed with the same methodology as for the insole and the same elements in the stroke. It began with the trace of the footprint with the flat foot, which is shown in Fig. 8.

Next, the 2D flexed footprint was modeled, as shown in Fig. 9. After completing the 2D models for the PU insole and the digitized fingerprints, we made them in

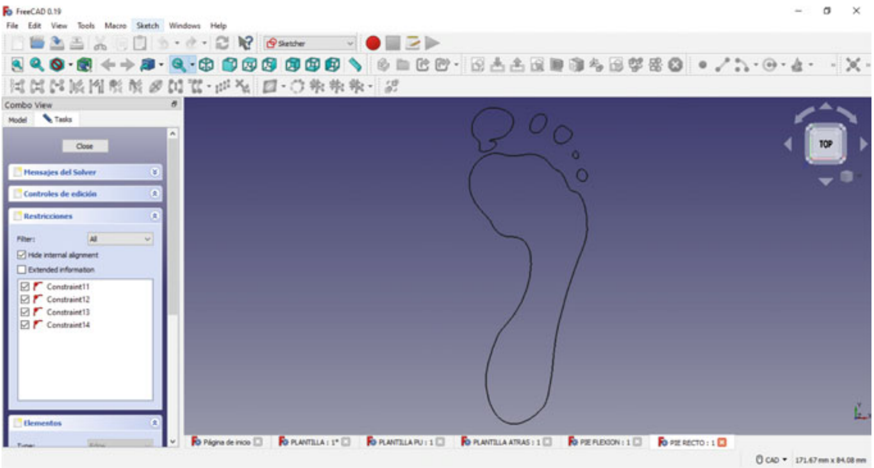


Fig. 8 2D footprint design in a stationary position

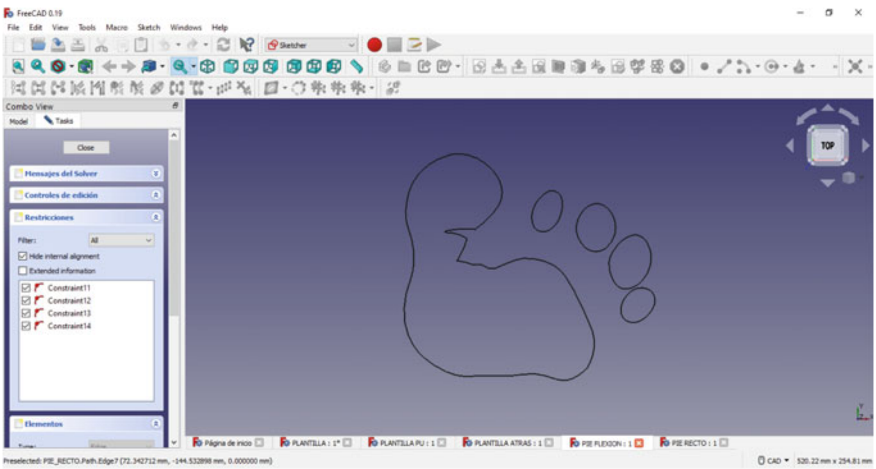


Fig. 9 2D design of the flexural footprint

3D by employing the ANSYS® Workbench software. The 3D modeling was carried out to simulate the properties of the material and its performance under operating conditions.

6.4 Creation of 3D Models

The insole parts and footprints were exported to the ANSYS® Workbench software with the tools of the "Static Structural" option in which static analysis can be performed for solid models. Once imported, the pieces made in the software FreeCAD® with the option to import- Geometry, opening the corresponding components. A 3 mm extrusion was made according to the shape of the physical insole.

The Static Structural module of the Workbench selects the "geometry" option for 3D modeling. Entering the submenu with right-click, select the option Geometry in Design Modeler. The modeling space is visualized, and the pieces made in the FreeCAD® software are imported. The PU insole imported the file and selected the import option to open the part.

We proceed to extrude the part to 3 mm. Based on the original design of the insole, we move to include details, such as breathing holes, which are also extruded internally, replicating the actual shape of the insole.

The same insole was made an oblique cut to give an angle or fall in the insole based on the original design. Since it is observed that the insole tends to have a greater volume in the heel, this is reduced as it reaches the tip of the fingers, replicating the design detail.

The designs of the footprints were also imported into ANSYS® Workbench software to integrate the weight parameters to simulate the deformation and effort generated in the insole. The extruded model of the foot flexed is shown in Fig. 10.

The 2D trace of the prints previously made in FreeCAD® is imported into space geometry in the design modeler to make the part in 3D, following the same procedure used in the insole. A neutral value is left for extrusion since people's weights will be added later.

6.5 Mesh Generation and Definition of Parameters in the Material

To create the solid in ANSYS®, we used the module "Model" to make the Mesh through the option Mesh- Generate Mesh, selecting the whole piece and obtaining the models shown in Figs. 11 and 12.

Meshing is a part of the engineering simulation process in which complex geometries are divided into simple elements that can be used as discrete local approaches

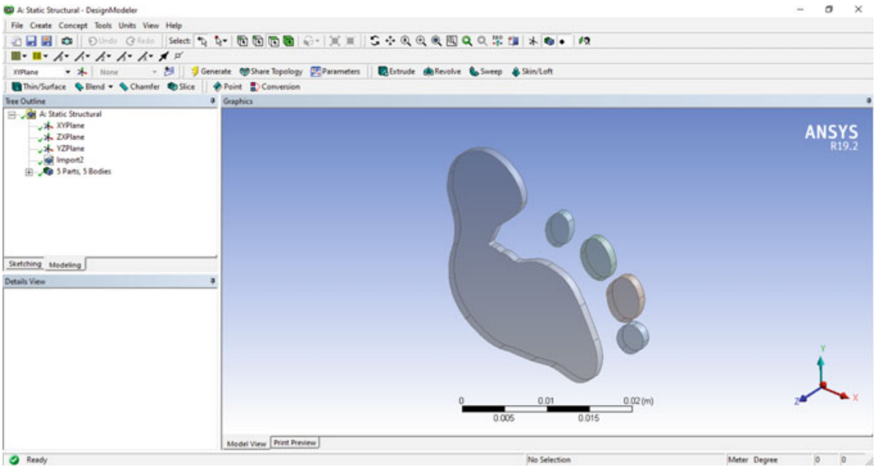


Fig. 10 3D flexed footprint at ANSYS®

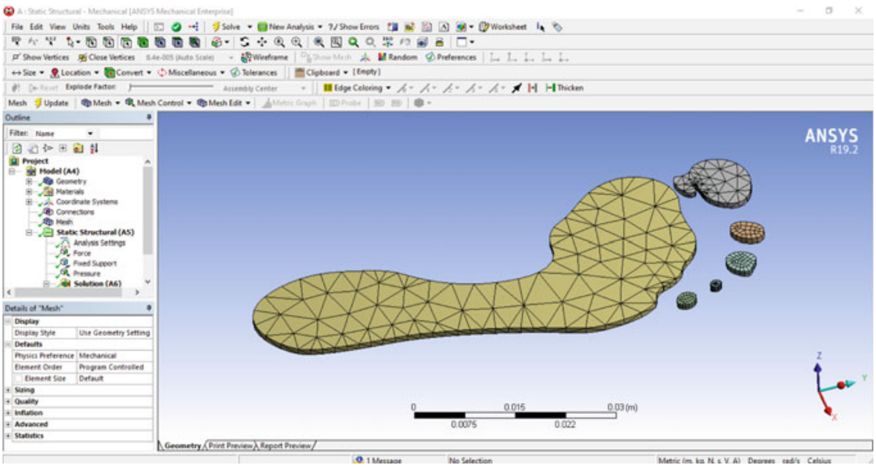


Fig. 11 Footprint meshing in a 3D stationary position

to the larger domain. The Mesh influences the accuracy, convergence, and speed of the simulation. In addition, as Mesh often consumes a significant part of the time needed to obtain simulation results, the better and more automated the mesh tools are, the faster and more accurate the solution will be.

ANSYS® provides high-performance, automated and intelligent general-purpose mesh software that produces the most appropriate Mesh for precise and efficient multi-physical solutions, from an easy and automatic mesh to a very elaborate mesh (Ansys 2021).

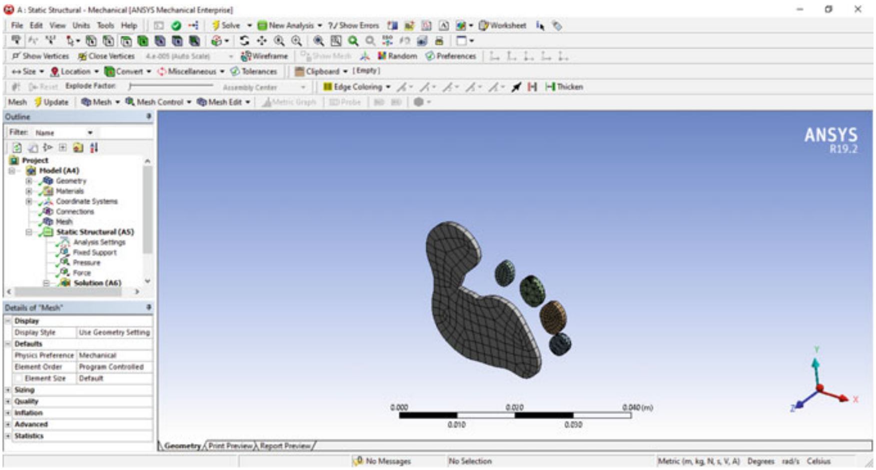


Fig. 12 3D flexed footprint meshing

Once we have meshing pieces, we prepare the insole with generated values. Fixed support is given in the module. This will be a lower part, flat foot, and bent foot simulating. This is the insole area that supports the effort. The procedure is performed by selecting the faces at the bottom.

3D models for the footprint and the footprint with flexed feet replicate the contact area of the foot on the volume of the material with which they make contact in the tread. These areas are where the stress and deformation are performed during the use of the insole and will allow a more accurate evaluation of the average deformation to which the PU material reinforced with silver nanoparticles is subjected.

The next step is to define the material parameters for the simulation in ANSYS® Structural- Mechanical. The required parameters are the Young modulus, Poisson coefficient, density, bulk, and shear modulus.

The Young modulus is a parameter that characterizes the behavior of an elastic material, depending on the direction in which a force is applied. It is one of the most used methods to know the elasticity of a material. The Young modulus has the same tensile value as compression for a linear and isotropic elastic material. It is a stress-independent constant provided it does not exceed a maximum value called the elastic limit. For the material used, the Young modulus was set at 4.53.

The Poisson coefficient is an elastic constant that measures the narrowing of a section of a linear and isotropic material when stretching longitudinally and thinning in the directions perpendicular to the stretching. For the material used, the Poisson coefficient was set at 0.32.

Density is a scalar magnitude that allows measuring the amount of mass that is in each volume of the substance. It is calculated by dividing the mass of the material by the volume, which indicates that the smaller the volume occupied by a given mass, the greater the density. Based on the foam-type PU material conditions, a relatively low-density value is determined at 62 kg/m^3.

Table 1 Properties of the material in the simulation

Material	Young modulus (Mpa)	Poisson's ratio	Density (Kg/m^3)	Bulk modulus (Pa)	Shear modulus (Pa)
PU reinforced with silver nanoparticles	4.53	0.32	62	3.70E05	1.51E05

Values used in the simulation software

The bulk modulus of a substance is a measure of how resistant to compression it is. It is defined as increasing the infinitesimal pressure coefficient to the resultant relative decrease in volume. For the material used, the value is 3.70^5 Pa.

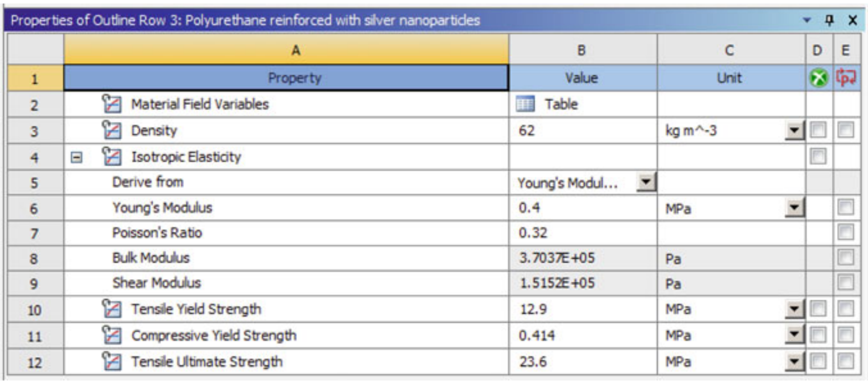
The shear modulus is a numerical constant that describes the elastic properties under the application of internal transverse forces. For the material, a value of 1.51^5 Pa was used.

The summary of parameters used for the definition of the material is given in Table 1.

The parameters of the material were programmed (Fig. 13). In pieces with meshing, the load analysis on the material is carried out, which is evaluated with the module "Force". The objective is to assess the force applied on the insole according to the person's weight, for which several weights were taken and evaluated according to Eq. (1).

$$F = w \cdot g \tag{1}$$

ANSYS® allows the selection of predefined materials in a database. For the analysis case, the option of defining a new material according to the parameters



Properties of Outline Row 3: Polyurethane reinforced with silver nanoparticles

	A	B	C	D	E
1	Property	Value	Unit		
2	Material Field Variables	Table			
3	Density	62	kg m^-3		
4	Isotropic Elasticity				
5	Derive from	Young's Modul...			
6	Young's Modulus	0.4	MPa		
7	Poisson's Ratio	0.32			
8	Bulk Modulus	3.7037E+05	Pa		
9	Shear Modulus	1.5152E+05	Pa		
10	Tensile Yield Strength	12.9	MPa		
11	Compressive Yield Strength	0.414	MPa		
12	Tensile Ultimate Strength	23.6	MPa		

Fig. 13 Values used in the simulation software

mentioned above was used. In addition, isotropic linear properties, elastic properties, thermal expansion, friction coefficients, electromagnetic properties, conductivity, among others, can be included. The properties defined in the material will significantly affect the simulation of the material's mechanical properties.

Where F is the force applied in the insole, w is the weight of the person or user, and gravity is a constant with a value of 9.81 m/s^2. Finally, the "Pressure" module is added, which represents the pressure that exists on the insole, for which the average value of the atmospheric pressure of 101,325 Pa on the Z-axis is taken as a reference of the pressure towards the bottom of the part, all faces of the part are selected to apply this value.

7 Results

Thirteen values were taken for the weight fluctuating between 60 and 120 kg to evaluate the deformation in the insole material. The force calculations for each proposed weight were loaded into the ANSYS® simulator in the Static Structural—Force module. The system was subsequently resolved for each force value concerning the analyzed weights. As an example, Fig. 13 shows the simulation's behavior for a person of 120 kg with a force of 1177.2 N. The effect is shown in Fig. 14 to observe the effect of the force in the material.

Simulations can be animated at a time determined by the user. The example was done in lapses of a second, in which you can observe how the footprint sinks into the material and how the material returns to its original form once the load on it is removed. The simulation also yields three results obtained in the simulation: The minimum deformation, the average deformation, and the maximum deformation. The average deformation is a good indicator of the effect of deformation in the contact area of the foot with the insole.

It is observed that the material of the insole is soft and tends to deform in contact areas of the foot and fingers. For all cases, it is observed that the maximum deformation can exceed the thickness of the insole. The insole improves grip and cushions

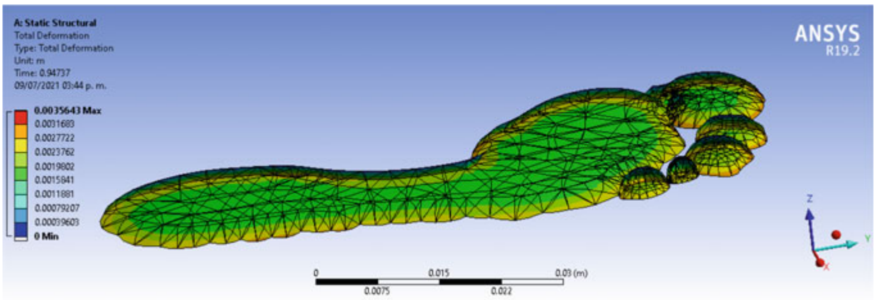


Fig. 14 Simulated stationary flat foot force applied in time 0.95 s

Table 2 Simulation results for insole deformation in standing position

Weight of the person (Kg)	Gravity (m/s2)	Force (N)	Minimal deformation (m)	Average deformation (m)	Maximum deformation (m)
60	9.81	588.60	0	0.0006848	0.0019487
65	9.81	637.65	0	0.0007319	0.0020833
70	9.81	686.70	0	0.0007792	0.0022181
75	9.81	735.75	0	0.0008265	0.0023526
80	9.81	784.80	0	0.0008738	0.0024872
85	9.81	833.85	0	0.0009211	0.0026219
90	9.81	882.90	0	0.0009684	0.0027565
95	9.81	931.95	0	0.0010157	0.0028911
100	9.81	981.00	0	0.0010631	0.0030258
105	9.81	1030.05	0	0.0011103	0.0031604
110	9.81	1079.10	0	0.0011576	0.0032951
115	9.81	1128.15	0	0.0012049	0.0034297
120	9.81	1177.20	0	0.0012522	0.0035643

impact, as well as helping to distribute weight and balance back and hip. It also helps the foot to adapt to the shoe. Table 2 shows the results obtained for the simulation of the effect of the applied forces on the material about the proposed weights.

In average deformation, values fluctuate between 0.6 mm and 1.2 mm, within the insole thickness. Analyzing the PU insole in physics, it is observed that the results make sense since it is a soft material that tends to take the shape of the weight that it has on top. By removing the load on the insole, it tends to resume its initial form, showing good memory and almost no residual deformation, so it is considered that the simulator adequately replicates the material's behavior.

An additional observation is that the insole performs well at high weights such as 115 and 120 kgs. The deformation enters acceptable levels, and only in the maximum deformation values are observed that may exceed the thickness in the insole. Under natural conditions, the other elements in the shoe will be absorbed as with the midsole, heel insole, plant, sole, and heel, so that the impacts will be absorbed by the footwear properly.

The pressure and the force behavior that occurs in the material is linear as the weight of the person increases the deformation in the material at the time of applying the force. The following analysis is given with the flexed foot model to verify if there is a significant difference based on the contact area of the foot when taking this position.

Figure 15 illustrates the simulation of the load on the insole at different times. The foot's position tends to deform the insole more than when the person is in a standing position with the foot flat. Table 3 shows the results obtained in the simulation for each of the selected subjects.

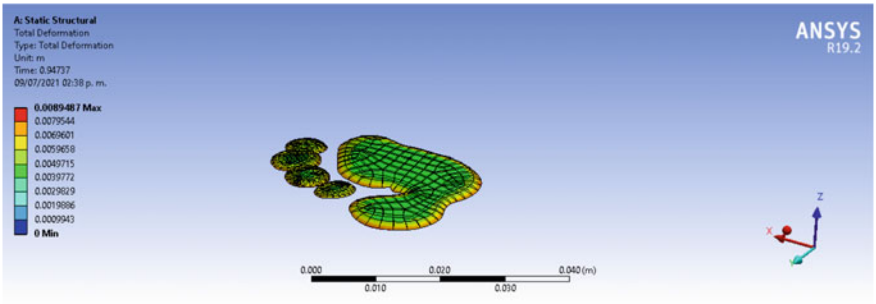


Fig. 15 Bending foot simulation of force applied in time 0.9 s

Table 3 Simulation results for insole deformation in bent foot position

Weight of the person (Kg)	Gravity (m/s^2)	Force (N)	Minimal deformation (m)	Average deformation (m)	Maximum deformation (m)
60	9.81	588.60	0	0.0015756	0.0044754
65	9.81	637.65	0	0.0017068	0.0048482
70	9.81	686.70	0	0.0018381	0.0052211
75	9.81	735.75	0	0.0019693	0.0055938
80	9.81	784.80	0	0.0021008	0.0059665
85	9.81	833.85	0	0.0022318	0.0063393
90	9.81	882.90	0	0.0023631	0.0067121
95	9.81	931.95	0	0.0024943	0.0070849
100	9.81	981.00	0	0.0026255	0.0074576
105	9.81	1030.05	0	0.0027567	0.0078304
110	9.81	1079.10	0	0.0028881	0.0082032
115	9.81	1128.15	0	0.0030192	0.0085761
120	9.81	1177.20	0	0.0031504	0.0089487

The results obtained from the average deformation range from 1.5 mm to 3.1 mm, so the values in the maximum deformation are reported in levels between 4.4 mm to 8.9 mm when the foot takes this position. It tends to receive more deformation since it is a bit contact area, and however, the contact time is also less.

In comparison with the results obtained with the footprint tests in the standing position, it is observed that, in general, the insole receives a more significant deformation and effort when the foot takes the bending place. It is based on the contact area that covers the foot in this position, which is noticeable in the person's walking and in the wear that shows the footwear on the sole after a specific time.

As in the case of the footprint in the stationary position, the excess deformation in the insole area will also be absorbed by the other elements in the footwear to reduce the impacts when stepping, jumping, etc.

It is noticeably observed a more significant deformation of the insole when it takes the shape of a bent foot, which depends on the area of the foot that is in contact with the insole in each of the cases. In the same way, as in the case of the flat foot and stationary position, the deformation increases linearly as the person's weight increases. It is considered that the simulation results are reliable and attached to reality since an insole of this material tends to be soft to contact but with good resistance.

The pressure and the force behavior in the material are linear as the weight of the person increases the material's deformation when applying the force.

Studies for the two types of footprints show that applied force and deformation behavior are linear, indicating that there will be more deformation as more weight is applied to the insoles. The material has good elastic properties and low residual deformation, so such temporary deformations will help improve the foot's stability under normal conditions and provide cushioning to the foot when contacting the floor, adequately absorbing the energy received in the footprint.

8 Discussion and Conclusions

For the analysis case, it was observed that the insole has good behavior in regular use. The material absorbs the user's weight. It tends to deform when applying the load, but it will retake the initial form after using it. The properties of PU make it a good material for use by people with delicate feet and can be the solution to many different ailments.

The deformation of the material makes it possible to provide good cushioning, allow displacement, and maintain balance. The elastic memory of the material allows it to recover its original shape after use, so the durability of the product represents another advantage for the user compared to other types of materials.

It is noted that the simulation can adequately replicate the behavior of the materials in the insole. It is noted that in some cases, the deformation may exceed the thickness of the insole. Still, it should be recalled that the insole will be accompanied by other materials both on top with covers of some textile materials, as in the lower part as are the heel, the plant, midsole, and the sole. The combination of all the footwear components provides the necessary protection to the user and can adequately absorb the loads generated by the user.

Computational simulation is widely used in companies in the product design phase to analyze, improve and predict the behavior of products. There is various software for the simulation of the behavior of materials under various mechanical conditions. The method used by the software is based on the FEA, which allows obtaining answers for different engineering problems.

The geometry of the part subject to loads and constraints is subdivided into smaller pieces known as elements, representing the continuous domain of the problem. The division of geometry into small pieces solves a complex problem by subdividing it into more straightforward problems, allowing the computer to perform tasks more efficiently.

The method proposes that an infinite number of unknown variables be replaced by a limited number of elements with well-defined behavior. The number of factors is fixed and takes its name from "finite elements" connected by points called nodes.

In this chapter, computation options were analyzed within the product delivery stage, particularly at the point of development of new products, testing, and simulation in an insole of a nanoparticle-reinforced PU material that attributes antifungal properties to it. FreeCAD® software is presented as an excellent free choice for computer-aided design activities with features like their cost competitors.

The ANSYS® software is one of the most used and robust systems for the simulation of mechanical properties in materials and products, representing one of the essential tools applied in the industry. The use of these software means a pathway for quality assurance in products.

The scope of this study was limited to the analysis of deformation to insole material is subjected when standing and foot bent. The research presents essential areas of opportunity and can be extended to more complex studies such as analyzing dynamic stress conditions on the workforce in regular use, walking, and sports activities.

It is essential to add in the simulation with FEA the temperature and humidity conditions presented in the daily use of the footwear and its impact on the deformation of the insole. Another critical factor is the time of use of the insole under natural conditions to assess residual deformation in the material after a certain period of use.

The use of sensors and software platforms for baropodometric and biomechanical analysis allows multiple dynamic and static studies to extend the scope of research to evaluate the effects of foot pressures, overload points, and possible joint damage. The above is to design more efficient antifungal orthopedic insoles with more significant benefits for end-user.

It is desirable to study people with sensitive feet due to diabetes, Leprosy, among others. Since it is a particular segment of potential users, it is necessary to focus efforts on the generation of insoles that help them take care of their skin and maintain comfort when they use footwear in their daily activities.

References

Abdul Razak, A.H., Zayegh, A., Begg, R.K., Wahab, Y.: Foot plantar pressure measurement system: a review. Sensors (Switzerland), **12**. Sensors (Basel) (2012). https://doi.org/10.3390/s120709884

Ansys: Simulation Software—ANSYS Meshing—ANSYS—meshing enginery (2021)

Beckerdite, J., Herrington, R., Hock, K., Company, D.C.: Flexible polyurethane foams. Dow Chemical Company, Dow Plastics (1997)

Braun, B., Baritz, M.: FEM modelling of shoes insoles components for standing and walking simulation. MATEC Web of Conferences, vol. 94. EDP Sciences (2017). https://doi.org/10.1051/matecconf/20179401002

Cheung, J.T.M., Yu, J., Wong, D.W.C., Zhang, M.: Current methods in computer-aided engineering for footwear design. Footwear Sci. **1**, 31–46 (2009). https://doi.org/10.1080/19424280903002323

Costea, M., Mihai, A., Bilalis, N.: Finite element analysis for insole-sole prototypes. In: Proceedings of the 4th International Conference on Advanced Materials and Systems, ICAMS 2012 (2012)

Ghassemi, A., Mossayebi, A.R., Jamshidi, N., Naemi, R., Karimi, M.T.: Manufacturing and finite element assessment of a novel pressure reducing insole for Diabetic Neuropathic patients. Australas. Phys. Eng. Sci. Med. **38**, 63–70 (2015). https://doi.org/10.1007/s13246-014-0319-0

Healy, A., Dunning, D., Chockalingam, N.: Effect of insole material on plantar pressure. Footwear Sci. **3** (2011). https://doi.org/10.1080/19424280.2011.575804

Karkalic, R., Radulović, J., Jovanovic, D.: Characteristics of polyurethane and elastomer parts for shoe industry produced by liquid injection molding technology. Vojnotehnicki Glasnik **65**, 948–967 (2017). https://doi.org/10.5937/vojtehg65-10543

Korada, H., Maiya, A., Rao, S.K., Hande, M.: Effectiveness of customized insoles on maximum plantar pressure in diabetic foot syndrome: A systematic review. Diabetes Metabolic Syndrome: Clin. Res. Rev., **14**. Elsevier Ltd. (2020). https://doi.org/10.1016/j.dsx.2020.06.041

Lee, C.S., Lee, J.M.: Failure analysis of reinforced polyurethane foam-based LNG insulation structure using damage-coupled finite element analysis. Compos. Struct. **107**, 231–245 (2014). https://doi.org/10.1016/j.compstruct.2013.07.044

Li, Y., Leong, K., Gu, Y.: Construction and finite element analysis of a coupled finite element model of foot and barefoot running footwear. Proc. Inst. Mech. Eng. Part P: J. Sports Eng. Technol. **233**, 101–109 (2019). https://doi.org/10.1177/1754337118803540

Lin, L.Y., Chen, C.H.: Innovation and ergonomics consideration for female footwear design. Procedia Manufacturing **3**, 5867–5873 (2015). https://doi.org/10.1016/j.promfg.2015.07.891

Luo, G., Houston, V.L., Garbarini, M.A., Beattie, A.C., Thongpop, C.: Finite element analysis of heel pad with insoles. J. Biomech. **44**, 1559–1565 (2011). https://doi.org/10.1016/j.jbiomech.2011.02.083

Mahesh, C.C., Ramachandran, K.I.: Finite element modelling of functionally graded elastomers for the application of diabetic footwear. Mater. Today: Proc., vol. 5. Elsevier Ltd. (2018). https://doi.org/10.1016/j.matpr.2018.05.133

Mills, N.: Polyurethane Foams: Processing and Microstructure. Elsevier, Polymer Foams Handbook (2007). https://doi.org/10.1016/b978-075068069-1/50003-9

Nouman, M., Dissaneewate, T., Chong, D.Y.R., Chatpun, S.: Effects of custom-made insole materials on frictional stress and contact pressure in diabetic foot with neuropathy: results from a finite element analysis. Appl. Sci. **11**, 3412 (2021). https://doi.org/10.3390/app11083412

Nouman, M., Leelasamran, W., Chatpun, S.: Effectiveness of total contact orthosis for plantar pressure redistribution in neuropathic diabetic patients during different walking activities. Foot Ankle Int. **38**, 901–908 (2017). https://doi.org/10.1177/1071100717704427

Paul, S., Kumar, D.P., Siva, B.: Material analysis for therapeutic insoles—a short report. Lepr. Rev. **92**, 75–81 (2021). https://doi.org/10.47276/lr.92.1.75

Pourjavadi, A., Soleyman, R.: Novel silver nano-wedges for killing microorganisms. Mater. Res. Bull. **46**, 1860–1865 (2011). https://doi.org/10.1016/j.materresbull.2011.07.040

Sadeghi, B., Garmaroudi, F.S., Hashemi, M., Nezhad, H.R., Nasrollahi, A., Ardalan, S., Ardalan, S.: Comparison of the anti-bacterial activity on the nanosilver shapes: Nanoparticles, nanorods and nanoplates. Adv. Powder Technol. **23**, 22–26 (2012). https://doi.org/10.1016/j.apt.2010.11.011

Shariatmadari, M.R.: Finite element analysis into the foot—footwear interaction using EVA footwear foams. IFMBE Proceedings, vol. 23. Springer, Berlin, Heidelberg (2009). https://doi.org/10.1007/978-3-540-92841-6_404

Taha, Z., Norman, M.S., Omar, S.F.S., Suwarganda, E.: A Finite element analysis of a human foot model to simulate neutral standing on ground. Procedia Eng., vol. 147 (2016). Elsevier Ltd. https://doi.org/10.1016/j.proeng.2016.06.240

Tsung, B.Y.S., Zhang, M., Mak, A.F.T., Wong, M.W.N.: Effectiveness of insoles on plantar pressure redistribution. J. Rehabil. Res. Dev. **41**, 767–774 (2004). https://doi.org/10.1682/JRRD.2003.09.0139

Witkiewicz, W., Zielinski, A.: Properties of the polyurethane (PU) light foams. Adv. Mater. Sci. **6**, 17 (2006)

The Technological Adaptation of SMES Through Fuzzy Cognitive Maps

Marisol Hernández-Hernández

Abstract SMEs are the fundamental base of the economy of Latin America and the Caribbean since they are an ideal element for the generation of jobs. However, in most of these companies, the administrative and production processes are carried out manually, which generates daily problems that, in many cases, cause them an economic imbalance that can rise to a level that can lead to failure. This work dynamic is reason enough to guide these companies towards a digital transformation, hoping to make them more competitive to stay longer in the commercial field. This research proposes novel strategies for implementing technologies based on a fuzzy logic model, where a vague cognitive map shows how each action benefits these companies. This analysis starts with a neural network simulation that learns and confirms four proposed hypotheses through specialized software created to streamline and specify the hypothesis verification operations; thus, this is available to any company, variable or, idea. The computer simulator was developed in a high-level multiplatform language with free access, allowing technology to automate processes, generate the increase or decrease of the selected variables, and improve the operation of the companies. The interpretation of the results issued by the simulator showed that process automation increases with the introduction of technology to the company. Consequently, many aspects will facilitate achieving its primary objective, which is to increase its profits in multiple elements and decrease the actions that cause problems to the company as a waste of time and money.

Keywords Fuzzy cognitive maps · Fuzzy logic · SMEs · Manufacturing

1 Introduction

Small businesses are an essential part of the economy of Mexico and Latin America. According to INEGI, in 2020, there will be 3.9 million SMEs in Mexico. Although they decreased due to the pandemic, 79.2% of the 4.9 million in 2019 survived

M. Hernández-Hernández (✉)
UAEM Valle de Chalco University Center, Autonomous University of the State of Mexico, Av Hermenegildo Galeana 3, Maria Isabel, 56615 Valle de Chalco Solidaridad, Mexico, Mexico
e-mail: mhernandezh@uaemex.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_13

(National Institute of Statistics and Geography [INEGI] 2020). In Latin America, more than half of the jobs are SMEs, precisely 61% according to a revelation from ECLAC (Economic Commission for Latin America and the Caribbean [ECLAC] 2018); INEGI (2020) also reported that the workforce of SMEs represented 99.8% of the 27 million people in all companies.

SMEs continue to be a fundamental part of sustaining the countries' economies, at least in Mexico and Latin America. However, the pandemic affected their development and growth. SMEs are key actors to increase the potential effect of Latin America due to their significant heterogeneity in their access to markets, technologies, and human capital, in addition to their links with other companies. These factors affect their productivity, export capacity, and potential for increase. (ECLAC 2018).

Currently, SMEs in Latin America represent 99% of companies and employ 67% of workers. Its contribution to the Gross Domestic Product is low; This reveals deficiencies in their productivity levels (ECLAC 2018); Therefore, it is necessary to implement strategies that manage to reorient companies towards a digital transformation.

There is a lag effect mainly due to the need to readjust organizations and human resources training that takes advantage of technological investment and production processes and methods changes. Otherwise, even if there is an investment in technology, it will not have any material impact on productivity (Katz 2015).

Companies must apply a transformation to their different areas, such: production, sales, and of course, their administration; Under this premise, the traditional company known before the pandemic tends to disappear; In contrast, a company with new and refreshed technology may outperform another that has been doing the same for the past 20 years.

There are many aspects for which we must take into account the great help that technology makes in people's lives, for example, and by way of reflection:

- How many people would like to find places without the help of Google Maps? Paper guides helped locate sites; accuracy, visualization, and time savings are unmatched by Google maps. Of course, access to smartphones allows any time, almost anywhere, and anywhere.
- Who would want to go back and write down the phone numbers in a notebook? Losing the pages or renewing the numbers every time they had a new schedule.
- Or perform mathematical operations on paper? Time spent manually performing operations can be used to do more important things.
- When can they have everything on a mobile device- Or watch movies on a fixed player? -Even listening to music on a big, heavy audio player?
- Likewise, the speed of disseminating the news through social networks or digital newspapers.
- The use of marketing that has its places of consultation digitally.
- Sales are accelerated with the barcode reader.
- Quick search for sites or information about events through Quick Response.
- The sale through digital catalogs.
- Saving time on trips used to move objects and deliver packages.

It is essential to realize that technology helps in many aspects of people's modern lives with all the above.

It is easy to realize that the world has constantly transformed, adapted, and renewed. Consequently, human beings must change their way of life because whoever does not adapt can perish. Still, people often think that it is impossible to aspire to innovations if their money flow is not high or that innovation depends on creative ingenuity. Only gifted mentalities have access to this essential human factor of economic and social benefits (Colina et al. 2015).

Technological innovation is a crucial element in the development of companies; The problem is that many small businesses operate on a rustic basis. Companies where the workers are family members and whose managers do not see the benefit of the implementation of technology in their companies; Therefore, they continue to carry out the processes related to the administration of human resources, inventories, and production processes manually.

Although this has worked for them, the processes must change towards where technology goes hand in hand with the growth of companies and, therefore, orient their actions towards being a cutting-edge company, in which technology remains within the statistics of living companies.

To implement innovation in companies Stamm and Trifilova (2017) says that it is a question of attitude and, therefore, a question of culture and business leadership, where despite taking risks, it becomes a challenge and a possibility of success, which in this case is the realization and or improvement of the existing production and management processes.

History has shown that it is challenging to change people's paradigms. Still, if a company leader changes it, they will achieve excellent results in the short and long term, perceiving opportunities never seen before (González et al. 2010). The problem is that on many occasions, company administrators do not realize or do not know how to implement the technology.

This research is a fuzzy logic model. Through the design, programming, and interpretation of a Fuzzy Cognitive Map "FCM," improvement solutions are for a manufacturing company that was the object of study. The proposals made a knowledge matrix, contrasted with some hypotheses raised, to obtain the solution strategies.

Specialized software called "Computer simulator" was developed and designed in Java, a high-level programming language that produces free and multiplatform software.

The simulator served to test the hypotheses raised quickly and accurately by training a neural network implemented through a knowledge matrix. The software helps suggest the strategies that the company must practice to make it work, this, in case the technology has been proposed as an improvement strategy. If there is no technology, then there is no automation; therefore, the software shows the areas where there is a decrease in profit. The solutions are different depending on the hypothesis established in the simulator.

With this proposal, companies can migrate to technology safely, focusing on the opportunities generated by using technologies. The proposal contains how they could address them and thus solve the problems raised.

2 Background

The “fuzzy logic” has its origin in the premises of human language, which are imprecise to describe phenomena that are not well defined. There are times when you cannot say yes or no, because you need to specify more information. For example, if you have a picture of a red apple painted the color of caramel orange, would the color answer be red? Or orange? The truth is complex and strange because the color response could be clear; Fuzzy logic holds that logic (0/1) is often fiction (McNeill and Thro 1994).

In reality, “fuzzy logic” contains clear-cut logic, similar to the choice to say whether a person is tall or intelligent since other details would have to be known to make this assertion. Unlike artificial intelligence, where the result of this evaluation would yield concrete data: is it high? Yes or no or, is it smart? Yes or no; fuzzy logic treats information imprecisely, as it uses expressions that are neither entirely accurate nor thoroughly false; that is, it is logic adaptable to concepts that can take any value of truth in a set of values that fluctuate between 2 extremes: the absolute truth and the total falsehood (Zadeh 2008, mentioned in Restrepo and Vanegas 2015).

Derived from “fuzzy logic,” fuzzy sets arise to provide mathematical tools for treating this type of information, known as uncertain, imprecise, or vague. Lofti A. Zadeh was the one who introduced Fuzzy Theory in 1972, intending to create a formalism to handle the imprecision of human reasoning efficiently.

According to Zadeh cited in (Fayek 2018), a fuzzy set is a transition between “belonging to a set” and “not belonging to a set,” this transition is gradual and smooth, and its characteristic is a membership function. Loosely defined sets play an essential role in human thinking, particularly in pattern recognition, information communication, and abstraction (Zadeh cited in Fayek 2018).

The “fuzzy theory” uses fuzzy sets. They are sets without a defined limit. A fuzzy set has elements that belong to it (degree of membership 1) or does not belong to it (degree of membership 0); That is, they belong to a certain degree “between 0 and 1”, and their function using degrees. This theory contrasts with most traditional tools, models, and methods based on critical group theory, where the elements are deterministic and precise (Chaira 2019).

In contrast to complex sets, Fuzzy sets using degrees of membership; are the degrees of intervals between [0,1]. For example, the difference between a set of “hard values” would be 0, 1, and their corresponding Fuzzy value could be 1.0, 07.

The diffusion of a set quantified by the fuzzy entropy means that it is the uncertainty or disorder of a system, which measures the degree of vagrancy in a fuzzy set (Wang et al. 2019). Membership functions are the way to represent a fuzzy set over the universe graphically and generally triangular and trapezoid shapes.

An example of the representation of “diffuse entropy” occurs in determining whether a person is tall or not; it is in Fig. 1a, with the graph of the triangular figure. The contrast of belonging or not to the group of tall people is, this infers in their degree of belonging, which means that if $\mu = 0$, the person is not tall, on the other

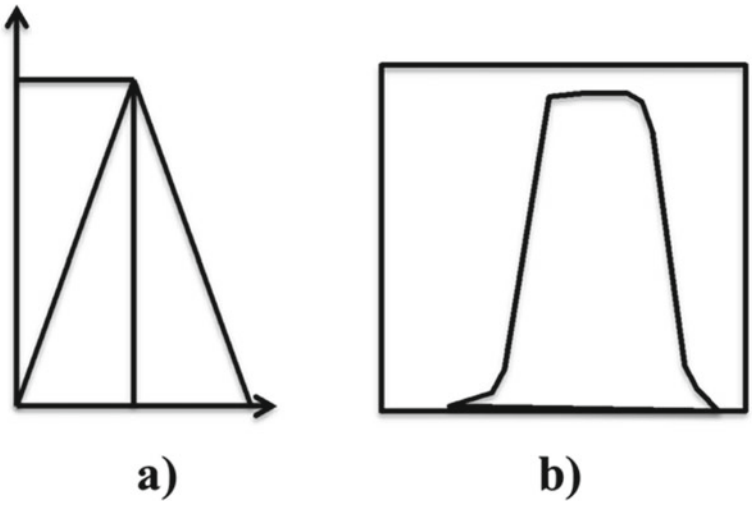


Fig. 1 **a** Triangular membership function, **b** Generalized bell membership function *Source* Own elaboration

hand, if $\mu = 1$, the person is very tall This occurs depending on the performance parameter of the person.

On the other hand, in the graph with the trapezoidal figure (Fig. 1b), the diffuse set is visualized, which shows the degree of height with a continuous line; This can be observed in the person with whom it has compared, showing the vagueness of 0.0–0.9 (Singh and Lone 2020).

Fuzzy sets are functions of some universe of natural objects at the interval [0,1], so the membership function, a basic idea in fuzzy sets theory, perceives their values in degrees. The things satisfy definite properties imprecisely.

Lotfi A. Zadeh proposed type-2 fuzzy sets (Medel 2019), which can better handle phenomena whose nature is no-linear and stochastic at the same time. Fuzzy type 2 systems can also model complex no-linear systems, achieving better performance from controllers designed under this approach, generating promising applications in mobile systems contexts.

Under this approach, various products, systems, and software have been made, with this type of theory, such as Washing machines, microwave ovens, thermal systems, linguistic translators, video cameras, televisions, digital image stabilizers, and automatic focus systems in cameras, photographic, elevator systems, trains, automobiles, traffic controls, air conditioning control systems, handwriting recognition systems, software for medical diagnostics, security, data understanding, computer technology and fuzzy databases for storing and consulting inaccurate information, design of a controller for an automatically guided vehicle.

An FCM fuzzy cognitive map draws a causal figure. The concepts of a system that represent the characteristics of a system, in general, are linked, such as events,

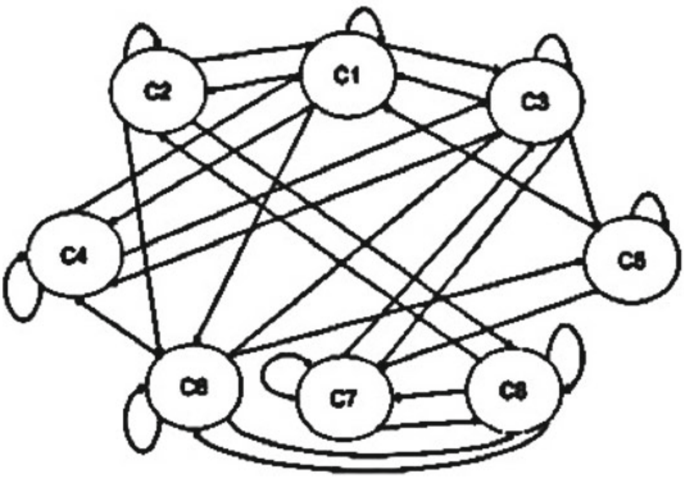


Fig. 2 A FCM with eight nodes. *Source* Buckley and Eslami (2002)

actions, goals, values, or trends (Buckley and Eslami 2002). A graphic representation of a fuzzy cognitive map is in Fig. 2.

An FCM allows predicting how complex events interact and act (Kosko 1993 cited in Paz-Ortiz and Gay-García 2015); An FCM draws a causal figure, where it links facts to things, processes to values, and policies to objects. These events can be represented in an interval of [0,1] or the interval of [− 1, + 1], which form a vector A = [A1, A2… An], where n is the number of nodes, and the interval represents one node's degree of causality or connections over another.

The degree of causality and the connections established, derived from the collection of data mapped by specialists on the subject; To do the mapping, specialists can help each other from a set of values associated with their corresponding values (Paz-Ortiz and Gay-García 2015).

It is essential to mention that an FCM incorporates ideas of artificial neural networks and fuzzy logic, which be applied effectively in management science (Mourhir 2021), where nodes represent neurons, and causality relationships to interneuron connections. Learning the neural network consists of directly assigning the weights provided by the human expert for each of the causal relationships.

Causation involves transferring qualities from cause to effect, denoted by a directed arrow (Sobrino et al. 2018).; Each causal model M can be represented by a directed graph G (M), called a causal diagram (Sobrino 2012). The FCM can agree with their respective knowledge matrix, where values noted coordinate with the weight the experts give to each action; these weights are according to experience on some subject.

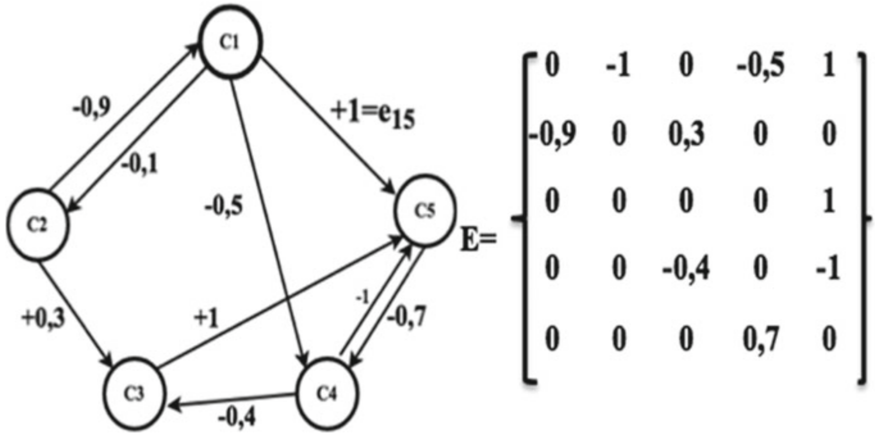


Fig. 3 An illustrative example of a Fuzzy Cognitive Map (FCM) with its connection matrix E. 2021 *Source* Vaščák et al. (2021)

The connections in concepts will have a value in the interval [− 1, + 1], representing the degree of causality and the connections in the actions. The fuzzy information employs linguistic values associated with corresponding numerical values, described in a weight matrix. A map's weight matrix (E) can be like the one shown in Fig. 3.

2.1 Main Focus of the Chapter

Some companies surveyed to detect the problems they have related to technology implementation. A target company that has been in business for 30 years was studied, although several companies were similar in several respects. The leaders have always been familiar with 60 workers in their portfolio, representing higher income from assets in times of advance.

The target company, like many SMEs, has factors that limit their financial capabilities, such as the lack of advice in their processes, having a paradigm rooted in family work history, avoiding investment in technological equipment, and the Covid 19 pandemic. Among others, they have caused the company to find itself in a financial imbalance derived from its administration; and the company could be part of the dead companies' statistics.

The company's problems are controlling inventories, quality control, payments, supplies, outputs, and returns of the work carried out, long process times, imprecise calculations, poorly elaborated manufacturing processes, waste of material. Consequently, there is a decrease in profits and problems of concern for employers, such as company instability and discontent among employees.

One way to simulate the behavior of a system before the variation of the values of evidence of the concepts is with a fuzzy cognitive map. The simulation is done based on the deep knowledge of the work in each company area. This research focuses on the following areas of the company studied:

- Human Resources
- Inventory
- Productive processes

In this way, the company will have the opportunity to select and opt for the technologies it will apply to its business.

2.2 General Objective

Propose strategies for adapting technology to small and medium-sized companies through a fuzzy cognitive map that simulates their behavior through a neural network. Actions combined in hypotheses that are confirmed and interpreted.

3 Methodology

The investigation developed through the development of the following methodology:

(A) List the problems in the company due to lack of technology implementation.
(B) Carry out a fuzzy algorithm to solve the problem and propose solution strategies, considering the following phases:

   1. Draw the nodes on a cognitive map with the input variables and set their fuzzy value in a knowledge matrix with the cause-and-effect variables of the system.
   2. Establish the proposed actions for the listed problem and convert them into input variables of a Neural Network.
   3. The software coding to train the neural network with the hypotheses.
   4. The computer simulator tests the hypotheses raised to obtain all the causes and effects of implementing the technology in the company.

(C) Interpret the output actions of the simulator.
(D) Make the solution proposal.

3.1 Problematic

The change in business processes arises from the challenge of keeping them alive; in this case, this need could be from the events caused by Covid-19. Based on this premise, it is that new strategies be to achieve that, through modern and efficient technologies, a solution can be provided to the company in the face of such an unfortunate event as the pandemic.

The analyzed company is at a decision point; if the implementation of the technology is not in your processes, it could be part of the statistics of dead companies left by the covid-19 pandemic, as many companies do. Many companies are on the verge of "renew or die."

Some common problems of these companies are listed below:

- There is no precise control of the material delivered to the workers to manufacture the product, which results in the loss of material or delay in the delivery of the work due to subsequent material requirements.
- When a garment is defective, the workers correct it and return it, and in many cases, they are paid again for the same garment since they do not record the entries and balances; This causes monetary losses.
- The payment process is very long and tiring because the calculations are done manually on sheets of paper. Operations are out with a basic calculator, which can cause loss of information and, consequently, payments that generate money losses.
- There is no control of the product inventory, which causes ignorance of what you have and what you should have.
- The manufacturing process is not adequate; The workers have only explained the garment's design without giving them more tools to do the work without problems. The employees do not understand all the instructions and perform poorly at work, resulting in a delay in delivery and loss of material waste and the low confidence of the parent company staff that provides them with the job.
- The quality of the product is low because no technique helps workers make the garment properly.
- The production time is lengthened due to errors in the realization of the products, caused by loss of material, or because the workers do not remember the product's image.

3.2 Fuzzy Algorithm

The fuzzy algorithm proposal consists of the following stages:

- The "Computer simulator" was created to capture hypotheses sequences and train them with a series of established actions, contrasted with fuzzy operations in a knowledge matrix.
- It begins by establishing and defining input and output variables, which are actions for implementing technology in a small company.
- An FCM was simulated utilizing the computer application to obtain a logical proposal derived from establishing a knowledge matrix.

- Four hypotheses were the first three to validate and interpret the performance of a small company with the implementation of technology and automation in its processes. The last hypothesis validated the business effort without being implemented by these technological and automation aspects.
- The four hypotheses were verified and interpreted in the computer simulator, which also issued the final proposal for each idea, composed of the strategies obtained from the analysis.
- The company's final proposal was defined, reflecting the actions aimed at implementing and adopting technology and automation that solve the problems in small companies.
- A model was proposed, based on fuzzy logic, so that entrepreneurial SMEs can adapt it according to their needs and achieve, as far as possible, transform their company's path towards the technological forefront.

3.3 Computer Simulator

An application called "computer simulator" was developed, whose purpose was to evaluate and test the hypotheses raised; it was coded in Java, which is a high-level programming language, to make free-type applications and for multiplatform.

The "computer simulator" was created to evaluate the behavior of the neural network derived from the knowledge matrix generated from the actions defined in a cognitive map, which were with the connection relationships between neurons.

The functions of the computer simulator were to define the knowledge matrix, whose values were in coherence with the FCM, and thus subsequently perform the fuzzy operations that would verify the established hypotheses.

The software has been used to define the matrix, capture the hypotheses and perform the following operations:

- The input hypothesis is multiplied by the matrix, generating a new vector that acts as a result and becomes a new hypothesis called the "result hypothesis."
- The results of the vector values become a new "hypothesis of the result." The simplification process concerning the evolution of the activation values of the nodes is, limiting the resulting values of 0 and 1, following the criterion of converting to 0, the negative result, converting to 1, the positive outcome, and do not change the output value if the result is 0.
- The exact process is carried out until the stability of the resulting hypothesis is.
- The resulting hypothesis obtains the data from the input variables and concatenates them with the results obtained, forming the sentences that will make up the suggested proposal.

Figure 4 shows the simulator interface, which contains the button called "Generate weight matrix," which shows the matrix used to test the hypothesis, which is with the button named "Generate hypothesis" and which is displayed in the input box and in the vector called "hypothesis."

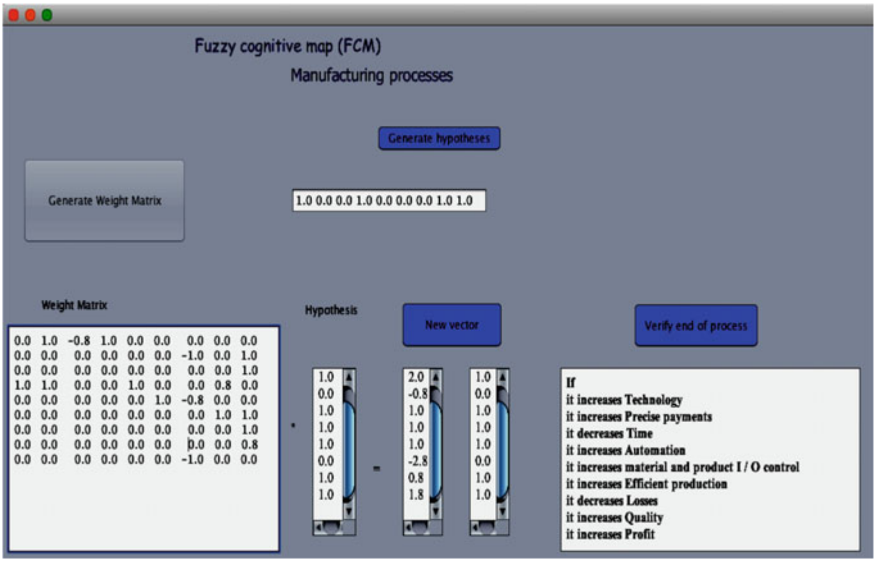


Fig. 4 Interface of the "computer simulator"

The simulator interface has a button called "new vector", which is in charge of applying the formula X.1 and at the same time interacts with the button called "verify the process", which compares the results in each interaction and stops when they stabilize, that is, when the new vector no longer changes its values; this serves as a basis for translating the results obtained when contrasting the hypothesis into strategies proposed by the software itself.

3.4 *Fuzzy Cognitive Map and Knowledge Matrix*

An FCM is considered a neural network, where the nodes represent the neuron, and the causal relationships are the connections between neurons. The neural network formed is a monolayer network similar to the Hopfield network, a class of non-linear dynamic systems called classical neural networks (Feng et al. 2018). The map of the studied company with these strategies is in Fig. 5.

The connections between nodes will have a value in the interval of [−1.0, + 1.0], representing one node's degree of causality or influence on another; the data set is established by specialists with mastery of the proposed topic.

This process emits diffuse information about the influence of one concept on another, which can be by linguistic values associated with their corresponding numerical values. The values taken into account in this proposal were those shown in Table 1.

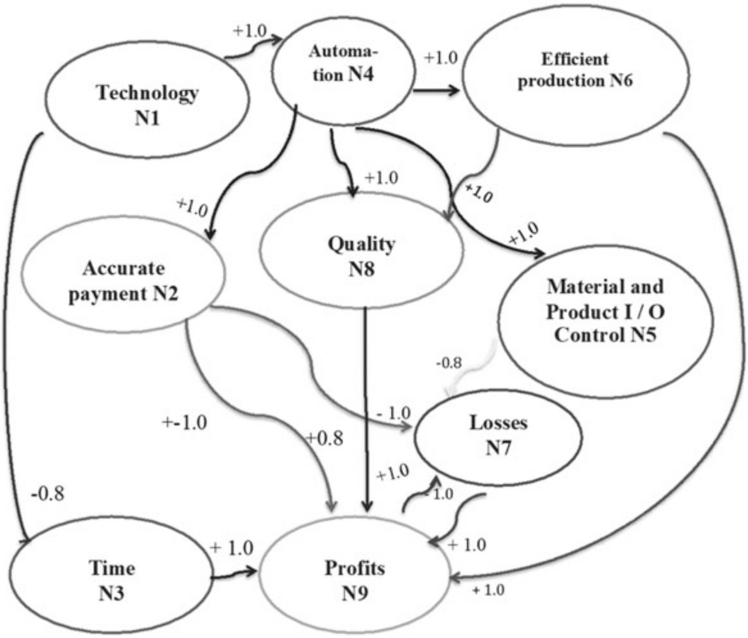


Fig. 5 Cognitive map. *Source* Own elaboration

Table 1 Fuzzy equivalence table on the influence of concepts

Linguistic values	Numerical values
Direct cause	1.0
Considerable effect	0.8
Moderate effect	0.6
Without effect	0.0

Source: Author's elaboration

After establishing the rules, the learning was in a neural network, which consists of assigning weights represented by values proposed by the human expert in the study area; in this case, the causal relationships in the knowledge matrix (E), for the FCM of Fig. 4, is shown in Fig. 6.

With the interaction relationships defined, we proceed to determine the knowledge matrix, which in this case was nine rows and nine columns, listing them as follows:

N = (N1, N2, N3, N4, N5, N6, N7, N8, N9).

Each of the nodes represents an action that can be in the FCM shown in Fig. 5.

The knowledge matrix is with the weights of these nodes and, if there is no interaction between the nodes of the relationship, zeros will be the knowledge matrix was as shown in Fig. 6.

$$E=\left\{\begin{array}{|c|c|c|c|c|c|c|c|c|}\hline 0.0 & 0.0 & -0.8 & 1.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 \\ \hline 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & -1.0 & 0.0 & 1.0 \\ \hline 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \\ \hline 0.0 & 1.0 & 0.0 & 0.0 & 1.0 & 1.0 & 0.0 & 0.8 & 0.0 \\ \hline 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & -0.8 & 0.0 & 0.0 \\ \hline 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 & 1.0 \\ \hline 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 1.0 \\ \hline 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.8 \\ \hline 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & 0.0 & -1.0 & 0.0 & 0.0 \\ \hline \end{array}\right.$$

Fig. 6 Knowledge matrix. *Source* Own elaboration

After establishing the knowledge matrix, the behavior of the system is simulated, given the variation of the values that are evidence of the concepts; This is through input variables that represent the hypothesis and that will be tested and will have an effect on the company based on its true or false value.

The simulation is out with the three hypotheses representing the implementation of technology considered beneficial for companies. In the end, it is among the fourth hypothesis that does not contain technology items. The operations carried out are of fuzzy union, selecting the maximum value of the data expressed by the different experts for each of the causalities. Its mathematical representation is in Eq. (1), Acampora, and Loia, cited in apageorgiou and Salmeron (2013).

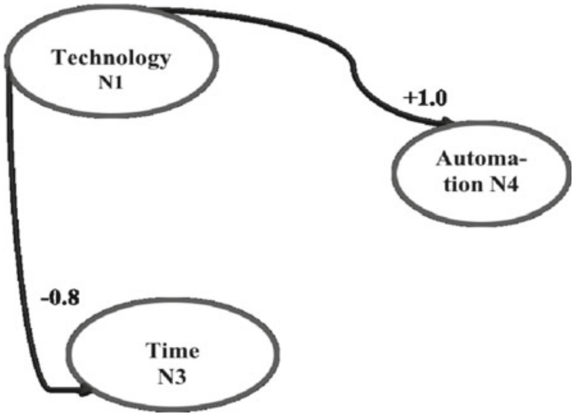
$$Ai(K+1) = f\left(Ai(k)\sum_{J=1}^{N} Aj(\mathrm{k}).eji\right) \tag{1}$$

The nodes and connections of the FCM were to obtain their corresponding fuzzy numbers. Figure 7 shows the links that, as Chaira (2019) points out, allow us to predict complex events that interact and act. These connections show the interaction between "Technology" and "Automation" and between "Technology" and "Time."

Relationships are with d weights provided by tech experts (show Table 1).

In the case of the relationship "Technology" - "Automation," its weight is " + 1.0", which means that the association is of the "direct cause" type; that is, if there is "Technology," then "Automation" increases by 1.0; This value shows the degree of importance of technology to automate processes in the company.

Fig. 7 Interaction between technology nodes



The second relationship shown in Fig. 7 is "Technology" - "Time," where the experts give the value − 0.8, this according to Table 1, is a considerable effect, which means that if implements technology in the company, then process execution times will be reduced by 0.8. In this case, they do not give a weight of direct cause, because the times do decrease. However, maybe factors that cause the technology not to be such as electricity, equipment or internet connection, that is why they are given slack in interaction.

In the same way and as can be seen in Fig. 8, to the relationships between the Automation nodes with "Efficient production," "Quality," "Material and product I/O control," and "Accurate payments"; They were a weight of + 1.0, which according to the table is of the direct cause, this means the following:

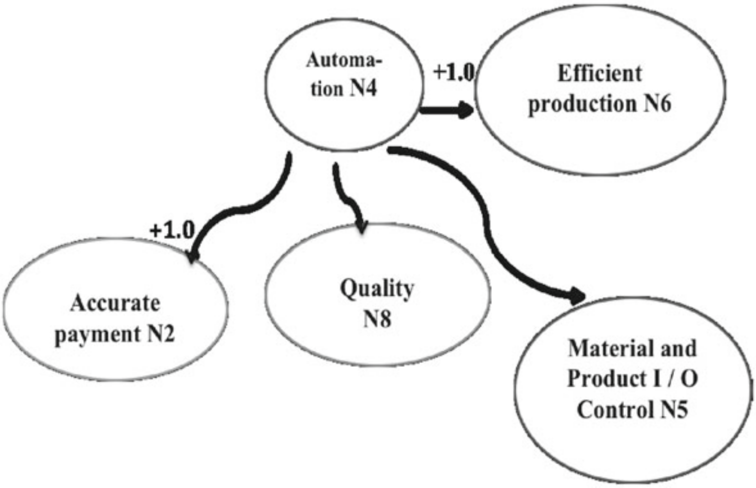


Fig. 8 Interaction between automation nodes

- If there is "Automation," "Efficient production" increases by 1.0
- If there is "Automation," then the "Quality" increases by 1.0
- If there is "Automation," then the "Material and Product I / O Control" is increased by 1.0 and finally
- If there is "Automation," then the "Accurate payment" increases by 1.0.

3.5 Input Variables

The input variables are the actions proposed for the company to use technology; these, in turn, become nodes of a fuzzy cognitive map that simulates a neural network; in addition, they are the values with which a knowledge matrix affects the behavior of a company.

The actions that were into account are:

Node1 = "Technology". It is the implementation of digital tools both at the hardware and software levels.

Node 2 = "Accurate payment". They are actual payments given for work performed.

Node 3 = "Time". It is the time used to carry out administrative and manufacturing actions.

Node 4 = "Automation". It is the digitization of management and manufacturing processes.

Node 5 = "Material and product I / O control". Es el inventario automatizado de materiales y productos manufacturados.

Node 6 = "Efficient production". It is the process in which the products are made on time and correctly.

Node7 = "Losses". It decreases resources in terms of money, time, material, and production.

Node 8 = "Quality". It is the fulfillment of the specifications established in the manufacturing requirements.

Node 9 = "Profit". It is the utility in monetary, material, time, production, or commercial stability terms.

3.6 Hypothesis

Three hypotheses were to simulate the behavior of the network, which were from implemented rules. The rules and ideas are described in next paragraphs.

3.6.1 Hypothesis 1

If there is "Technology" (N1 = 1.0), then there is "Automation" (N4 = 1.0).

If there is "Automation" (N4 = 1.0) then there is "Quality" in the processes (N8 = 1.0).

If there is "Quality" in the processes (N8 = 1.0) then there are "Profits" (N9 = 1.0).

The input hypothesis is as follows:

N1	N2	N3	N4	N5	N6	N7	N8	N9
1.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	1.0

The formula applied and the evolution of the activation values of the nodes was until reaching the stability that consists in obtaining a sequence that no longer changes.

The interpretation of this hypothesis can be observed in the simulator interface shown in Fig. 8, where the following sequence of values were obtained:

Network (T1) = (1 0 0 1 0 0 0 1 1) $\rightarrow$ (1.0 2.0 − 0.8 1.0 1.0 0.0 − 1.0 0.8 0.8)

Network (T2) = (1 1 0 1 1 0 0 1 1) $\rightarrow$ (1.0 2.0 − 0.8 1.0 1.0 1.0 − 2.8 0.8 1.8)

Network (T3) = (1 1 0 1 1 1 0 1 1) $\rightarrow$ (1.0 2.0 − 0.8 1.0 1.0 1.0 − 2.8 1.8 2.8)

Network (T4) = (1 1 0 1 1 1 0 1 1) $\rightarrow$ (1.0 2.0 − 0.8 1.0 1.0 1.0 − 2.8 1.8 2.8)

The interpretation was as follows:

If

"Technology" increases

"Accurate payments" are increased

"Time" decrease

"Automation" is increased

"Material and product I/O control" is increased

"Efficient production" increased

"Losses" decrease

"Quality" increased

"Profits" increased

3.6.2 Hypothesis 2

If there is "Technology" (N1 = 1.0), then there is "Automation" (N4 = 1.0) and "Time" decrease (N3 = − 0.8), if there is "Automation" (N4 = 1.0) then there "Material and product I / O control" (N5 = 1.0), therefore there are fewer "Losses" (N7 = − 0.8) and consequently there are gains (N9 = 1.0) and, if there is "Quality" in the processes (N8 = 1.0) then there are gains (N9 = 1.0).

The weights of hypothesis 2 are:

N1	N2	N3	N4	N5	N6	N7	N8	N9
1.0	0.0	– 0.8	1.0	1.0	0.0	– 0.8	0.0	1.0

The aforementioned stability formula was applied, and the following sequences were obtained:

Network (T1) = (1 0 – 0.8 1 1 0 – 0.8 0 1) → (1.0 2.0 – 0.8 1.0 1.0 1.0 – 1.8 0.8 – 1.6)

Network (T2) = (1 1 0 1 1 1 0 1 0) → (1.0 2.0 – 0.8 1.0 1.0 1.0 – 1.8 1.8 2.8)

Network (T3) = (1 1 0 1 1 1 0 1 1) → (1.0 2.0 – 0.8 1.0 1.0 1.0 – 2.8 1.8 2.8)

Network (T4) = (1 1 0 1 1 1 0 1 1) → (1.0 2.0 – 0.8 1.0 1.0 1.0 – 2.8 1.8 2.8)

The interpretation was as follows:

If

"Technology" increases

"Accurate payments" increased

"Time" decrease

"Automation" is increased

"Material and product I/O control" is increased

"Efficient production" increased

"Losses" decrease

"Quality" increased

"Profits" increased

3.6.3 Hypothesis 3

If there is "Technology" (N1 = 1.0), then there is "Automation" (N4 = 1.0), there is "Quality" (N8 = 1.0) and, consequently, "Profits" are increased (N9 = 1.0).

The weights of the hypothesis are:

N1	N2	N3	N4	N5	N6	N7	N8	N9
1.0	0.0	0.0	1.0	0.0	0.0	0.0	1.0	1.0

The sequences obtained after applying the formula and stability were:

Network (T1) = (1 1 0 0 0 0 1 1) → (0.0 0.0 – 0.8 1.0 0.0 0.0 – 2.0 0.0 – 1.8)

Network (T2) = (1 1 0 1 0 0 0 1 1) → (0.0 1.0 – 0.8 1.0 1.0 1.0 – 2.0 0.8 1.8)

Network (T3) = (1 1 0 1 1 1 0 1 1) → (0.0 1.0 – 0.8 1.0 1.0 2.0 – 2.8 1.8 2.8)

Network (T4) = (1 1 0 1 1 1 0 1 1) → (0.0 1.0 – 0.8 1.0 1.0 2.0 – 2.8 1.8 2.8)

If

Technology decreases

"Accurate payments" are decreased

"Time" decrease

"Automation" decreases

"Material and product I/O control" is decremented

"Efficient production" decreases

"Losses" decrease

"Quality" decreases
"Profits" decrease

3.6.4 Hypothesis 4

In this hypothesis, it is the same as hypothesis 2, except that in this hypothesis, "Technology" is not considered, and therefore, there is no "Automation", being the following:

There is no "Technology" (N1 = 0.0), then there is no "Automation" (N4 = 0.0) and "Time" decrease (N3 = – 0.8), if there is "Automation" (N4 = 1.0) then there "Material and product I / O control" (N5 = 1.0), therefore there are less "Losses" (N7 = −0.8) and consequently there are gains (N9 = 1.0) and, if there is "Quality" in the processes (N8 = 0.0) then there are gains (N9 = 1.0).

The weights of hypothesis 4 are:

N1	N2	N3	N4	N5	N6	N7	N8	N9
0.0	0.0	– 0.8	0.0	1.0	0.0	– 0.8	0.0	1.0

The aforementioned stability formula was applied and the following sequences were obtained:

Network (T1) = (0 0 −0.8 0 1 0 −0.8 0 1) → (0.0 0.0 0.0 0.0 0.0 1.0 −1.8 0.0 −1.6)

Network (T2) = (0 0 0 0 0 1 0 0 0) → (0.0 0.0 0.0 0.0 0.0 0.0 0.0 1.0 1.0)

Network (T3) = (1 1 0 1 1 1 0 1 1) → (0.0 1.0 −0.8 1.0 1.0 2.0 −2.8 1.8 2.8)

Network (T4) = (1 1 0 1 1 1 0 1 1) → (0.0 1.0 −0.8 1.0 1.0 2.0 −2.8 1.8 2.8)

The interpretation was as follows:

If
Technology decreases
"Accurate payments" are decreased
"Time" decrease
"Automation" decreases
"Material and product I/O control" is decremented
"Efficient production" decreases
"Losses" decrease
"Quality" decreases
"Profits" decrease

4 Discussion

The fuzzy cognitive map for implementing technology in a company was automated and trained through a neural network and took as input variables the actions that occur with implementing the technology in the company. The calculations were with the hypotheses that were with the knowledge matrix.

This training carried until each result stabilized; that is, it no longer changed; at that time, the simulator showed the set of strategies, which were the same for the first three hypotheses because they included technology and process automation.

For the fourth hypothesis, hypothesis 2 was taken as a basis, modifying the technology and automation nodes to zero; they were not in the actions. The result of the calculations showed a series of strategies contrary to those that resulted in the behavior. Other hypotheses visualized that the lack of technology and automation led to a decrease in profits; with this, it found that if the technology is not in a company, it will be challenging to correct the problems raised.

The strategies resulting from the fuzzy cognitive map of the studied company configure an improvement proposal for any SME in the short, medium, and long term, with activities that improve their productivity and consequently increase their earnings in monetary resources and time.

This proposal gives rise to activities where it is essential to acquire computer equipment to automate processes, using office software or even information systems adapted to the needs of each company. The type of software chosen for the automation of the company's methods would have to carry out the following operations:

1. Automated operations that record the identification data of the products and the entries, exits, and returns of materials and products; will keep you in control of your business operations.
2. The company's material control will be easy to consult at any time if they have automated records; Material losses, and consequently money losses.
3. The automation of the company's processes will allow knowing the stock of the material so that production does not stop due to lack of supplies. Thus, with this action, the loss of materials and products will be corrected.
4. 4. Regarding the payment of employees, the registration of the same can, noting the necessary data for an automated payroll, work data of the personnel, such as days or hours worked, type of position or number of overtime hours, adding the earnings and deductions of each person.
5. Create piecework payment records, noting all the characteristics of each garment and the quantity produced by each worker. The appropriate operations will make the payment automatic, fast, and efficient with this system.
6. Eliminate long payment times, the fatigue of this task, and above all, payments will be more accurate, which will avoid losses and therefore generate gains in time and money.
7. The data record may be out to control administrative and manufacturing processes, noting the entries, exits, and returns; In this way, you will avoid paying for the same job more than once and controlling Inventories of materials and products.
8. In the manufacturing process, cutting-edge technologies can be implemented, such as augmented reality or monitoring with a Quick Response code, which

helps in the manufacturing process and providing a more efficient way to carry out the work.

Whit this technology, workers, could consult the way to do the work step by step, thus avoiding errors that generate lost time and materials, which would consequently improve the quality of production, which would lead to better gains in time and money.

This model proposes other improvement strategies for different companies depending on the established input variables. To make this type of modification, one would have to generate an FCM with new nodes, show the knowledge matrix according to those nodes, and set the input variables. These data would be in the "computer simulator" to automate operations and issue strategies; With these results, it is easier to define the proposal delivered to the entity that requests it.

5 Conclusions

SMEs are a fundamental basis for generating employment and sustaining a country's economy. Still, sometimes the human resources run them are people who do not believe in technology or know what actions to take to maintain their company.

Fuzzy logic provides tools such as FCM that link concepts whose meaning is the characteristics of a system; In this research, this model was taken as the basis for these characteristics to become proposed strategies to adopt them.

Actions represent the knowledge matrix, the learning network trained to generate knowledge. The network simulation verifies that any hypothesis applied by the technology as the model's start increases benefits and disadvantages.

Likewise, any hypothesis utilized in this simulator, where technology is not the basis, will not result in improvements, if not the opposite. With this, it can see that fuzzy logic can generate proven responses to hypotheses raised, in this case, for the improvement of companies and, therefore, with national and even international scope.

SMEs' adoption of this proposal can help entrepreneurs know what actions to take to effectively their production processes. Even other types of activities can add, and the system is to issue results.

In this case, the application of three different hypotheses gave the same positive result for the actions that benefit the company and damaging for those that do not; the condition is that the model begins with technology and automation, which are, according to specialists, essential elements to evolve a company.

With this premise, this model can be adapted to any problem and produce similar results to help entrepreneurs make strategic decisions.

Considering that fuzzy operations are out repeatedly, formulas are applied, numbers and positions exchanged, and results compared, doing the processes by hand would be complicated and time-consuming and could even lead to erroneous results. It is essential to mention that the "computer simulator" served to automate the FMC, thus speeding up the operations to solve the algorithm.

The software developed and reduced training time automates the output of responses. Above all, it is an application that can manage any problem related to the industry or any subject since the only thing required for their training would be the knowledge matrix, the strategic items, and the hypotheses.

References

Buckley, J.J., Eslami, E.: An introduction to fuzzy logic and fuzzy sets: with 50 figures and 14 tables. Physica-Verlag, Heidelberg (2002)

Chaira, T.: Fuzzy Set and Its Extension: The Intuitionistic Fuzzy Set. NJ Wiley, Hoboken

Colina, B.A., Colina, A.A., de Adrianza, J.A.: La innovación tecnológica en Venezuela: una cuestión de cultura. Opcion **31**(76), 211–229 (2015). https://www.redalyc.org/articulo.oa?id=31037732010

Economic Commission for Latin America and the Caribbean Economic Commission for Latin America and the Caribbean. In: Economic Commission for Latin America and the Caribbean. https://www.cepal.org/en. Accessed 10 Sept 2021

Fayek, A.R.: Fuzzy hybrid computing in Construction Engineering and Management: Theory and Applications. Emerald Publishing Limited, Bingley England (2018)

Feng, L., Cao, J., Liu, L.: Stability Analysis in a class of Markov switched stochastic Hopfield Neural Networks. Neural Process. Lett. **50**, 413–430 (2018). https://doi.org/10.1007/s11063-018-9912-7

González, A.J.M., Manríquez, S.O., González, B.O.: Revista Ean. La Visión Gerencial Como Factor De Compet. **69**, 42–59 (2010). https://doi.org/10.21158/01208160

Instituto Nacional de Estadística y Geografía (INEGI): In: Estudio sobre la demografía de los Negocios (EDN) (2020). https://inegi.org.mx/contenidos/saladeprensa/boletines/2020/OtrTemEcon/ECOVID-IE_DEMOGNEG.pdf. Accessed 3 Sept 2021

Katz, R.L.: El Ecosistema y la economía digital en América Latina. Fundación Telefónica, Madrid (2015)

McNeill, F.M., Thro, E.: Fuzzy Logic: A Practical Approach. Academic Press Inc., Cambridge, MA (1994)

Mendel, J.M.: Type-2 fuzzy sets as well as computing with words. IEEE Comput. Intell. Mag. **14**, 82–95 (2019). https://doi.org/10.1109/MCI.2018.2881646

Mourhir, A.: Scoping review of the potentials of fuzzy cognitive maps as a modeling approach for Integrated environmental assessment and management. Environ. Model. Softw. **135**, 104891 (2021). https://doi.org/10.1016/j.envsoft.2020.104891

Papageorgiou EI, Salmeron JL (2013) Methods and algorithms for fuzzy cognitive map-based modeling. Fuzzy Cogn Maps Appl Sci Eng 1–28. https://doi.org/10.1007/978-3-642-39739-4_1

Paz-Ortiz, I., Gay-García, C.: Fuzzy cognitive mapping and non-linear Hebbian learning for the qualitative simulation of the climate system, from a planetary boundaries perspective. Adv. Intell. Syst. Comput. 295–312 (2015). https://doi.org/10.1007/978-3-319-26470-7_15

Restrepo Morales, J.A., Vanegas López, J.G.: Internacionalización de las pymes: Análisis de recursos Y capacidades Internas mediante lógica difusa. Contaduría y Administración **60**, 836–863 (2015). https://doi.org/10.1016/j.cya.2015.07.008

Stamm, B, Trifilova, A.: The Future of Innovation. Routledge/Taylor & Francis Group, London (2017)

Sobrino, A., Puente, C., Olivas, J.Á.: Mining temporal causal relations in medical texts. In: Pérez García, H., Alfonso-Cendón, J., Sánchez González, L., Quintián, H., Corchado, E. (eds.) International Joint Conference SOCO'17-CISIS'17-ICEUTE'17 León, Spain, September 6–8, 2017,

Proceeding. SOCO 2017, ICEUTE 2017, CISIS 2017. Advances in Intelligent Systems and Computing, vol 649. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-67180-2_44
Sobrino, A.: Imperfect causality: combining experimentation and theory. Combining Experimentation Theor. 371–389 (2012). https://doi.org/10.1007/978-3-642-24666-1_25
Vaščák, J., Pomšár, L., Papcun, P., et al.: Means of IoT and fuzzy cognitive maps in reactive navigation of ubiquitous robots. Electronics **10**, 809 (2021). https://doi.org/10.3390/electronics10070809
Wang, Y., Yang, H., Qin, K.: The consistency between cross-entropy and distance measures in fuzzy sets. Symmetry **11**, 386 (2019). https://doi.org/10.3390/sym11030386

Distribution and Commercialization

A New Distribution Strategy for Psychotropic and Cold Chain Products in a Pharmaceutical Company

Galo Eduardo Mosquera-Recalde, Sonia Valeria Avilés-Sacoto, Mercedes Estefanía Pérez-Naranjo, and Christine Nicole Wright-León

Abstract One of the major interests in the retail industry of pharmaceutical products is related to the proper handling and distribution of products. In fact, one of the most important decisions in this industry involves the proper distribution of goods, such that it provides the right amount of the products, at the right pharmacy, at minimum cost and safety conditions according to the type of the products. Psychotropic and Cold-chain products are special products in this industry because of their high logistics cost and strict requirements and conditions for distribution until they reach the customer at a pharmacy. Retail chains in this industry have experimented a notable increase in the number of pharmacies within a region and it is necessary to have a distribution strategy with a proper methodology that meets all the distribution requirements for special products to reduce their distribution costs. In this study, a methodology based on a mathematical model that schedules the supply of pharmaceutical products is presented, focusing on the distribution of Psychotropic and Cold chain products to different pharmacies. The implementation of the mathematical model considers two stages. Stage 1 is the first strategy implementation, generating the first distribution schedule, and stage 2 uses these results of stage 1 to schedule overtime periodically. This model has been implemented in a real distribution company, and the results adequately respond to the company's needs.

G. E. Mosquera-Recalde · S. V. Avilés-Sacoto (✉) · C. N. Wright-León
Departamento de Ingeniería Industrial and Instituto de Innovación en Productividad, Logística CATENA-USFQ, Colegio de Ciencias e Ingeniería, Universidad San Francisco de Quito, USFQ, Diego de Robles s/n y Vía Interoceánica, Quito, Ecuador 170901
e-mail: svaviless@usfq.edu.ec

G. E. Mosquera-Recalde
e-mail: gmosquera@asig.com.ec

C. N. Wright-León
e-mail: christine.wright@alumni.usfq.edu.ec

M. E. Pérez-Naranjo
Departamento de Ingeniería Industrial, Colegio de Ciencias e Ingeniería, Universidad San Francisco de Quito, USFQ, Diego de Robles s/n y Vía Interoceánica, Quito, Ecuador 170901
e-mail: mperez1@alumni.usfq.edu.ec

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_14

Keywords Distribution · Psychotropic · Cold chain products · Pharmacies · Cost · Integer programming

1 Introduction

Lowering logistics costs for retail companies is critical, and this is no exception in the pharmaceutical industry. Pharmaceutical retail chains rely heavily on agile supply chains that keep the right amount of the right product in the right place. Therefore, proper handling and distribution of products are significantly important. Creating an effective and efficient handling and distribution system depends on multiple factors such as the nature of the product, the location of the different pharmacies, the demand forecasting methods, the inventory policies, the size of each pharmacy, the replenishment frequency, and other policies associated to the management of the pharmacy. Marsh (2011) asserts that multi-million-dollar clinical studies of promising pharmaceutical products have been scuttled due to not considering one or more of the factors mentioned above. This study focuses on a new distribution strategy that considers these and more factors in reducing the logistics costs of specific products through a mathematical model. This model was tested in a real company dedicated to distributing pharmaceutical products.

Consider the case of a company with a distribution center from which it distributes different products to more than 500 pharmacies of different sizes throughout the country. Approximately 12,000 Stock Keeping Units (SKUs –unique product reference number) are handled at the distribution center, and 3500 SKUs on average are dispensed at any pharmacy. The demand for each product at each pharmacy requires an appropriate and unique inventory, and therefore they use a reorder point inventory policy for each item at each location. Despite having operational forecasting and inventory systems, the replenishment of specific products, such as psychotropic and cold chain products, presents high logistics costs, requiring special attention. The nature of these products requires special handling and safe and specific environmental conditions in their distribution. Examples of such conditions that increase handling and transportation costs can be the temperatures at which cold chain products must be handled and transported or the strict security conditions for storing psychotropic products. Together, psychotropic and cold chain SKUs account for 2% of all SKUs at the distribution center and 8% of all SKUs in a mid-size pharmacy. However, logistics costs are estimated to be around 15% of the total logistics costs in the distribution center (Naranjo 2018). Improving the handling and distribution systems for these specific products would significantly impact the logistic cost of the operation in the distribution center.

The study of the operations within this company shows the enormous amount of work due to the handling and transportation of cold chain and psychotropic products. In an average month, at least 1% of the pharmacies need to be replenished every day with different cold chains or psychotropic products. Another 41% of pharmacies must be restocked 11 out of 22 business days, and 58% must be restocked at least 4 out of

22 business days. This means that, on average, 141 pharmacies need to be restocked every business day with different cold chains or psychotropic products, reaching an average number of 3100 restocking events in a month. Special handling, packaging materials, labor, transportation, and equipment are needed for each replenishment event. The focus of this study is to reduce the number of replenishment events without increasing the inventories at the distribution center so that the logistic costs of cold chain and psychotropic products are also reduced.

The inventory model used by the company generates a high number of replenishment events, which is functional but costly for the cold chain and psychotropic products. For any product in each pharmacy, the inventory policy considers the minimum and maximum inventory levels in a continuous review policy. Suppose the inventory level is less than or equal to the minimum level (the reorder point). In that case, a replenishment order is generated to proceed with the dispatch considering the difference between the maximum inventory level and the current inventory level. Maximum and minimum inventory levels are calculated for each product at each pharmacy based on a forecast of several days of supply based on product rotation. Although it is a functional model for the company's operations, it is costly for cold chain and psychotropic products as replenishment amounts under current inventory policy could generally mean 1 or 2 units per replenishment event. Since these products require specific conditions for handling and transport, a modification in the current replenishment model is needed. The modification consists in aggregating the demand for these products that are estimated to be sold in a period of time (for example, a month) so that their supply justifies the high logistics costs of these products. This modification would decrease the number of replenishment events and logistics costs. However, it could also increase the inventory required at the distribution center because of the inventory needed for more extended time replenishment periods. This study presents a mathematical model that minimizes the number of replenishment events without increasing inventory in the distribution center by considering other factors the company faces in its operation. In order to get an optimal solution to this problem, an optimization modeling system was used to express the mathematical model of this particular setting, and AMPL/Gurobi deployed it straightforwardly.

Section 2 details the literature review that support the methodology proposed in this study. Section 3 describes the mathematical model used to solve the problem, and Sect. 4 illustrates the application of the mathematical model through an example. Finally, limitations and conclusions are presented in Sect. 5.

2 Literature Review

Worldwide pharmaceutical companies are under increased pressure due to the importance of a proper product distribution strategy, transportation methods, and risk mitigation plans to maintain their products (Shanley 2017). Additionally, customers' requests regarding product quality are becoming more and more demanding every day. These situations lead pharmaceutical companies to seek better processes to achieve proper product management (Sarin et al. 2014) and to adopt best practices to safeguard the quality of their supply chain networks. Nagurney et al. (2013) states that despite all the advances in manufacturing, storage, and distribution methods, some pharmaceutical companies do not have an effective strategy to meet market demands. In this context, Jaberidoost et al. (2013) emphasize that "the main goal of pharmaceutical supply chains is to provide sufficient medicine at the right time, with the best quality, and an appropriate price". Therefore, they need efficient optimization techniques to reduce costs and increase productivity and responsiveness to their customers. The proper amount of products to be delivered, the special characteristics required for the transportation such as temperature controls, packaging complexities, and costs (Shanley 2017), and a skilled workforce are all needed (Kulkarni and Suman 2013).

The number of pharmaceutical companies has increased, so a pharmaceutical company needs to have a competitive advantage that can respond quickly with effective and efficient logistics systems (Shao and Ji 2006). To get an idea, in 74 countries studied by the International Pharmaceutical Federation, the number of licensed or registered pharmaceutical companies is approximately 4,067,718 (International Pharmaceutical Federation 2017). From them, 5217 belonged to Ecuador up to the year 2014 (Ministerio de Salud Pública 2014).

Therefore, the strategies to keep a pharmaceutical company in the market include a suitable distribution strategy (Ji et al. 2014), with tables containing rates, schedules, generated costs, and other vital information to determine the best and a fairy distribution (De La Cruz et al. 2010). Additionally, the capacity of the containers, the chemical/physical characteristics in the processes, the processing time (Sarin et al., 2014), the scheduling level, and the starting/completion times of lots (Kim et al. 2008), without evaluating the costs associated to the different activities in the supply chain (Hammoudan et al. 2016). For example, product development cycles and manufacturing activities are critical because drugs are perishable, so they have specific time windows in which they can be used. If the expiration date is exceeded, the items must be wasted, causing financial losses to the company (Gebicki et al. 2014).

Among many pharmaceutical products, cold chain products constitute a group of drugs that require specific conditions during the different processes in supply chain management. The company's profits are significantly affected due to unnecessary expenses that must be incurred if these products are not appropriately managed (Kim et al. 2008). Cold chain products are temperature sensitive and require specific conditions before being delivered to consumers. The main components in this group of products are made up of biologics and active ingredients (McLean 2009). These ingredients have characteristics that are maintained when stored at temperatures between 2 and 8 °C (36 and 46° F); while others require to be stored in a freezer, at temperatures between –25 and –10 °C (–13 and 14° F) (McLean 2009). Cold chain products must be stored in low-temperature ranges during all processes (Li and Chen 2011), including production, transportation, storage, dispatching, and final packaging before the sale.

Additionally, the secondary packaging of cold chain products requires a particular insulating container for the input or output of heat (cooler) and cooling gels that help maintain optimal temperature conditions for this type of product. These products are perishable drugs that become waste if not handled properly. These conditions ensure the quality of the products, lower all the costs associated with the processes, and guarantee the advancement of the following production schedule (Li and Chen 2011). Furthermore, environmental conditions—also known as external conditions-such as light, humidity, pressure, oxygen, and even vibrations, must also be considered because they also contribute to the quality of those products (Li and Chen 2011). Temperature, the humidity of materials (raw material, drug substance, or drug products), continuous monitoring and accurate reporting, significantly less material shelf-life, strict controls imposed by regulatory bodies, and high probability of drug counterfeiting are factors that influence the conditions of these products (Kulkarni and Suman 2013). Likewise, the roles of raw material manufacturers, drug manufacturers, wholesalers, buyers, prescribers, hospitals, and the pharmacy community are essential throughout the supply chain (Mouaky et al. 2016); especially, "people who handle and regulate temperature-sensitive pharmaceutical products require the knowledge and skills to ensure those products maintain quality, integrity, safety, and efficacy throughout their shelf life" (Nagurney et al. 2013).

Other pharmaceutical products that require special attention are psychotropic products. Psychotropic products require security and controlled spaces to be stored and transported. Jordan Halter (2018) defines psychotropic products as drugs to treat mental illnesses caused by physical changes in the brain that can cause alterations in the patient's behavior. These products can be natural or synthetic substances that can modify psychic functions in people due to their action on the Central Nervous System (Bolaños 2009). Due to their complexity and effects on people, psychotropic products require specific safety controls due to their potential misuse as a hallucinogenic, depressant, or stimulant agent (Belixán et al. 2009).

The distribution strategy used for the cold chain and psychotropic products must also consider efficient and economical for management (Alvarado et al. 2008). The strategy should maintain features such as reduced delivery time and the achievement of a high degree of service reliability, including a cyclical review mode and incurred transportation costs (Kogan et al. 2009). Here, different optimization techniques are needed to reduce costs and increase productivity and responsiveness to their customers, foreseeing the proper amount of products to deliver, temperature controls, and packaging complexities (Shanley 2017).

In the same line, delivery and inventory scheduling stages are very difficult activities in this industry. Plans dealing with several potentially conflicting objectives, namely minimizing costs, completion times, and delays or maximizing profit, arise in this industry (Hammoudan et al. 2016). The transportation cost is generally proportional to the distance traveled in delivery activities. In contrast, the inventory holding cost is proportional to the inventory level at customers and at the supplier (Hammoudan et al. 2016). In the same way, considering these activities, it is vital to name the products that are not always available for order from the suppliers. This limited availability means that lead times for items can vary considerably, causing a cost called out-of-stock (Gebicki et al. 2014).

The studies conducted by Hammoudan et al. (2016), Gebicki et al. (2014) described several costs associated with different activities in the pharmaceutical industry. For example, "the cost of ordering includes the time and effort to place an order, shipping of an order, and other costs that vary with the number of orders. The carrying cost (cost of holding inventory in house) includes opportunity cost (money tied up in inventory), cost of space, and other costs that vary with the amount of inventory on hand. The cost of stockouts associated with the inability to meet demand". Additionally, a fleet of trucks with a finite capacity also costs, depending basically on the vehicle routes and the service level to meet the demand.

Costs are the main challenge in the pharmaceutical industry. A suitable reconfiguration of the distribution strategy, involving reducing the number of visits to the different facilities and the consolidation of the carrier, is required (Shao and Ji 2006). To achieve this objective, a careful distribution plan, proactive communication among the different supply chain members, and technology must be analyzed (Shanley 2017). All the elements mentioned above help avoid, reduce or even eliminate errors in the distribution of temperature-sensitive products (De La Cruz et al. 2010). In this context, it is relevant to mention that to facilitate this process, and work environments must be designed for productivity without forgetting workers' well-being since both factors are interconnected, as Edwards and Jensen (2014) mentioned.

Since scheduling in a distribution strategy plays an important role, various methodologies have been explored over the years to determine effective scheduling and delivery of products, for example, in the study from Kim et al. (2008) two heuristics are included. The former heuristic involves the equipment classification in the processes, while the latter heuristic considers a two-stage optimization problem, where two scheduling models, such as the inner scheduling model and the outer scheduling model, are handled. Additionally, research by Li and Chen (2011) includes technology for pharmaceutical cold-chain logistics. In this study, the relevance of included Radio-frequency identification (RFID) systems and tags contribute positively to the management of cold supply chain, since thanks to them it is possible to monitor and obtain real-time information of the products such as temperature in the transportation; however, the high cost and a high cargo damages rate is high as well (Li and Chen 2011). Also, DEA two-stage models have been widely applied to pharmaceutical companies. The aim of those studies, such as the one done by Chorfi, Benabbou and Berrado (2016) is to determine the efficiency of the pharmacies in terms of how well the resources of the pharmacies are being used for a certain level of productions. Other models used in this field include the supply chain network game theory model, relevant to pharmaceutical products and fashion and high-tech products (Anna. Nagurney and Li 2015). This model was developed with the objective to minimize their total costs and the weighted disrepute costs. Nagurney and Li (2015) demonstrated the generality of the model and also the generality of the computational scheme. The main idea in this study was to decide the optimal make-or-buy decision and the contractor selection decisions for the firms. Other studies on pharmaceutical scheduling require the analysis of various related aspects, such as batch scheduling, cyclical campaign planning/ scheduling, integration of plant design and campaign scheduling, and consideration of uncertainties in demand and processing time (Sarin et al. 2014).

It is also essential to consider the picking process of the products in the distribution center. Different picking strategies have been used in several studies done in pharmaceutical companies. For example, the study by Venkitasubramony and Adil (2017) includes a vertical travel component in the picking activity. This study mentions how technology can improve both vertical and horizontal movements, making the process friendly, incurring lower costs in the process. Other studies also mention the relevance of the physical characteristics of the products to be collected. Some Heuristics and metaheuristics were developed to provide high-quality solutions to this problem (Chabot et al. 2018).

On the other hand, some studies consider orders and time windows as important elements in the picking time; this is the case of Shiau and Ma (Shiau and Ma 2014), which, through clustering and scheduling orders, improves the distribution process and also includes the packing function in the distribution strategy. Some clustering strategies in warehouses are also revised by Moshref-Javadi and Lehto (2016). Additionally to these studies, Markov chains consider non-deterministic picking time, which usually occurs in pharmaceutical companies. Here, the blockage of workers and the narrow aisle are analyzed to improve the picking in the warehouse (Parikh and Meller 2010).

A correct product distribution strategy includes ensuring that the products demanded by a point of sale or distribution center arrive in good condition and meet the appropriate consumption requirements. Thus, the population's needs are covered, and a high level of service is provided. That is why it is important to have a mathematical model and software that allows optimal results to be obtained, which impacts productivity, customer service, time, and quality of delivery to improve the company's operational performance. One of the software used within the optimization problems in product distribution is AMPL.

2.1 A Mathematical Programming Language—AMPL

AMPL modeling software uses a high-level representation of mathematical models integrated with solvers that contain solution algorithms for a wide variety of problems, including linear and nonlinear. Many organizations and companies in any industry, such as Nasa, Huawei, AT&T, SAS, Siemens, UPS, LinkedIn, Yahoo, and others, use AMPL (2020). Its main advantages are a robust support for handling sets and set operators, its natural syntax for arithmetic expressions, automatic handling of linear and convex quadratic problems, nonlinear programming features, and alternative notations for specific problems (AMPL 2020).

Additionally, AMPL has its programming language. It is possible to connect to row-data files, databases, and spreadsheets to receive input or deliver results as output.

With all these features, AMPL promotes rapid development and reliable results. This software has also been used extensively in research involving optimization problems. For example, the study carried out by Proano et al. (2012) used the AMPL as an optimization model to solve a heuristic that seeks to determine an approximation to the best allocation of combination vaccines in low-income countries.

From another perspective, the study done by Sawik et al. (2017) used the AMPL programming language to solve a multi-objective green logistics optimization problem, using data from a Spanish grocery company, to reduce environmental costs and minimize pollution and noise. Another study involving the procurement of fuel for electricity generation, including logistics constraints used AMPL to solve the problem considering a multistage stochastic model and involving three heuristic strategies to solve such problem over a time horizon (Zimberg et al. 2019). As well, Loree and Aros-Vera (2018) use the AMPL software to solve a mathematical model that seeks to solve the problem of finding distribution points to reach survivors and allocate inventory for local distribution in post-disaster humanitarian logistics circumstances.

3 Methodology

The methodology will be described together with a case study. Consider the case of a pharmaceutical company that handles approximately 12,000 products in its distribution center. The operations of this company extend to almost all the cities of the country, with 500 pharmacies in total, and each month new pharmacies are opened. These pharmacies are classified into three, small, medium, or large depending on the monthly sales volume. Generally, a larger city would have more pharmacies (see Fig. 1). The logistics department of this company ensures an adequate and exclusive inventory for an average of 3500 products in each pharmacy. Thus, the company runs its forecasting model for one and a half million product-pharmacy combinations and must distribute the correct quantity of each product to each pharmacy. Additionally, the pharmacy size is also used to determine specific replenishment days during the week. For example, large pharmacies can be visited every business day for a week, while small pharmacies can be visited once or twice a week. Despite managing a functional forecasting and distribution system, the company identified that psychotropic and cold-chain products require specific handling conditions that directly influence their distribution costs. There are approximately 100 cold chain products to replenish.

The company uses a replenishment system based on maximum and minimum levels for any product in a specific pharmacy. The system daily compares the inventory level of each product in each pharmacy with the minimum level of the product to generate a replenishment order at the distribution center and schedules the dispatch to the transportation department for the next replenishment day.

The current inventory replenishment model is shown in Fig. 2 for a single pharmacy. Figure 2 shows the inventory level overtime for two products. Although this

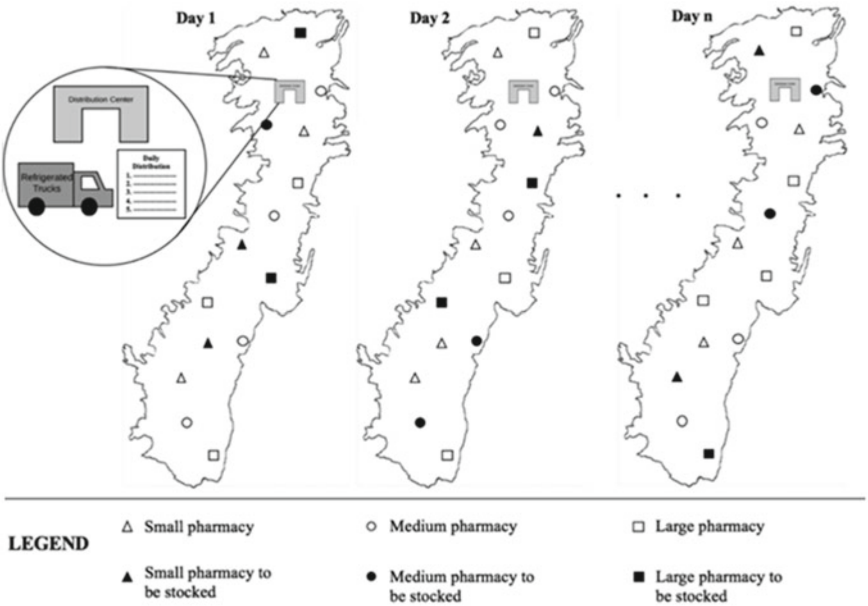


Fig. 1 Map of the city showing various pharmacies and sizes

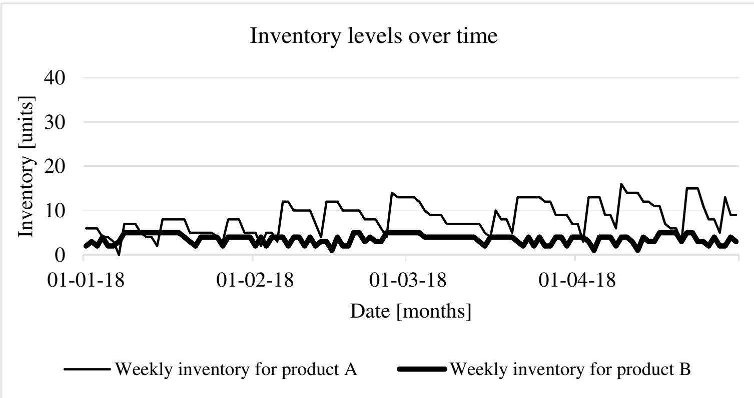


Fig. 2 Current replenishment model for cold chain products for a high-level rotation product (**a**) and a low-level rotation product (**b**)

model is functional due to its high responsiveness, it also has some disadvantages. First, each line with a positive slope means a replenishment event has been generated. Therefore, the current model does not consider that cold chain products incur higher distribution costs than other products. Each time a replenishment is needed, coolers, cooling gels, special personnel, vehicles, and security are needed. From Fig. 2, for example, product A would be replenished 12 times in 4 months, while product B would be replenished 26 times within the same period. Second, operations in the distribution center are unnecessarily inflated due to the special operations required to handle cold chain products. For example, to safely transport a cold chain product, the picking team would take a cooler, use cooling gels, insert the product or products, cover and label the container, and finally send it in a special vehicle with controlled temperature. The time it takes to do this depends primarily on the order size, so even if a pharmacy requires only a couple of units of a specific product, the same operation process is needed. Third, pharmacy operations are also unnecessarily congested due to the reception of multiple and small packages. So, the replenishment periods are not necessarily aligned, increasing the number of times a pharmacy is visited due to different products. Finally, the cooling capacity in pharmacies is not used to the maximum since small inventories are kept inside the cooling container that each pharmacy has. Taking into account all these aspects, even when the current replenishment model is functional, in the end, the costs of operations and distribution of special products increase.

The model required by the company is shown in Fig. 3. The purpose is to aggregate the operations that would have been needed over a period of time for each pharmacy, for example, a month of cold chain inventory. Under this model, the picking and transportation team would work in a specific number of pharmacies to replenish all the cold chain products in each working day. Consequently, product A in Fig. 3 would be replenished four times, and product B would be replenished eight times in the same time window as in Fig. 2. The example for product B in Fig. 3 is used to show that even when demand variability increases unusually, the product will be

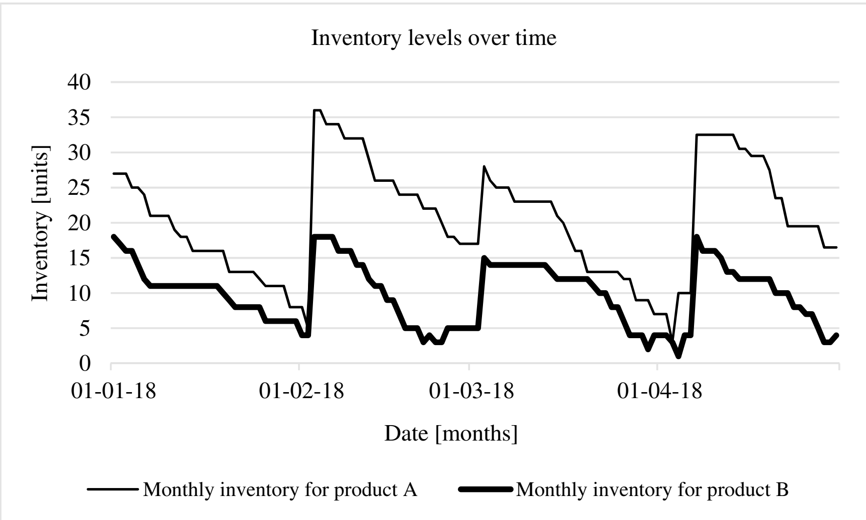


Fig. 3 Replenishment model desired for cold chain products for a high-level rotation product (**a**) and a low-level rotation product (**b**)

replenished using the current model to avoid stockouts. As shown, the number of visits required for a pharmacy will necessarily be less than the current replenishment model and operating, and transportation costs will also be reduced. However, this could lead to increased inventory in the distribution center due to the added inventory intended to be replenished over a more extended period (a month). The question that the company must answer is: when should each pharmacy be restocked so that the inventory level in the distribution center does not increase and the operations in the distribution center are stable?

The following mathematical model expresses the methodology to address the company's requirement.

Sets:

S	Set of products
P	Set of pharmacies
NP	Set of new pharmacies
T	Set of periods for the current month
T_{-1}	Set of periods for the last month

Parameters:

d	Number of workdays in the current month
h	Tolerance for average monetary value per period
a_{pl}	Average sales per day of product l at pharmacy p
r_l	Cost of product l
e_{pt}	Binary parameter being 1 if pharmacy p is replenished at period t
v	Allowable number of days from the last month's replenishment date for the current month
n	Number of replenishment periods per week

Variables:

x_{pt}	Binary variable that will take the value of 1 if pharmacy $p \in P$ needs to be replenished at period t
z_{pt}	Binary variable that will take the value of 1 if pharmacy $p \in P$ needs to be replenished at period t. This variable is a penalty to keep track of the feasibility of the problem
$f(x_{pt}, z_{pt})$	Objective function that minimizes the sum of visits to pharmacies and penalties.

Equation (1) represents the objective function, whereas Eqs. (2–8) represent the restrictions.

$$Minimize f(x_{pt}, z_{pt}) = \sum_{pinP} \sum_{tinT} (x_{pt} + z_{pt}) \tag{1}$$

subject to:

$$\sum_{pinP}\sum_{linS} x_{pt}a_{pl}r_l - \sum_{pinP}\sum_{sinS} z_{pt}a_{pl}r_l \leq \frac{\sum_{pinP}\sum_{linS} a_{pl}r_l}{d} + h \quad tinT \tag{2}$$

$$\sum_{pinP} x_{pt} \leq \frac{P \cup NP}{d} + 1 \quad tinT \tag{3}$$

$$\sum_{tinT} x_{pt} \geq 1 \quad pinP \tag{4}$$

$$x_{pt} \leq e_{pt} \quad pinP, tinT \tag{5}$$

$$-v_n \leq \sum_{tinT} x_{pt}t - \sum_{tinT_{-1}} x_{pt}t \leq v_n \quad pin(P/NP) \tag{6}$$

$$\sum_{tinT} x_{pt}t \leq v_n \quad pinNP \tag{7}$$

$$x_{pt}, z_{pt} binary \quad pinP, tinT \tag{8}$$

3.1 Description of the Model

The objective function (Eq. 1) minimizes the number of replenishment events, reducing the number of days a pharmacy will be visited. The objective implicitly seeks to reduce the logistics costs of products in the cold chain segment. A pharmacy can be visited more than once; however, the objective function will minimize visits for the entire set of pharmacies. The desired situation is when each pharmacy is visited only once a month.

Restriction 2 (Eq. 2) ensures that, in each period, the sum of the dollar amount that is planned to be sent to the different pharmacies is as uniform as possible among all periods of the month. One solution would be to restock all the pharmacies at the beginning of the month. However, by doing that, the inventory required at the distribution center would peak at the beginning of the month, and operations within the distribution center would require additional labor. A suitable solution would not increase inventory levels and would keep operations stable during the month. Restriction 2 considers the decision to restock several pharmacies in a period. The total dollar amount of the products cannot exceed the average dollar amount that must be shipped daily plus a tolerance to allow minor deviations above the mean. This restriction ensures that in each period, the dollar amount sent to all pharmacies in a period is close to the average dollar amount that must be sent daily.

Restriction 3 (Eq. 3) ensures that the number of pharmacies to visit is as uniform as possible in each period. Considering the example given for restriction 2, all pharmacies could be replenished at the beginning of the month. In addition to ensuring the dollar amount sent daily, a proper solution would consider visiting the same number of pharmacies in each period so that transportation resources can be managed uniformly. Restriction 3 adds the number of pharmacies with the new pharmacies (the ones that recently opened in the last month) and calculates an average number of pharmacies that need to be replenished per day. Then, a tolerance is given so that the actual number of pharmacies restocked can have integer values above the mean. Consequently, this restriction ensures that the actual number of pharmacies restocked per period is roughly the average number of pharmacies scheduled to visit.

Restriction 4 (Eq. 4) allows visiting any pharmacy at least once. This ensures that all pharmacies are replenished at least once a month.

Restriction 5 (Eq. 5) considers the days that a pharmacy can be visited and ensures that only on those days will a pharmacy be visited. Each pharmacy is different from the others in several characteristics. Two of the most important are the total sales in a month, which is used to classify pharmacies, and their geographic location within the country, which is used to schedule the supply. Both aspects are considered in determining the number of days per week that a pharmacy could replenish any product. According to managerial decisions, this policy must also be respected for the cold chain products segment to facilitate the reception of the product at each pharmacy on the same day that it is already scheduled. Restriction (5) will ensure that each pharmacy's replenishment day has been assigned.

Restriction 6 (Eq. 6) establishes the link between the last and the current month. The link will allow one to visit a pharmacy within a range of $\pm\, v$ days (5 days, for example) from the date that a pharmacy was visited in the previous month. This is to avoid the possibility that a pharmacy that was replenished at the beginning of the last month may be able to replenish at the end of the current month. In this scenario, such a pharmacy would have to wait almost two months to be replenished. Restriction 6 uses a tolerance that creates a solid 10-day range in which a pharmacy can be replenished compared to the last month. The functionality of restriction 6 is expressed in Fig. 4. There are two timelines. In the first timeline, the replenishment date for a pharmacy was the 15th of the previous month ($T_0 - T_1$). Therefore, for

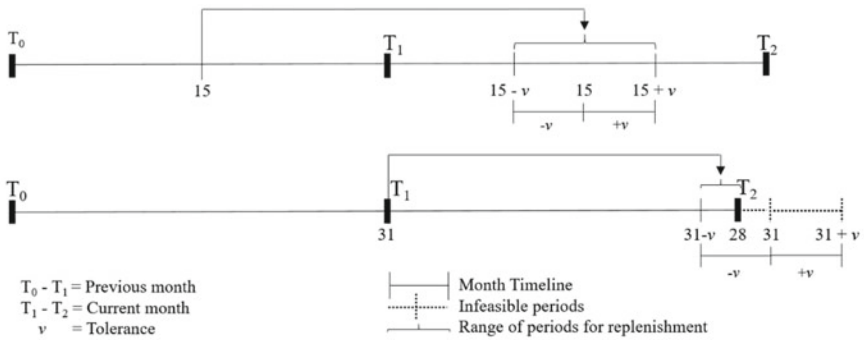


Fig. 4 Replenishment restriction considering previous month replenishment

the current month, the replenishment will be either five days more or five days less than the 15th of the current month ($T_1 - T_2$). The second timeline shows an extreme case where the previous month has 31 days and the current month has 28 days. The replenishment date for the previous month was the 31st day; thus, for the current month, the only days available are from the 26th to the 28th. All days after the 28th become infeasible as the model finds a solution to replenish once a month.

Restriction 7 (Eq. 7) considers new pharmacies that are opened during a month. To consider the new pharmacies in the problem, it should be considered that a new pharmacy should not be replenished at the end of a month because it would not have products to sell until the next time. Therefore, restriction 7 ensures that the visit will be within the first v days of the month (the first five days, for example). Finally, restriction 8 (Eq. 8) ensures that the decision variables are binary.

The implementation of the mathematical model consists of two stages. Stage 1 considers the objective function (Eqauton 1) and restrictions 2 to restriction 5 and restriction 8. This stage generates a first replenishment schedule without information about last month's replenishment. Stage 2 is used to generate a replenishment program considering the objective function (Eq. 1) and restriction 2 to restriction 8 to take into account the dates of the previous program and to schedule new points of sale.

4 Application

The modeling software used to run the mathematical model is AMPL version 3.6.4 with Gurobi 9.1.1 solver. The processor used is an Intel(R) Core(TM) i7-8550U CPU @ 1.80 GHz, 2.00 GHz and 8 GB in RAM. The solver finds an optimal solution in 0.75 s, but it should be noted that these numbers can vary depending on the number of points of sale that are currently running within the model. As the company increases in the number of pharmacies, the authors estimate that the time to resolution would not be an issue. Additionally, in practice, the company could use a version of the model that solves in Python using solver Pulp, an open source software. The results obtained will be followed described.

4.1 Stage 1

As an example, the following case has been studied. The end of December is approaching, and a company wants to improve the distribution of its cold chain products. In the country, this company would have 506 pharmacies in 92 cities. Currently, 72 cold chain products are part of the company's general catalog. To improve its distribution, the company needs a schedule for January that establishes the day on which a pharmacy restocks with enough product to sell in January. Consider that January has 31 days but only 22 working days (visits to pharmacies cannot be Saturdays, Sundays, or holidays, see Table 1). Additionally, each pharmacy's average daily sale of each product is variable but known through forecasting methodologies (see Table 2). Finally, the company's main objective would be to create the January schedule without impacting inventory and operations at the distribution center.

Table 1 Days in the month that the replenishment can be done

Point of sale	Days					
	1	2	3	..	30	**31**[a]
P1	1	0	1	..	0	1
P2	0	1	1	..	1	1
P3	0	1	1	..	1	1
P4	0	1	0	..	1	0
..	..	..	..	..	..	..
P504	1	0	1	..	0	0
P505	0	0	1	..	0	0
P506	0	1	1	..	0	0

a_{pl} = average sales per day of product l in pharmacy p

Table 2 Average daily sales of 72 products in 506 pharmacies

Pharmacy	Product					
	L1	L2	L3	..	L71	L72
P1	0.0186	0.0000	0.0000	..	0.0000	**0.0407**[a]
P2	0.0000	0.0000	0.0000	..	0.0000	0.0000
P3	0.1255	0.0000	0.0000	..	0.0000	0.0000
P4	0.0000	0.0000	0.0768	..	0.0000	0.0000
..	..	..	..	..	..	..
P504	0.0000	0.0000	0.0000	..	0.0000	0.0000
P505	0.0000	0.0000	0.0000	..	0.0000	0.0000
P506	0.1687	0.0000	0.0000	..	0.0000	0.0000

[a] a_{pl} = average sales per day of product l in pharmacy p

Table 3 January replenishment metrics for stage 1

Replenishment metrics	Value
The average number of points of sale replenished per day [u]	23.00
The standard deviation of the number of points of sale replenished per day [u]	1.88
The average monetary value of inventory replenished per day [USD]	85,659.86
The standard deviation of the monetary value of inventory replenished per day [USD]	91.03

Table 4 February replenishment metrics for stage 2

Replenishment metrics	Value
The average number of points of sale replenished per day [u]	25.40
The standard deviation of the number of points of sale replenished per day [u]	1.20
The average monetary value of inventory replenished per day [USD]	146,584.00
The standard deviation of the monetary value of inventory replenished per day [USD]	82.74

Under these conditions, the model is run without considering restrictions (6) and (7). The adjusted problem contains 23,380 binary variables and 1458 inequality constraints. The results are shown in Figs. 5 and 6. The average number of pharmacies to visit per working day is 23, and the standard deviation of the observations is 1.88 pharmacies. However, this variability occurs mainly in 3 of the 22 periods. Based on the results, 86% of the periods are scheduled to replenish 22, 23, or 24 pharmacies, considering a range of values between 1 pharmacy above and one pharmacy below the average.

In comparison, the remaining 14% of the periods are scheduled to replenish 17,19 and 20 pharmacies. Figure 6 shows the monetary value sent to pharmacies in each period. The average monetary value sent per period is $85.660,00, and the standard deviation is $91,04 generating a coefficient of variation of 0.0011 (Table 3).

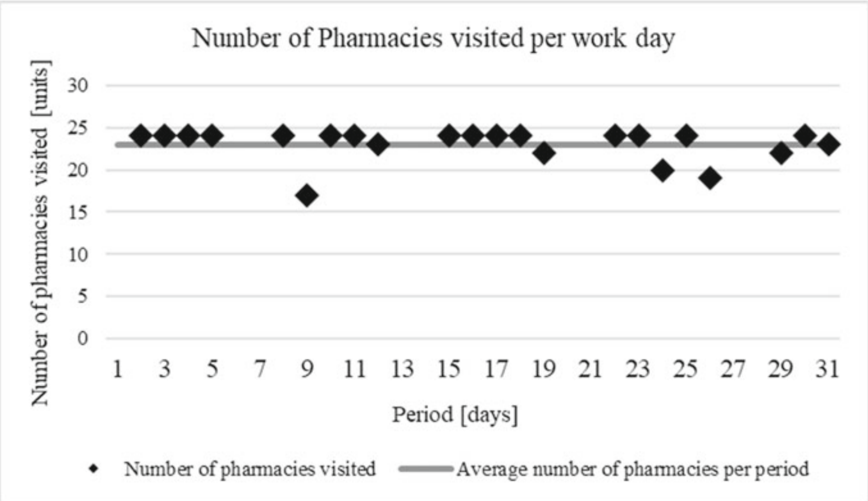


Fig. 5 Stage 1 Schedule results measured by the number of pharmacies replenished in each period

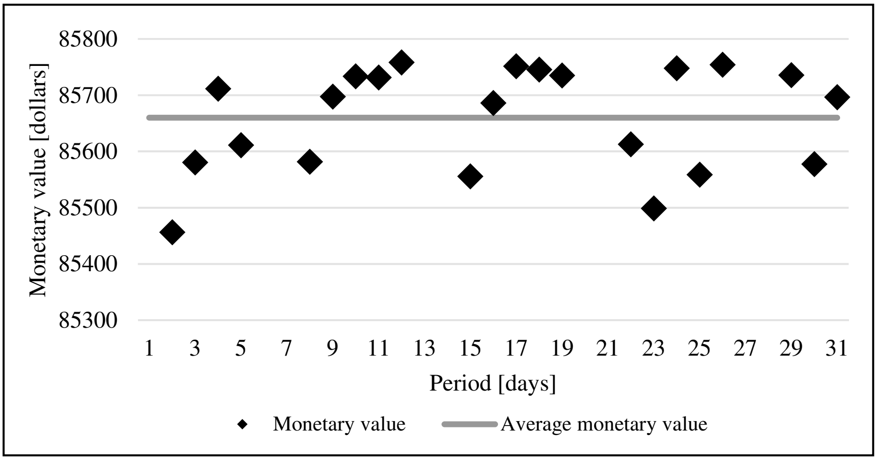


Fig. 6 Stage 1 Schedule results measured by the expected monetary value to be sent to the pharmacies in each period

4.2 Stage 2

The company successfully implemented the January replenishment Schedule, and now they want the February schedule. The implementation of the replenishment schedule for February considers additional restrictions. For a month, the company opens new pharmacies and closes pharmacies not selling as expected. New pharmacies should not wait to be replenished for the first time, say at the end of the month; therefore, new pharmacies must be replenished at the beginning of the month. Additionally, a non-new pharmacy should be replenished close to the last month's restock date to avoid stockouts and overstocks. Finally, cold chain products can also be added or removed from the catalog based on their sales or the supplier capacity availability.

Consider the following assumptions for February. February has 28 days and only 20 working days. Pharmacies P192, P246, P295, P415, P496, P499, and P69 were closed while P507 to P515 were opened. The company needs to replenish 508 pharmacies by February. Furthermore, product L54 was discontinued while L73 and L74 were added to the catalog. Consequently, 73 products must be replenished in different pharmacies according to the information from the forecasting department.

Under these conditions, the model is run considering restrictions (6) and (7). The adjusted problem contains 19.217 binary variables and 1458 inequality constraints. The results are shown in Figs. 7 and 8. The average number of pharmacies to visit per working day is 25.4, and the standard deviation of the observations is 1.2 pharmacies. Only one period increases variability. In period 21, only 21 pharmacies are scheduled to replenish. 95% of the periods are scheduled to replenish 24, 25, or 26 pharmacies, which considers a range of values between 1 pharmacy above and one pharmacy below the average.

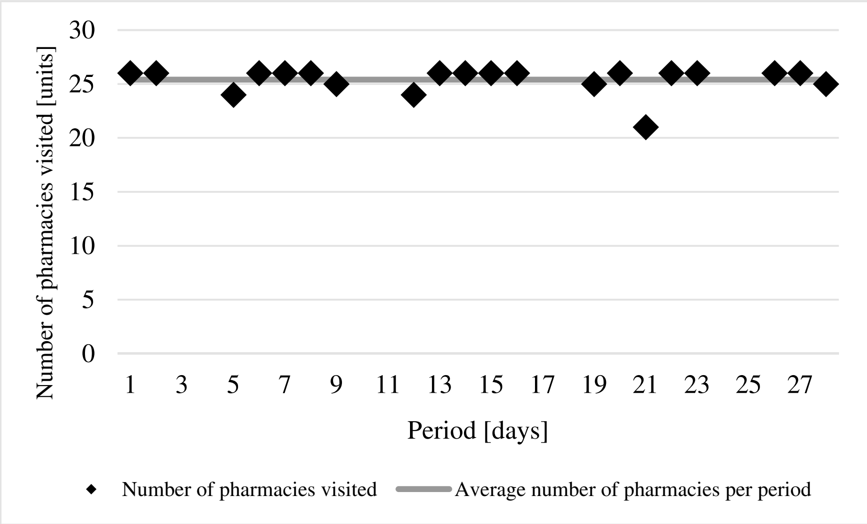


Fig. 7 Stage 2 Schedule results measured by the number of pharmacies replenished in each period

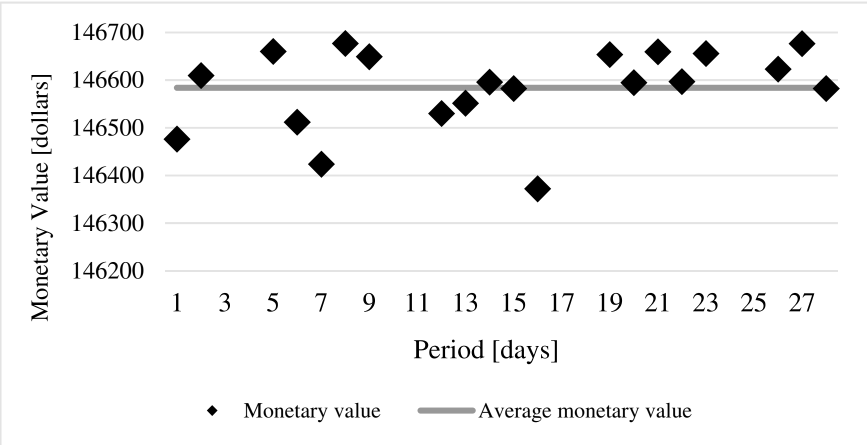


Fig. 8 Stage 2 Schedule results measured by the expected monetary value to be sent to the points of sale

In comparison, the remaining 5% of the periods are scheduled to replenish 21 pharmacies. Figure 8 shows the monetary value sent to pharmacies in each period. The average monetary value sent per period is $146.584,00, and the standard deviation is $82,73, generating a coefficient of variation of 0.00056 (Table 4).

5 Conclusions

Pharmacies replenishment scheduling was obtained for one month according to the company's needs, reducing the number of replenishment events and, therefore, the logistics costs associated with cold chain and psychotropic products. In the real application, the replenishment events were reduced from 3100 to 950 events (a 70% reduction in replenishment events). This model runs at the end of one month to schedule the replenishment dates for the next month for each pharmacy. The schedule considers available days to replenish and aggregates the demand for the products for each pharmacy, which is replenished once a month, week, or every other week.

The software used to solve the problem presented in this paper was Gurobi solver with AMPL programming language that provides an optimal solution. The implementation of the model consists of two stages. In stage 1, a first replenishment schedule is generated at the beginning of a month. For subsequent months, the previous month's schedule is considered to generate the current month's schedule in stage 2. The results are measured quantitatively and satisfy the company's needs. Within a month, each working day has approximately the same number of pharmacies to replenish products; the inventory in the distribution center is not affected.

The variability of monetary values between working days is negligible compared to dollars sent each working day. Finally, the new pharmacies are replenished at the beginning of each month to meet the demand for these products. The mathematical model is flexible to changes in the size of the problem, and new and discontinued products are easily accounted for in the model. Similarly, new pharmacies and pharmacies that have been closed are updated each time the model is run. As a result, the model is robust to changes in the real application.

6 Limitations and Future Studies

One limitation of the study is that the exact reduction in costs is not necessarily proportional to the reduction in replenishment events, and therefore it cannot be calculated precisely. This lack of cost traceability is that when inventory is aggregated for more extended periods, it can be possible to use more storage and packaging materials for one larger order than for one smaller order. However, one should notice that reducing replenishment events will reduce the need for storage and packaging materials.

Since this study proposes a model that could be used in a specific region (e.g., cities, countries, etc.), it can be possible that all the pharmacies in the same city are replenished on the first day of a month. That means there will be no replenishment for the city until next month. This is undesirable given that when a pharmacy runs out of stock, nearby pharmacies can send their products to avoid lost sales. This process is called transfer. It could be helpful to modify the model so that for a specific city having several pharmacies, the replenishment schedule visits them in equal time windows along the month. In other words, the visits to all the pharmacies within the same city will be done not just in the former or the latter days. Instead, the visits will be distributed relatively during the month.

A more advanced model would consider the franchise model that the company manages. Currently, the company owns approximately 60% of all pharmacies in the country. Within the remaining 40%, investors who acquired a franchise for their pharmacies managed from 1 to 5 pharmacies and not necessarily in the same city. Transferring products from pharmacies that belong to the same investor is easier. Therefore, the mathematical model could consider pharmacy ownership probably in the same city or nearby cities to replenish fairly during the month.

More studies should be done to determine the value of the parameter h, the tolerance for the average monetary value sent daily. Although the value of h was imposed in this study, satisfactory results were obtained. However, better results can be found if the model finds the lowest value of h that minimizes the standard deviation of the reported monetary values while considering the other restrictions of the model.

Finally, it would be interesting to include the use of DEA to evaluate the performance of each pharmacy, before and after the implemented methodology.

References

Alvarado, M., De la Paz, S., Fuentes, C.M.: Diseño de un modelo de logística inversa para mejorar la competitividad de las empresas del sector farmaceútico en El Salvador. (Ingeniería Industrial). Universidad de El Salvador, Ciudad Universitaria (2008)

AMPL.: Customers (2020). Retrieved from https://ampl.com/products/ampl/

Belixán, N., Miguens, F.M., Doctorovich, B.V., Alvarez Constantino, M.P.: Pscicotrópicos: una visión abarcativa. In Pscicotrópicos y Estupefacientes: Visión farmacológica y normativa, pp. 117–142 (2009)

Bolaños, R.: Uso Racional de Medicamentos y buenas prácticas de Prescripción. In: Psicotrópicos y Estupefacientes: Visión Farmacológica y Normativa. Organización Panamericana de Salud (2009). https://docplayer.es/123899532-Psicotropicos-y-estupefacientes-vision-farmacologica-y-normativa.html

Chabot, T., Lahyani, R., Coelho, L.C., Renaud, J.: Alternative heuristics for solving the multi-constrained order picking problem. Paper presented at the 9th IEEE-GCC Conference and Exhibition, Manama, Bahrain (2018)

Chorfi, Z., Benabbou, L., Berrado, A.: A two stage DEA approach for evaluating the performance of public pharmaceutical products supply chains. Paper presented at the 3rd International Conference on Logistics Operations Management (GOL), Fez Morocco (2016)

De La Cruz, V., Luna, M.d.R., Ramírez, M.A., Robles, E.O., Tapia, T.: Diseño de una estrategia logística de rutas para la distribución de productos farmacéuticos. (Administración Industrial Ingeniería Industrial. Ingeniería en Transporte). Instituto Politécnico Nacional, México D.F (2010)

Edwards, K., Jensen, P.L.: Design of systems for productivity and well being. Appl. Ergon. **45**, 26–32 (2014). https://doi.org/10.1016/j.apergo.2013.03.022

Gebicki, M., Mooney, E., Chen, S.-J.G., Mazur, L.M.: Evaluation of hospital medication inventory policies. Health Care Manag. Sci. **17**, 215–229 (2014). https://doi.org/10.1007/s10729-013-9251-1

Hammoudan, Z., Grunder, O., Boudouh, T., Moudni, A.E.: A coordinated scheduling of delivery and inventory in a multi- location hospital supplied with a central pharmacy. Logistic Res. **9**, 18 (2016). https://doi.org/10.1007/s12159-016-0145-8

International Pharmaceutical Federation, I.P.F.: Pharmacy at a glance (2017). Retrieved from https://fip.org/files/fip/publications/2017-09-Pharmacy_at_a_Glance-2015-2017.pdf

Jaberidoost, M., Nikfar, S., Abdollahiasl, A., Dinarvand, R.: Pharmaceutical supply chain risks: a systematic review. Daru J. Faculty Pharmacy, Tehran Univ. Med. Sci. **21**(69), 69 (2013). https://doi.org/10.1186/2008-2231-21-69

Ji, S.W., Wu, X., Wang, Y.F., Su, G.: Study of optimization of cargo space allocation based on jointown pharmaceutical logistics center. Appl. Mech. Mater. 701–702 (2014)

Jordan Halter, M.: Varcolis' Foundations of Psychiatric-Mental Health Nursing, 8 edn. Elsevier (2018)

Kim, H., Jeong, H.-I., Park, J.: Integrated model for production planning and scheduling in a supply chain using benchmarked genetic algorithm. Int. J. Adv. Manuf. Technol. **2008**(39), 1207–1226 (2008). https://doi.org/10.1007/s00170-007-1298-z

Kim, J., Kim, H., Moon, I.: A novel scheduling model for pharmaceutical industries using heuristic techniques. Paper presented at the International Conference on Control, Automation and Systems 2008, COEX, Seoul, Korea (2008)

Kogan, K., Perlman, Y., Hovav, S.: Equilibrium replenishment in a supply chain with a single distributor and multiple retailers. IMA J. Manag. Math. **20**(4), 395–409 (2009)

Kulkarni, N.S., Suman, N.: Multi-echelon network optimization of pharmaceutical cold chains: a simulation study. Paper presented at the Proceedings of the 2013 Winter Simulation Conference (2013)

Li, F., Chen, Z.: Brief Analysis of application of RFID in pharmaceutical cold-chain temperature monitoring system. Paper presented at the International Conference on Transportation, Mechanical, and Electrical Engineering (TMEE), Changchun, China (2011, December 16–18)

Loree, N., Aros-Vera, F.: Points of distribution location and inventory management model for Post-disaster Humanitarian Logistics. Transp. Res. Part **3**(116), 1–24 (2018). https://doi.org/10.1016/j.tre.2018.05.003

Marsh, D. (2011). Selection of Drug Delivery Approaches for the Back of the Eye: Opportunities and Unmet Needs. In E. H. Kompella U. (Ed.), Drug Product Development for the Back of the Eye (Vol. 2). Boston: Springer.

McLean, D.: Cold Chain Shipping: Protecting Temperature Sensitive Products (2009)

Ministerio de Salud Pública, M.S.P.: Entidades que deben realizar el reporte de precios de medicamentos (2014). Retrieved from http://instituciones.msp.gob.ec/images/Documentos/medicamentos/medicamentos2014/entidades_que_deben_reportar.pdf

Moshref-Javadi, M., Lehto, M.R.: Material handling improvement in warehouses by parts clustering. Int. J. Prod. Res. **54**(14), 4256–4271 (2016). https://doi.org/10.1080/00207543.2016.1140916

Mouaky, M., Berrado, A., Benabbou, L.: A Kanban based system for multi-echelon inventory management: The case of pharmaceutical supply chain. Paper presented at the 2016 3rd International Conference on Logistics Operations Management (GOL), Fez, Morocco (2016)

Nagurney, A., Yu, M., Masoumi, A.H., Nagurney, L.S.: Pharmaceutical supply chains. In: Networks Against Time. Springer Briefs in Optimization. Springer, New York, NY (2013). https://doi.org/10.1007/978-1-4614-6277-4_5

Nagurney, A., Li, D.: A supply chain network game theory model with product differentiation, outsourcing of production and distribution, and quality and price competition. Ann. Oper. Res. **226**(1), 479–503 (2015). https://doi.org/10.1007/s10479-014-1692-5

Naranjo, I. (2018, July 11, 2018) Estimated costs of psycotropics and cold chain products distribution. (Interviewer: G. Mosquera)

Parikh, P.J., Meller, R.D.: A note on worker blocking in narrow-asile order picking systems when pick time is non-deterministic. IIE Trans. **42**(6), 392–404 (2010). https://doi.org/10.1080/07408170903171043

Proano, R.A., Jacobson, S.H., Zhang, W.: Making combination vaccines more accessible to low-income countries: the antigen bundle pricin problem. OMEGA Int. J. Manag. Sci. **40**, 53-64. https://doi.org/10.1016/j.omega.2011.03.006

Sarin, S.C., Sherali, H.D., Liao, L.: Primary pharmaceutical manufacturing scheduling problem. IE Trans. **2014**(46), 1298–1314 (2014). https://doi.org/10.1080/074081714.2014.882529

Sawik, B., Faulin, J., Pérez-Bernabeu, E.: A multicriteria analysis for the Green VRP: A Case discussion for the distribution problem of a Spanish retailer. Transp. Res. Procedia **22**, 305–313 (2017)

Shanley, A.: Cold Chain: zeroing in on the last mile. Pharm. Technol. **41**(2), 68–71 (2017)

Shao, X., Ji, J.: Reconfiguration of Pharmaceutical logistics operations in China: an empirical study. Transp. J. **45**(4), 52–66 (2006)

Shiau, J.-Y., Ma, H.-L.: An order picking heuristic algorith for economical packing. Paper presented at the 11th IEEE International Conference on Networking, Sensing and Control, Miami, FL, USA (2014, 7–9 April 2014)

Venkitasubramony, R., Adil, G.K.: Design of an order-picking warehouse factoring vertical travel and space sharing. Int. J. Adv. Manuf. Technol. **91**(5–8), 1921–1934 (2017). https://doi.org/10.1007/s00170-016-9879-3

Zimberg, B., Testuri, C.E., Ferrari, G.: Stochastic modeling of fuel procurement for electricity generation with contractual terms and logistics constraints. Comput. Chem. Eng. **123**, 49–63 (2019). https://doi.org/10.1016/j.compchemeng.2018.12.021

Inventory Management Optimization of a Container Glass Products Manufacturer

Lucia Medina, Berend Raaijen, Manuel Peña, Ana Luna, and Mario Chong

Abstract This research focuses on inventory management in Peru's container glass products manufacturer. Glass is a packaging option aligned to human safety and planet sustainability. We analyzed its strategic situation aligned to its operational plan. Then, the supply chain strategy develops an inbound raw material and outbound products balance, with the interactions between purchasing, production and sales. The proposed solution optimized the paint flow, reduced its inventory and its related material obsolescence. The stored data existed in the SAP S/4 Hana cloud system, simplifying the project execution from the bottom line to the up line and relating with the company's green line vision. Due to the increasing influence of the information systems and their implementation for specific problems, we presented an MRP, S&OP or IBP dilemma.

Keywords Supply chain management · Glass producer · Inventory management

1 Introduction

Despite the "*Niño costero*" phenomenon adverse effects at the beginning of 2017 and corruptions cases in Peru, the economy is growing (Parodi 2017). Likewise, technological advances and communication development are taking place; the consumers

L. Medina · B. Raaijen · A. Luna · M. Chong (✉)
Universidad del Pacífico, Jr. Sanchez Cerro N°2141, Jesus María, Lima 15072, Peru
e-mail: m.chong@up.edu.pe

L. Medina
e-mail: gl.medinaa@alum.up.edu.pe

B. Raaijen
e-mail: bp.raaijenl@alum.up.edu.pe

A. Luna
e-mail: ae.lunaa@up.edu.pe

M. Peña
Universidad Nacional Mayor de San Marcos, Calle Germán Amézaga N° 375, Lima, Perú
e-mail: manuel.pena3@unmsm.edu.pe

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_15

are more informed and demand competitive (Deloitte 2016), innovative, and environmentally friendly companies (Castillo et al. 2019). Software development has myths of managers, clients, and developers (Pressman 2014), but in this project, we broke several myths with this applied project from the design to the test.

In Peru, more than 60% of consumers strongly influence their purchases (Arellano Marketing 2014). Companies have significant challenges in this context; they must manage their internal processes and integrate their external entities, flows, and procedures with their entire supply chain (Chopra 2020). Operations research models and tools determine optimal purchases, operations, sales, supply chain, and other processes (Cheater 2017) despite technological development. Peruvian companies usually manage their inventory problems with over-hedging policies (Gonzalez-Feliu et al. 2019). In this work, we studied and analyzed the case of a Peruvian glass manufacturing plant with a market share of 90% and strategical influence for 30 years.

One of the financial objectives of this company, presented in its strategic plan, is to obtain more than 2.5% of Earnings Before Interest and Taxes (EBIT). The Decision-makers consider that this objective has two options: increase prices or reduce costs. Currently, the two production plants utilization rate is near 95%, and contracts committed their future productions. Increase their prices would be counterproductive; its natural substitute, polyethene terephthalate (PET) products (Samadi et al. 2019) (Roberta et al. 2020), could increase their market share. Reducing the cost by optimizing the process is the best decision. Therefore, one of the objectives of the company is to understand its entire cost structure. Thus, the company supports several projects to improve competitiveness in the packaging market and the projection of expenses.

This research will optimize paint inventory management through the following steps: optimizing the paint inventory level, reducing the cost of obsolete material, and unfreezing working capital. The remainder of this study is structured as follows: Sect. 2 develops the methodology. Section 3 describes and discusses the main results. Section 4 addresses the conclusions. Finally, in Sect. 5, recommendations for future research are presented.

2 Methodology

This section describes the methodology through three phases: strategic planning, process analysis and the improvement proposal. We used data provided by internal system information with SAP S4/Hana Cloud, processed data using SAP Predictive Analytics and analyzed the information supported by the company's decision-makers. We used the quality software metrics of correction, reliability, efficiency, integrity, maintenance, flexibility, test capacity, portability, reusability, interoperability, and reusability (Pressman 2014) in this development.

2.1 Phase 1—Strategic Planning

This systematic process of developing and implementing plans to achieve goals or objectives has three steps: external analysis, internal analysis, and competitive advantage. The external analysis develops the macro environment (political-governmental-legal, economic, sociocultural-demographic, environmental, and technological variables) (Weinberger 2009; David et al. 2017), the microenvironment (five forces; competitive rivalry, power of the provider, power of the buyer, threat of new entrants, and substitutions) (Porter 2009), the competitive profile and other external factors (David et al. 2017). The internal analysis develops the business model, the value chain, the functional areas, and other internal factors (Porter 1998, 2009). Competitive advantage develops its competitive strategy, objectives, and value proposition (David et al. 2017).

The company produces and distributes container glass within the packaging sector. In Peru, the annual demand for container glass exceeds US$90 million/year, driven by the food and beverage sectors growth (Robayo 2017; Roberta et al. 2020). The packaging industry is growing, driven by population and international trade growth (Diaz et al. 2020). With a market share first position, the company has been able to take advantage of its opportunities. Its significant investments in technology, production plants, research, and development have allowed it to generate very high barriers to the entry of other players. The sector is considered attractive due to the absence of solid competitors and risky at the same time due to the level of investment it involves in technology (Senge et al. 2011), fixed assets, and research and development (Gonzalez-Feliu et al. 2019). On the other hand, the force that represents a threat is that of substitute products, since there are categories such as PET or aluminum that could be attractive to customers due to the lower cost involved.

2.2 Phase 2—Process Analysis

We analyzed the relevant processes with greater relevance to the strategic financial objectives. The increase in profitability stands out by having an adequate cost structure with environmentally friendly processes. These processes are:

- Planning (P1)
- Sales (P2)
- Production (P3)
- Purchasing (P4)
- Distribution (P5)
- Supply (P6)
- Financial planning (P7)
- Quality assurance (P8)
- Forming-Decorating-Packing (P9)
- Credit and collections (P10)

- Recruitment (P11)
- Technology (P12).

We used the key performance indicators (KPI) aligned with the Supply Chain Operations Reference model (SCOR-model) (Bolstorff 2012; Weenk 2019). We linked the company's objectives with logistic processes and developed a systematic approach to identify, monitor, and improve its performance (Pressman 2014). The criteria for evaluating supply chain processes will be customer reliability and agile with a competitive cost. Then, we used the Analytical Hierarchy Process (AHP) (Saaty 1995) to select the critical operations, organize criteria and analyze complex decisions in a structured way (Holguín-Veras 1995), as Customer service level (C1), Responsiveness and flexibility (C2), Supply chain costs (C3), and Asset Management (C4).

Finally, we identified the causes and evaluated the effects of the main problem (Glenday and Brunt 2007); and analyzed the interactions between planning, production plant (Weenk 2019) and decorative paints using the Value Stream Mapping (VSM) (Venkataraman et al. 2014; Rohac and Januska 2015).

2.3 Phase 3—Improvement Proposal

The outcome of this project was improving the inventory management aligned to human safety and planet sustainability that support the decision-makers at the production plant. The analysis presented by SAP S4/Hana reports identifies the most influential process and provide information to other areas: operations, supply chain management and sales.

3 Results

We conducted several interviews with the company's collaborators, focused on manufacturing plant, purchasing and demand planning to validate the methodology phases (strategic planning, process analysis and improvement proposal). The AHP technique (Table 1) identified the most critical issues: planning and managing inventories of raw materials and supplies, sales projection, and production schedule.

Then, a cause-effect diagram (Valencia 2002) identified the main problem: the stock and obsolescence of decoration-painting raw materials. The cause was the silo effect between areas, which impacted on low turnover and obsolescence of these products (Fig. 1).

In the current project, we proposed integrated planning considering the project's coverage by MRP (Material and Requirement Planning) (Kortabarria et al. 2018; Westkämper et al. 2018; Chopra 2020), S&OP (Sales and Operation Planning)

Table 1 Process evaluation results

	C1	C2	C3	C4	Weight
Process/criteria	0.541709	0.055492	0.226866	0.175933	
	54%	6%	23%	18%	
P1	0.217	0.195	0.233	0.025	0.185
P2	0.189	0.186	0.166	0.093	0.167
P3	0.163	0.157	0.147	0.086	0.145
P4	0.11	0.119	0.112	0.083	0.106
P5	0.082	0.101	0.084	0.075	0.083
P6	0.068	0.071	0.072	0.194	0.091
P7	0.045	0.05	0.049	0.204	0.074
P8	0.034	0.03	0.042	0.058	0.040
P9	0.035	0.029	0.036	0.059	0.039
P10	0.021	0.025	0.025	0.04	0.026
P11	0.021	0.018	0.018	0.046	0.025
P12	0.014	0.016	0.016	0.037	0.019
	1.000	1.000	1.000	1.000	1.000

Source Own elaboration

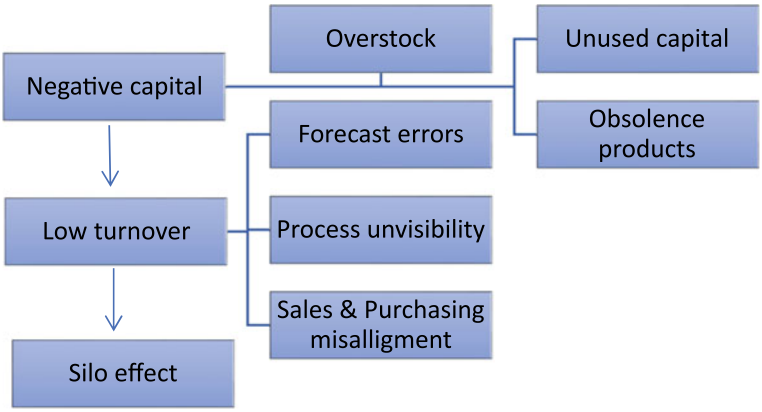


Fig. 1 Tree diagram. *Source* Own elaboration

(Palmatier and Crum 2013; Wallace and Stahl 2014) or IBP (Integrated Business Planning) (Weenk 2019; Chopra 2020) shown in Table 2, with these parameters:

- Consider paint inventory turnover rate per year greater than six.
- Maintain inventory coverage for more than two months.
- Reduce obsolesce products.
- Decrease the cost of inventory management.

Table 2 Project's coverage

Coverage	MRP	S&OP	IBP
Promote and improve coordination between areas		X	X
Increase operational processes automatization	X		
Provide greater visibility		X	X
Improve the decision-making process	X	X	X
Support compatibility with ERP and company software	X	X	
Encourage integrated planning		X	
Adapt to the culture of teamwork	X	X	X
Facilitate training and coaching	X	X	
Support and encourage change management	X	X	X
Total	6	8	5

- Eliminate urgent orders.
- Manage processes automatization.
- Generate savings.

The implementation cost of the MRP and S&OP has these three parts: software and infrastructure, maintenance, and training, shown in Table 3. Finally, we obtained the implementation saving by area, shown in Table 4.

The critical process identified and described in Tables 3 and 4 impacted the company's planning inventories divisions shown in Table 5. Incorporating the MRP Controller carried out several benefits: update painting purchases, reduce

Table 3 Implementation costs

Cost\tool	Weight (%)	MRP	S&OP
Software and infrastructure	50	$10,000	$10,000
Maintenance	15	$1000	$1500
Training	35	$3000	$15,000
Total	100	$14,000	$26,500

Source Own elaboration

Table 4 Implementation benefits

Profit\tool	Weight (%)	MRP	S&OP
Savings by reducing inventory management costs	50	$197,400	$564,000
Savings for extra costs of express delivery	15	$22,400	$56,000
Saving obsolete inventory reduction	35	$77,000	$154,000
Total	100	$296,800	$774,000

Source Own elaboration

Table 5 Company's inventory categories

Category	Percentage (%)	Turnover rate
Packaging	09	67
Raw materials	38	82
Spare parts	48	380
Supplies	05	56
Total	100	

Source Own elaboration

obsolescence, adjust inventory, establish order points, replenish order requests and acquisition, and purchase raw materials by categories.

Based on specific pre-established criteria, the MRP Controller prioritizes the paint material as relevant. The lack of confidence regarding the information on the decoration plan, which is different from the prepared consumption plan, was identified. This fact generates uncertainty in consumption and distrust towards future projects. The proposal for S&OP seeks to enhance the procedure related to the scheduling of purchase orders (Fig. 2):

- Collaborative culture
- Change management

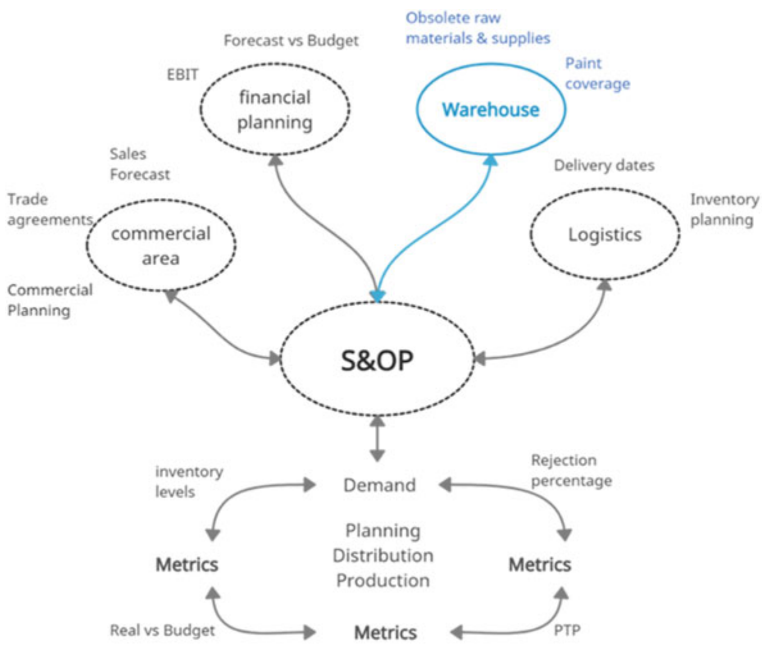


Fig. 2 Proposal for S&OP. *Source* Own elaboration

- A team committed to the process, systems and maintenance.

We used the Failure Mode and Effects Analysis matrix (FMEA) to measure the proposal's impact (Wu and Tang 2020). This tool comprises three steps:

First step: supply process of paints and effects.
Second step: causes and occurrence.
Third step: controls and detection.

The Risk Priority Number (RPN) was calculated considering severity, occurrence, and detection of all the process steps (Wu and Wu 2021). For the paint consumption process, an RPN equal to 210 was obtained, which is better than the score obtained before the improvement process, an RPN of 630 (Table 6).

The project scope divided into seven steps shown in Fig. 3, had the following benefits:

- Increase teamwork shared risk management between different areas
- Improve complete product-material delivery, reducing costs
- Reduce inventory reduction and obsolescence
- Collaborate between shareholders and internal and external customers
- Incorporate the MRP Controller into the S&OP process (Table 7).

We calculated the risk matrix and expected losses of each implementation phase in Table 8.

Table 6 FMEA matrix summary

Process step/entry	Previous RPN	Obtained RPN
Sales forecast	567	189
Production program	420	280
Paint consumption	630	210
Warehouse/purchases	600	150
Consumption	540	100
Forecast consolidation and shipping	450	100

Source Own elaboration

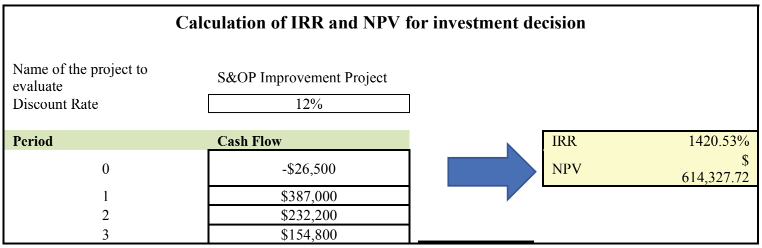


Fig. 3 S&OP proposal. *Source* Own elaboration

Table 7 Project scope

S&OP process	Introduction	Presentation
		Documentation
		Kick off
	Management change	Team presentation
	SAP interface	Transactions' development
		MRP setup
		User training
	Data analysis	Production information
		BOM analysis
		SAP BOM
	Simulation	MRP execution
		MRP validation
	Implementation	Production information
		MRP execution
		MRP validation
		Inventory validation
	Close	Paint purchase
		Production plan
		Purchase plan

Source Own elaboration Based on: Palmatier and Crum 2013; Wallace and Stahl 2014

3.1 Economic Evaluation

The feasibility and profitability evaluation analyzed the NPV (Net Previous Value) and the IRR (Internal Rate of Return) based on future flows. The improvement in paint inventory management and the cost–benefit of S&OP implementation are shown in Fig. 3.

According to the results, this project generates a positive NPV and a good percentage of IRR. Therefore, the project is highly viable and generates quantified benefits. The results show the positive impact of optimization in paint inventory management.

Table 8 Risk matrix

Risk	Risk factor	Total loss $	Risk controllers	Risk %	Impact controllers	Impact %	Expected loss $
R1	Production program	20,000	Plant Manager	40%	Analysis and restructuring of roles and tasks	80%	6400
R2	Leadership	15,000	Human Resource Management	20%	Feedback	70%	2100
R3	Collaborator profiles	10,000	Contingency staff	20%	Analysis and restructuring of roles and tasks	60%	1200
R4	Commitment	10,000	Sponsor commitment	10%	Teamwork incentive program	60%	600
R5	Consensus	5000	Prioritization criteria	10%	Task monitor	40%	200

Source Own elaboration

4 Conclusions

- After analyzing the different variables, we propose to continue the growth strategy planning, focus on improving the cost structure and optimizing processes.
- This company improves its expenses and working capital with a generic cost strategy. The objective of +2.5% in EBIT is achieved through higher sales volume.
- The new position of the MRP Controller in the S&OP process would reduce 132 days of paint inventory and minimize obsolete inventory by $150,000.
- The S&OP impacts are:
  - Reduce the cost of inventory management
  - Reduce obsolescence
  - Reduce the average value of inventories
  - Reduce cost overruns due to stock break
  - Align planning, production, purchasing, and warehouse areas
  - Improve paint rotation rate
  - Align all areas for maintaining a working capital of +7.47%

5 Recommendations

Future researches in inventory management with this methodology should be designed considering the balance between strategic and software development. To introduce the technological solution, organizations need a robust system of information to consolidate accessible and processed databases. In this applied case, we demonstrated that the organization's competitiveness is based on the efficiency of their operations, and it requires the integration, collaboration, communication, and trust of their community.

References

Arellano Marketing: El consumidor peruano ha subido un peldaño (2014)
Bolstorff, P., Rosenbaum, R.: Supply chain excellence: a handbook for dramatic improvement using the SCOR model. American Management Association, New York (2012)
Castillo, J.C., Goicochea, E., Chong, M., Rodriguez, M.: Inmegacity characterization: trends and realities. Manag. Res. (2019)
Cheater, A.: Why Inventory Management Should Be a Company-wide Conversation. En: Supply Chain Blog. August 18th. Consulted: 30/08/2017 (2017)
Chopra, S.: Supply chain management: strategy, planning, and operation. Pearson Education Limited, New York (2020)
David, F.R., David, F.R., David, M.E.: Strategic Management: Concepts and Cases: A Competitive Advantage Approach. Pearson (2017)
Deloitte: 2016 Global Manufacturing Competitiveness Index (2016)
Diaz, C., Ketan, R., Evans, T., Trabold, T., Draper, K.: Thermoformed containers based on starch and starch/coffee waste biochar composites. Energies **13**(6034), 6034 (2020)
Gonzalez-Feliu, J., Chong, M., Vargas, F.J., Padilla, S.J.: Handbook of Research on Urban and Humanitarian Logistic (2019)
Glenday, I., Brunt, D.: The Principles of Lean Value Stream Design (2007)
Holguín-Veras, J.: Comparative assessment of AHP and MAV in highway planning: case study. J. Transp. Eng. **121**, 2 (1995)
Kortabarria, A., Apaolaza, U., Lizarralde, A., Amorrortu, I.: Material management without forecasting: from MRP to demand driven MRP. Omnia Sci. (2018)
Palmatier, G.E., Crum, C.: Transition from sales and operations planning to integrated business planning: moving from fundamental demand and supply balancing to strategic management (2013)
Parodi, C.: Decisiones y entorno económico político y externo (2017)
Porter, M.: The Competitive Advantage: Creating and Sustaining Superior Performance. Free Press, Nueva York (1998)
Porter, M.: Estrategia competitiva: Estrategia Competitiva: Técnicas para el análisis de la empresa y sus competidores. Pirámide, Madrid (2009)
Pressman, R.: Software Engineering. McGraw-Hill, New York (2014)
Robayo, L.: Industria latinoamericana de envases y embalajes: fortalezas para un escenario de cambio (2017)
Roberta, S., Giulia, B., Anna, R., Giuseppe, V.: Plastic or glass: a new environmental assessment with a marine litter indicator for the comparison of pasteurized milk bottles. Int. J. Life Cycle Assess., pp. 1–18 (2020)

Rohac, T., Januska, M.: Value stream mapping demonstration on real case study. Procedia Eng. **100**, 520–529 (2015)

Saaty, T.L.: Decision Making for Leaders. The Analytic Hierarchy Process for Decision in a Complex World. RWS Publications, Pittsburgh (1995)

Samadi, K., Francisco, M., Hegde, S., Diaz, C.A., Trabold, T.A., Dell, E.M., Lewis, C.L.: Mechanical, rheological and anaerobic biodegradation behavior of a Poly(lactic acid) blend containing a Poly(lactic acid)-co-poly(glycolic acid) copolymer. Polym. Degrad. Stab. **170** (2019)

Senge, P., Smith, B., Kruschwitz, N., Laur, J., Schley, S.: The Necessary Revolution: How Individuals and Organisations Are Working Together to Create a Sustainable World. Nicholas Brealey Pub, London (2011)

Valencia, W.A.: El árbol causa y efectos – Una metodología para los proyectos de inversion privada. Gestión en el Tercer Milenio, **5**(9), 97–101 (2002)

Venkataraman, K., Ramnath, B.V., Kumar, V.M., Elanchezhian, C.: Application of value stream mapping for reduction of cycle time in a machining process. Procedia Mater. Sci. **6**, 1187–1196 (2014)

Wallace, T.F., Stahl, R.A.: Sales & operations planning: the how-to handbook (2014)

Weenk, E.: Mastering the Supply Chain: Principles, Practice and Real-Life Applications (2019)

Weinberger, K.: Estrategia para lograr y mantener la competitividad de la empresa. USAID–Ministerio de la Producción, Lima (2009)

Westkämper, E., Mussbach-Winter, U., Wiendahl, H.: Material Requirement Planning (MRP), 87–97 (2018)

Wu, D., Tang, Y.: An improved failure mode and effects analysis method based on uncertainty measure in the evidence theory. Qual. Reliab. Eng. Int. **36**(5), 1786–1807 (2020)

Wu, X., Wu, J.: The risk priority number evaluation of FMEA analysis based on random uncertainty and fuzzy uncertainty. Complexity, 2021 (2021)

Distribution Network Optimization in the Peruvian Agro-Industrial Sector

Fernando Pallete, Lucero Rivera, Luis Tacza, Ana Luna, and Mario Chong

Abstract In recent years, palm oil has been established as the most-produced oilseed oil in the world—its production volume has increased from 41 million tons in the 2007/08 season to more than 76 million tons in the 2018/19 season—and a crucial part of the Latin American agro-industrial sector. However, following a slowdown in export growth due to the 2020 COVID-19 lockdown, there is a vital need for sustainable expansion alternatives such as the production of value-added oil-palm products. This chapter presents the business process integration methodology and strategies pursued by a palm oil producer in Peru to optimize the vertical growth of its operational processes within the Latin American palm oil agro-industrial sector, based on the SAP S/4Hana Business Modules: Materials Management (for purchasing), Production Planning (for making), Sales and Distribution (for selling), Controlling (for tracking) and Human Capital Management (for managing staff).

Keywords Palm oil · Network DESIGN · Center of gravity · Mixed-integer linear programming

F. Pallete · L. Rivera · L. Tacza
Pacífico Business School, Universidad del Pacífico, Jr. Sanchez Cerro N° 2141, Jesús María, 15072 Lima, Perú
e-mail: fj.palletea@alum.up.edu.pe

L. Rivera
e-mail: LR.RiveraT@alum.up.edu.pe

L. Tacza
e-mail: la.taczam@alum.up.edu.pe

A. Luna · M. Chong (✉)
Facultad de Ingeniería, Universidad del Pacífico, Jr. Sanchez Cerro N° 2141, Jesús María, 15072 Lima, Perú
e-mail: m.chong@up.edu.pe

A. Luna
e-mail: ae.lunaa@up.edu.pe

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_16

1 Introduction

The main drivers of the growth of palm oil are the high productivity of oil palm and the development of various applications for it. The main palm oil-exporting countries during 2019 were Indonesia (57%), Malaysia (27%), and Thailand (4%).

These results contributed to more than 88% of the world's supply (Index Mundi 2019). At the South American level, the countries with the largest palm cultivations are Colombia, Ecuador, and Brazil, with a joint share of 4% of the global surface area, equivalent to a total of approximately 542 thousand hectares (Ministerio de Desarrollo Agrario y Riego 2020). In the specific case of Peru, its production during 2019 was 193,000 tons, which represents 0.3% of the total worldwide (Index Mundi 2019).

In 2020, because of the COVID-19 pandemic, the price and the demand for palm oil fell worldwide. The evolution of the world palm oil price during 2020 and the substantial reduction in prices in the first half of the year were as follow: Between January and May, the decline amounted to approximately 40%, but a sustained recovery from June followed this. The price reached in mid-November 2020 was US$827, even higher than the initial price that same year. (Malaysian Palm Oil Board 2020).

April and May 2020 were critical months, marking a reduction in sales that exceeded 60%. Global sales fell from 5.9 to 2.1 million tons from March to April 2020. However, by the end of October, recovery was observed, with sales reaching 3.7 thousand tons—an improvement of 70%—though this was still well short of pre-pandemic levels. (Investing.com 2020).

Thus, while crude palm oil prices recovered after the first months of the pandemic, sales volumes did not follow the same pattern. The reason was the supply contraction due to unfavorable weather in South America coupled with a labor shortage in Malaysia (Trading Economics 2020). In the particular case of Peru, palm oil production is restricted to four regions: San Martín, Ucayali, Loreto, and Huánuco; with 46% (114,703 tons), 35% (88,501 tons), 15% (36,839 tons), and 4% (9,014 tons) (Ministerio de Desarrollo Agrario y Riego 2020).

Given Peru's biodiversity and favorable climate conditions, there is great potential for the crop in areas such as Madre de Dios and Junín (Ministerio de Desarrollo Agrario y Riego 2020). Unfortunately, the COVID-19 pandemic prompted a drop in palm oil prices and a contraction of internal and external markets, causing losses of approximately US$20 million (Cámara de Comercio Industria y Turismo de Ucayali 2020).

In April 2020, Peruvian producers found it impossible to offload 25% of national production, and in May of the same year, production was stopped entirely. This was a direct consequence of the reduction in demand from restaurants in oils, butter, and margarine, due to the country's lockdown measures. In addition, government biosecurity measures forced personnel reductions, further decreasing productivity. Storage capacity and the frequency of servicing of the crude palm oil tanks were also affected by the drop-in demand (Ministerio de Desarrollo Agrario y Riego 2020).

No minor point was the approval of Supreme Decree No. 021-2007 (Ministerio de Transportes y Comunicaciones 2007), which regulates the commercialization of biofuels and seeks to diversify the fuel market, promoting agricultural and agro-industrial development, generate employment, and reduce environmental pollution. However, the current demand for biodiesel is entirely met through foreign soy imports whose price is lower than domestically produced biodiesel made from oil palm (Fort and Borasino Deustua 2016).

The case study documented in the present chapter focuses on a leading company in the cultivation and sustainable production of oil palm in Peru. The company's current strategy is to maximize productivity through operational efficiency and innovation, serving national and international markets. To identify the problem—related to defining the most critical process within the oil palm production area, we used the analytic hierarchy process (AHP) technique—employing a methodology based on the supply chain operations reference (SCOR) model. In implementing the proposed solution, SAP Enterprise Resource Planning and SAP Generic Corporate Structure software was employed.

The rest of the chapter is structured as follows: Sect. 2 presents a general analysis of the case study, Sect. 3 identifies the problem, Sect. 4 addresses the methodology, Sect. 5 sets down the results of the mathematical model, Sect. 6 and 7 show the results, and finally, Sect. 8 contains some conclusions and recommendations.

2 Case Study: Analysis

Peru has recently undergone a political crisis amid a challenging economic and health situation. In 2020, the country changed its president three times, with the last five being involved in political corruption trials. The consequent economic and social instability is highly detrimental to the country's development. The potential impacts on the company in this case study could add to drop-in export in a global recession and high price volatility.

From an economic perspective, projected annual world growth for 2021 and 2021 was 3.3% and 3.4%, respectively (Fondo Monetario Internacional 2020a, b). However, the emergence of the COVID-19 pandemic had devastating effects on the economies of the world and human lives. As a result, the IMF projected that the world economy would suffer a sharp contraction of −4.4% in 2020 and modest growth of 5.2% in 2021 (Fondo Monetario Internacional 2020a, b).

Furthermore, according to Baldwin and Weder Di Mauro, COVID-19 will give the global manufacturing sector a "triple blow." Firstly, it will cause supply interruptions because the countries with the highest transmission rates have industrial economies. Second, the least affected economies will find it difficult to obtain fair prices and supplies from those industrial economies. Third, changes in demand will emerge due to falls in aggregate demand and speculation by consumers and investors awaiting a drop-in price (Baldwin and Weder di Mauro 2020).

As a result of the pandemic, a study by the World Bank (Banco Mundial 2020) and BBVA Research (BBVA Reseach 2020) projected a fall in the Peruvian economy of −13%. On the other hand, the study also estimated a GDP growth of approximately 10% during 2021, following the presidential elections and vaccination. International trade was also one of the sectors affected by the consequences of COVID-19. According to the World Trade Organization (WTO), world trade volumes fell by 9.2% in 2020, but a 7.2% recovery is expected in 2021 (Service Congressional Research 2020).

In Peru, the drop-in exports were 23.1% between January and August 2020 compared to 2019 (ADEX 2020). The government launched a plan for virus containment and economic revival. The measures focused on aspects such as strengthening the health services, public spending, hygiene measures in the education and transportation sectors, and the transfer of humanitarian aid, among others, equivalent to 20% of the country's gross domestic product (GDP) (Ministerio de Economía de Finanzas 2020). In addition, monetary subsidies were assigned to the most vulnerable households and families (Ministerio de Desarrollo Agrario y Riego 2020).

In this context, the agro-industrial sector is considered attractive due to the small number of competitors, among other reasons. Moreover, the consumer sector poses additional challenges. The company studied is a leader in the cultivation and production of oil palm and has consolidated itself as one of the most relevant players in the agro-industrial sector in the Latin American market. Currently, its operation is vertically integrated from the field to the factory. It transforms the raw material obtained into high-quality products with added value for mass consumption, the food industry, and biodiesel.

In December 2008, the company built a new extraction plant, achieving production of more than 180 thousand tons. The company has now been operating for 40 years, with more than 25,000 ha planted. At present, it is migrating to a "push–pull" system, adjusting its production to demand without neglecting its sustainability and its fully integrated production chains. In addition, the company is seeking out new markets at the national and international levels based on the added value of its innovation in products and processes. The plantations are in the east of Peru, and the oil is extracted at each site, finally being refined in its entirety at one of the refinery sites.

The company's products are classified into raw materials and refined products. Among the raw materials are crude palm oil and crude palm kernel oil, both extracted from the fruit of the oil palm. Refined products are sub-classified into industrial products, consumer products, and biodiesel. The industrial products are further divided into industrial bulks, finished products, palm kernel cake, fatty acids, and glycerol. Industrial bulks include refined, bleached, and deodorized (RBD) palm oil and RBD palm kernel oil derivatives, most of which are distributed in ISO tanks. Finished products encompass fats, oils, and butter distributed in packaged form. Finally, the industrial products also include some consumer brands (oils, butter, and soaps).

2.1 General Analysis

The company's competitive advantage is based on the following four pillars:

2.1.1 Sustainability Policy

The company is committed to the responsible and sustainable production of palm oil, and this policy governs all processes within its business lines, including its suppliers. Thus, the company promotes the reduction of deforestation, sustainable development of its plantations, best practices in its processes, compliance with applicable laws, respect for its workers, the inclusion of small products within the supply chain, respect for communities, and transparent dialogue with its stakeholders. In this way, it offers its customers and final consumers inputs and finished products 100% traceable.

2.1.2 Economies of Scale

The company has a 30% share of Peruvian production and assets, which allows it to extract and transform large volumes of oil compared to its competitors. Therefore, it can be more efficient and offer a more competitive price for its refined products.

2.1.3 Taking Advantage of Synergies

Having vertical integration allows the company to reduce waiting times throughout the supply chain and logistics costs. Likewise, this advantage means the company does not depend on third parties to supply raw materials.

2.1.4 Broad Product Portfolio

The great advantage of vertical integration is that the company can adapt its products according to the customer's needs—especially the oil and fat content, which varies from product to product. Likewise, the company's innovation and development area allow it to expand the number of products derived from palm oil. However, to improve net income, it is necessary to reduce operating expenses. Over the last two years, the company managed to reduce its financial expenses due to decreased debt level. The challenge is to improve production costs and seek greater efficiencies in operating expenses, and part of this responsibility falls on the Supply Chain Management area.

2.2 Supply Chain Analysis

The company's logistics are directed by the Supply Chain Management area, which reports directly to the General Management and encompasses the areas of Purchasing, Warehouses & Distribution, and Supply & Demand Planning.

The company's supply chain process is shown in Fig. 1.

The first planning stage is carried out through the Sales and Operations Planning (SOP) department and aims to reconcile sales forecasts with logistical and financial requirements. The commercial area reports how much it expects to sell in exports and finished products, and the company will project the recharge estimate based on the customers' inventory. Then, the Planning area receives the information from each production plantation in terms of Fresh Fruit Bunches (FFB). Its function is to forecast the amount of crude needed for the finished products. In addition, it is important to coordinate the storage capacity of each location; for instance, the company's premises in central Lima generally have excess capacity. This entails material requirements planning (MRP), a system usually associated with production planning software and an inventory control system.

The extraction process, carried out at three extraction plants operated by the company, comprises fruit reception, sterilization, removal, digestion, and pressing. At this stage, no chemical processes are involved. In this way, 100% of the fruit is used to obtain the three main products: crude palm oil, crude palm kernel oil, and palm kernel flour. Of this total, 25% is used during extraction processing, and the rest is sent to the cauldrons. The company plans that the fruit harvest will increase in terms of frequency and volume at its own plantations and by the small-scale farmers that supply it. The company obtains the products it sells as inputs for other industries from this process. Crude palm oil, for example, is used in the oil and fat industries to manufacture various human food such as vegetable oils, margarine, and others.

Meanwhile, crude palm kernel oil is used to produce butter and palm kernel flour, which is used for animal feed. The processed product is only 4% of the FFB and is directed for the business-to-business (B2B) channel. Crude palm oil and crude palm kernel oil are shipped in tanks, while palm kernels are shipped in polypropylene bags. During the refining phase, crude palm oil undergoes a refining, bleaching, and deodorizing process that removes the fatty acids, moisture, and impurities, transforming it into RBD palm oil. This process also changes the palm oil color from red to an intense yellow but maintains most of its nutritional and functional properties.

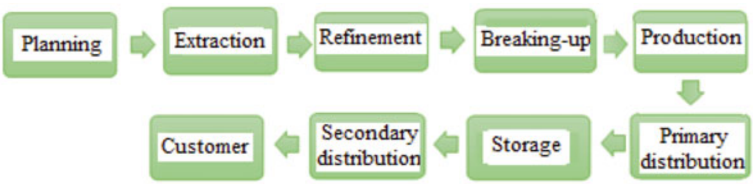


Fig. 1 Company's comprehensive supply chain process. *Source* Own elaboration

Generally, this intense yellow oil is marketed for final consumption in homes, either alone or mixed with other types of oil such as soy, sunflower, or others.

RBD palm oil is used as an input for its finished products and exported and sold locally in bulk in ISO tanks and tanks, respectively. Meanwhile, 100% of the crude palm kernel oil is transformed into RBD palm kernel oil, of which 60% is exported in bulk, and the remaining 40% is used for end-consumer products. In disintegration, the RBD palm oil becomes palm olein and palm stearin. The former is the liquid fraction, which can be mixed with any vegetable oil marketed for human consumption, while the latter is the solid fraction that serves as an input for margarine and soaps. Overall, the company's fractionation is 64% liquid (palm olein) and 36% solid (palm stearin).

There is greater market demand for palm olein than palm stearin, and the latter is subject to push demand. Thus, following the initial break-up, the company obtains finished products such as packaged palm olein and palm stearin. However, the surplus palm stearin is either sold in bulk locally or exported at market price. Since palm olein crystallizes (solidifies) at low temperatures, it can only be marketed in eastern Peru, in the Amazon basin.

Next, the palm olein undergoes a second fractionation, giving rise to super-olein and stearin in proportions of 55% and 45%, respectively. Super-olein resists lower temperatures and is marketed in coastal and central parts of Peru without any problems related to solidification.

The detailed process is known as "mass balance" and is limited by the fractionation ratios of palm olein and palm stearin. Production depends, in the first instance, on-demand in the east for palm olein since this product does not generate much palm stearin, which is in less demand and has a lower price. Likewise, the company is the only one in Peru that uses a "special oil" that allows it to modify the abovementioned fractionated products according to each client's specific requirements. The plant carries out the interesterification and hydrogenated processes.

Primary distribution comprises the transfer of material from the company's main refining centers, located in Peruvian Amazonia, to its eight distribution centers divided among Peru's major coastal cities and some in Amazonia. Likewise, the sending of products from one distribution center is also considered a primary form of distribution. This type of transaction generates extra costs for transportation and handling goods and represents one crucial opportunity for operational savings. Inventory management is carried out via the eight distribution centers; each has two administrative employees for monitoring the operation and billing of orders.

The warehouses in Amazonia are rented by the company but are operated and managed by its own personnel. Finally, the volume distributed in northern Peru is stored in positions rented by a customer in the same area. Orders are shipped to the specific region and invoiced from the capital. The distribution center, located in the same place as the refinery, is small, so the operation involves quickly dispatching all products to make space for newly produced ones. Inventory levels and the prices at each warehouse vary drastically between them because of the distribution costs.

Secondary distribution involves the transportation of final products from distribution centers in various country areas to final customers nationwide. The local customers can be divided into B2B (industrial companies) and B2C (distributors).

Another form of secondary distribution is sending directly from the main refining facility to customers, optimizing transport costs. Overall, the company's customers are located at more than 400 different sites, reached via external haulage companies with nationwide coverage. The distribution represents around 80% of total logistics costs and is thus a very critical component to optimize.

3 Identification of the Problem

To identify the problem, we defined the critical criteria for the company based on the SCOR methodology and the company's strategic objectives. Then, through the AHP methodology, we defined the most critical process in the supply chain.

3.1 Criteria for Evaluating Supply Chain Processes

As a result of the work sessions with the Supply Chain Management area, we determined four evaluation criteria in alignment with the company's strategic objectives. Two of them are customer-oriented external metrics: service level and flexibility, and the other two are business-facing: savings potential and efficiency in asset management. These latter two indicators correspond to the attributes used in the SCOR Model for measuring current supply chain performance (Stadler et al. 2015). The great advantages of the SCOR model are the possibility to analyze, represent and configure supply chain management, integrating business process concepts including reengineering, benchmarking, and identification of best practices. The criteria defined are detailed below.

3.1.1 Savings Potential

The company is focusing its actions on its corporate industrialization strategy, which encompasses increasing value-added product sales. Consequently, for its consumer line, the company has been developing a distribution network that seeks greater efficiencies and savings with a view to greater profitability and improved operating margins.

3.1.2 Service Level (Reliability)

This indicator refers to the perfect fulfillment of an order, achieved by delivering the correct product at the correct place and at the time requested by the customer. It guarantees coverage at the national level and allows an increase in the market share in a highly competitive market.

3.1.3 Flexibility

The company started by engaging in agricultural production and oil extraction. Over the years, it adapted its supply chain to support vertical growth. However, the sale of industrial products to a small number of customers (80% of its sales to the industrial sector are made up of ten clients) differs from the distribution of finished products, such as oils and soaps, at the national level. In this regard, the company's priority is to adapt to achieve a better response capacity and accompany the growth in consumer product sales.

4 Methodology

To evaluate the critical supply chain processes identified, we use the AHP technique to compare each process against a critical assessment criterion. The method was developed by Professor Thomas L. Saaty in the 1970s, incorporates both qualitative and quantitative aspects of human thinking, and supports strategies for better decision-making in complex situations (Saaty 2012). Given the methodology's broad application in various fields of study and intangible criteria to solve decision-making problems with multiple criteria (Brunelli 2015), we use the AHP technique.

The first phase involved conducting interviews with the Supply Manager; Warehouse and Distribution Manager; Head of Planning, Supply, and Demand; and Head of Distribution. We applied the AHP technique to these interviews to compare processes related to the critical criteria identified. Table 1 outlines the company's critical processes evaluated using the AHP model.

In turn, Table 2 presents the names assigned to the chosen criteria and their respective coding.

Using the numerical scale, the value 1 is assigned if it is of equal importance, and 9 if the importance is extreme when comparing one element against another.

Table 1 Company process coding

List of processes	Coding
Planning	W1
Production (extraction, refining & FRACTIONATION)	W2
Inventory management (storage)	W3
Primary and secondary distribution (dispatch & distribution)	W4
Reverse logistics	W5

Source Compiled by authors

Table 2 Criteria coding

Criterion name	Coding
Savings Potential	C1
Service level	C2
Flexibility	C3
Asset management efficiencies	C4

Source Compiled by authors

5 Results

The determination of the weighting factors for the criteria are shown in the following comparative and normalized matrices (Table 3).

Next, the matrix of assigned weights is set out in Table 4.

We then repeated the same procedure for each of the criteria presented in Table 2, obtaining the comparative and normalized matrices. Finally, we assigned the weights to the process. The most critical process, according to the corporate strategy guidelines, was Primary and Secondary Distribution (W4), followed by the Planning Process (W1) and Inventory Management (W3). These results are outlined in Table 5.

The result obtained using the AHP methodology is consistent and in line with the corporate strategy, focused on the industrialization of oil palm. We observed an increase in the share of refined products within the entire business, from 82 to 93%, between 2019 and 2020 (Fig. 2).

Table 3 Determination of the criteria weighting factors

Comparative matrix					Normalized matrix				
	C1	C2	C3	C4		C1	C2	C3	C4
C1	1	3	1/3	2	C1	0.21	0.26	0.19	0.26
C2	1/3	1	1/6	2/3	C2	0.07	0.09	0.10	0.09
C3	3	6	1	4	C3	0.62	0.52	0.57	0.52
C4	1/2	3/2	1/4	1	C4	0.10	0.13	0.14	0.13
	4	10	1	7					

Table 4 Process weight

Process	Weight (%)
W1	23
W2	8
W3	56
W4	13

Table 5 Results of the process evaluation

	C1	C2	C3	C4	Total
W1 (%)	48	16	14	26	24
W2 (%)	15	6	5	28	11
W3 (%)	8	29	26	19	21
W4 (%)	23	41	45	13	36
W5 (%)	5	9	9	13	9
Weighing	23%	8%	56%	13%	

Source Data provided by the company and compiled by authors

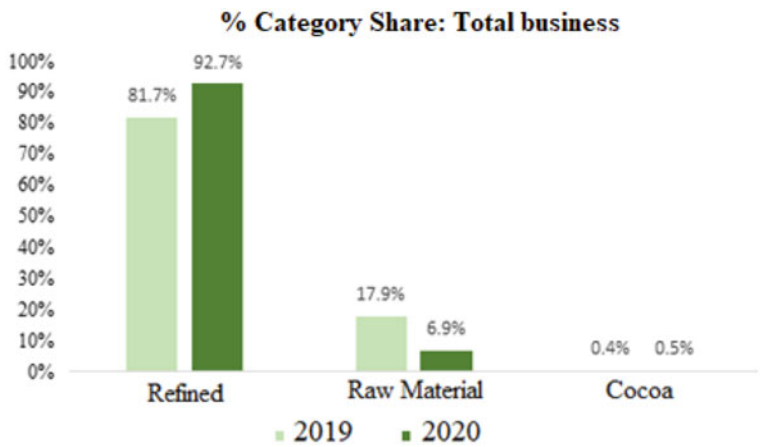


Fig. 2 Category share percentage: total business. *Source* Data provided by the company. Compiled by authors

After analyzing the Supply Chain area and interviewing keep employees from the Storage and Distribution Management area, we determined that the supply chain has a bottleneck in its operations and the storage of finished products at one of the company's production centers. At this center, production is continuous and does not stop at any time, given the volume of fruit it constantly receives. Consequently, finished products are quickly shipped to the distribution center not to exceed storage capacity.

The limited storage capacity of the abovementioned production center causes two major problems. First, it does not have enough stock to fulfill orders from the production center at the national level. Therefore, the same merchandise can be sent twice within the primary distribution process in some cases. Second, it creates high occupancy at the company's site in Lima, which receives much of what the refinery produces regardless of demand.

For a consumer goods company such as this, it is important to implement efficient and cost-effective logistics and seek to make the product more attractive than that of the competition. In the case of this company's consumer and industrial lines alike, the cost of freight per ton of primary distribution (T1) is higher than the cost of secondary distribution. This presents an opportunity for improvement since efficiencies can be sought through fewer merchandise movements before direct delivery to customers.

For the company, T1 accounts for 51% and 72% of consumer and industrial sales, while the volumes are 47% and 53%, respectively. Thus, the movements between distribution centers exceed last-mile transportation. Having identified this problem, our next step was the detailed analysis of the primary and secondary distribution routes to reinforce the critical process proposed by the AHP.

5.1 Route Description

We focused on both the industrial and consumer business lines for the analysis of savings opportunities.

5.1.1 Industrial Line

Almost all of the merchandise is sent to the Lima distribution center and from there to customers in the industrial line. When it comes to secondary distribution, in which just nine customers represent more than 80% of the volume and freight of the industrial business, the merchandise that the Lima center receives serves almost 100% of the region. Given this sales volume and its concentration among a small number of customers, an alternative would be direct shipping, which would avoid secondary distribution freight costs of US$100,300 and storage costs of US$25,300 per year.

5.1.2 Consumer Line

In the case of the consumer line, 96% of the merchandise originates from one of the company's refineries, which sends 55.3% of the total merchandise to Lima due to the need to free up space to continue producing. The rest of the merchandise, for the most part, is destined for distribution centers in the east. Only 2.6% is sent for "trans-shipment" to the cities and later sent to another distribution center. Analyzing the secondary distribution, Lima city accounts for a large proportion of the entire volume; 40% of the merchandise stays in Lima, while the remainder is sent to customers in the rest of the country. This centralization results in very high storage costs.

6 Proposed Solution

For our proposed solution, we restricted ourselves only to products classified as "*finished*", which make up a large percentage of transportation costs, and stock-keeping units (SKUs) that move between the distribution centers since the rest of the products are sent directly to customers. The solution we propose is based on a feasibility analysis of expanding one of the inefficient distribution centers to improve the supply of finished products. In addition, we evaluated the benefits of retaining current distribution centers in the context of route optimization. We used three interdependent tools consecutively to identify the solution. The first step is based on the analysis of all destination points for finished product distribution. Next, we use the center of gravity (COG) model to identify the main demand zones. Finally, we execute a mixed-integer linear programming model (MILP) for our proposal's numerical and quantitative validation.

6.1 Gravity Center

An important consideration when deciding on the location of an operations center is market proximity; for many organizations, it is vital to be as close as possible to their customers (demand), which helps to speed up deliveries and ensure timeliness. One of the models used to evaluate whether a plant location makes sense is the COG, which is valued for its simplicity and as a basis for the development of intuition for more complex models.

One solution to this model proposes that facilities be located at the center of a collection of demand zones or, for companies with many suppliers, of supply points. (Watson et al. 2013). For the case of logistics, a COG problem is generally defined as selecting the location of a facility so that the weighted average distance to all demand zones is minimized. If there are many small demand zones in a region, they will bring the facility closer to the region. On the other hand, the breakeven point is determined when no demand zone can bring the facility closer without creating a less beneficial solution to the entire system (Jacobs et al. 2004).

The COG model is used to define the ideal location of one of the company's plants based on the geographical location of the demand zones and the volumes thereof. In this way, it seeks to optimize the distribution network, minimize logistics costs, and meet sustained demand growth. The COG calculates a location based on the weighted averages of the zones and the volume of demand.

We used the company's 25 current demand zones for the present study to obtain the COG calculation. The new points generated using the COG method represent the ideal location for the new distribution center, optimizing the current distribution network through which most of the company's demand will be met. The location resulting from the model is only 30 miles away from the company's current distribution center and a production facility.

In sum, the location of the current distribution center is geographically the most suitable in the region, considering the current demand zones. The COG model provides the first approach to understanding the sources of the company's demand and will be used as a first input for linear programming (MILP) to minimize the logistics costs of the distribution network.

6.1.1 Mathematical Formulation

The COG mathematical model uses the cartesian coordinates (lat' and long') that find the equidistant point between the nodes and consider a weighting which, in the case of this study, is the product volume that each cluster demands, expressed in tons. The geographic coordinates of the latitude and longitude values are obtained from the quotient between the sum of the products of the latitude and longitude of each point with the demand and the sum of the tons ordered. The COG mathematical model is expressed as shown in Eqs. (1) and (2) (Ballou 2004):

$$Lat' = \frac{\sum_i (Lat)(d_i)}{\sum_i d_i} \tag{1}$$

$$Long' = \frac{\sum_i (Long)(d_i)}{\sum_i d_i} \tag{2}$$

where:
Lat' and $Long'$ correspond to the new coordinates of the distribution center.
Lat and $Long$ are the coordinates of the existing demand zones.
d_i is the weight in tons assigned to the demand zones.

We carried out the procedure at each of the 25 demand zones to determine the COG, thus obtaining the new and optimal coordinates.

6.2 *Mixed Integer Linear Programming Model*

Linear Programming is one of the most used techniques in the optimization process. It is applied in decision-making in cases where the quantities (variables) can take a real value (Stadtler et al. 2015). This mathematical tool maximizes or minimizes an established objective subject to different restrictions (Puente Riofrío and Gavilánez Álvarez 2018). According to Watson et al. (2013), given the complexity of the supply chain and large volume of data, this optimization technique is the best way to rank the various options, determine the best locations for facilities, and support better decision making.

The main advantages of linear programming are that: (i) it enables the optimal use of available resources, (ii) decision-making is carried out objectively, as long as the relationships between data and restrictions are well defined, and (iii) it allows possible bottlenecks in operations to be identified (Islam 2008). We estimated the solution to the identified problem using MILP, where some variables are integers while others can be fractions (Vanderbei 2001).

Operationally, the main limitation of the company we study here is the storage capacity of its distribution centers and, in particular, its production factory. The production of the main SKUs (oils, shortenings, laundry soap, and toilet soap) usually exceeds the storage capacity of the distribution center in the production plant. To evaluate different scenarios with different numbers of distribution centers and storage capacities, we carried out linear programming with many variables greater than the 200 allowed by the standard package. To this end, we worked with the Solver Plus tool (trial software from the Office 365 suite). The objective is to minimize the total costs of the distribution network.

6.3 Optimization Model

The optimization model seeks to optimize the company's current distribution network. The scope of this study is the company's Supply Chain Management area, which aims to minimize the total costs of distribution and effectively satisfy the demands of its customers. In sum, we seek an alternative that questions the current configuration of the network and proposes an optimal, viable, and profitable solution in the long term.

The results will help to inform strategically (whether to close or keep specific distribution centers open), tactical (which markets are served from where, as well as inventory policies), and operational decision-making (route optimization and drop size) (Chopra and Meindl 2013). In our model and the subsequent analysis, we considered some restrictions based on the company's operations under study. One of these restrictions is that the company has a single production plant that includes all four product categories.

The model includes the company's eight distribution centers, which sell finished products to more than 460 customers in 41 cities nationwide; for the model, we grouped these customers into 25 demand zones according to volume and distance.

Although the company has more than 500 SKUs pertaining to finished products, we only factored four categories into the model: oils, butter, laundry soap, and toilet soap. The model considered total demand for finished products to have been satisfied. We took historical sales for all clusters as a basis and compared them with the demand for the next five years for each city to forecast future company sales.

The production sent to the distribution centers is the same as that which goes to the clusters. In turn, transportation costs comprise the direct cost (supply) and the secondary cost (distribution). Their costs vary and depend on the routes assigned between the refinery and the distribution centers and from the latter to the demand zones. On the other hand, warehouse costs are subdivided into three categories.

The first category is the "in and out" cost, which is the rate that varies according to the distribution center, but in cases where the company rents the center or owns it outright, this does not apply. The second category corresponds to storage; those distribution centers that the company rents or owns are subject to fixed storage costs, while those located on the coast charge a fixed amount plus a variable depending on the use of the positions. The third category is the workforce, which is the cost applied at the distribution centers with operational personnel employed by the company. This includes warehouse managers, supervisors, assistants, and operators. For all the projected costs, an increase in annual rates is estimated based on average inflation of 2%.

6.4 Construction of the Mathematical Model

We defined three initial components in formulating the model: sets, variables, and parameters. A set is a group of similar objects in which each object in the group has characteristics related to the set (Lindo Systems Inc. 2003). The sets are the production plant, distribution centers, and demand zones for the present case. The variables are those unknown elements that, when solving the problem, are defined to optimize the objective function (Puente Riofrío and Gavilánez Álvarez 2018).

The parameters are the initial information required to develop the model (Mahmoudi et al. 2019) and remained constant during the simulation, but could change when the model requires adjustment. The initial components are summarized in Tables 6, 7 and 8.

The model should reflect how the company's supply chain works. It must include its production plant, the eight distribution centers nationwide, and all demand zones. It is important to retain the main characteristics of each one, such as their capacities, routes, demands, and costs (Fig. 3).

Figure 4 shows the configuration of the main sets and indices of the model.

The objective function shown In Eq. (3) minimizes the cost function Z, which includes the costs of transportation (between the production plant and the distribution centers and demand zones), storage, headcount, and in and out costs.

Table 6 Linear programming sets

Set type	Set	Description
Primary	S	Production plant
Primary	D	Distribution centers
Primary	P	Demand zones
Secondary	SxD	Relationship between production plant and distribution centers
Secondary	DxP	Relationship between distribution centers and demand zones

Source Compiled by authors

Table 7 Linear programming variables

Variable	Set	Description	Unit
αS	S × D	Amount of oils transported from S-D	Tons
βS	S × D	Amount of butter transported from S-D	
γS	S × D	Amount of laundry soap transported from S-D	
εS	S × D	Amount of toilet soap transported from S-D	
αD	D × P	Amount of oils transported from D-P	
βD	D × P	Amount of butter transported from D-P	
γD	D × P	Amount of laundry soap transported from D-P	
εD	D × P	Amount of toilet soap transported from D-P	

Source Compiled by authors

Table 8 Linear programming parameters

Parameter	Index	Description	Unit
CapacitySα	S	Oil production plant capacity	Tons
CapacitySβ	S	Butter production plant capacity	Tons
CapacitySγ	S	Laundry soap production plant capacity	Tons
CapacitySε	S	Toilet soap production plant capacity	Tons
CapacityD	D	Storage capacity in distribution center	Tons
CostInOutD	D	In/out cost in distribution center	Tons
cFixedD	D	Fixed cost of storage in distribution center	$
CostHcD	D	Distribution center headcount cost	$
cTranportSD	SxD	Transportation cost between production plant and distribution center	$/ton
cTraportDP	DxP	Transportation cost between distribution center and demand zone	$/ton
DemandPα	P	Oil demand at demand zone	Ton
DemandPβ	P	Demand for butter at demand zone	Ton
DemandPγ	P	Demand for laundry soap at demand zone	Ton
DemandPε	P	Demand for toilet soap at demand zone	Ton

Source Compiled by authors

$$\begin{aligned}\min Z = & \sum_{i \epsilon S, j \epsilon D} cTransportSD(i, j) * (\alpha ij + \beta ij + \gamma ij + \varepsilon ij) \\ & + \sum_{j \epsilon D, k \epsilon P} cTransportDP(j, k) * (\alpha jk + \beta jk + \gamma jk + \varepsilon jk) \\ & + \sum_{j \epsilon D} CostInOutD(j) * (\alpha jk + \beta jk + \gamma jk + \varepsilon jk)\end{aligned}$$

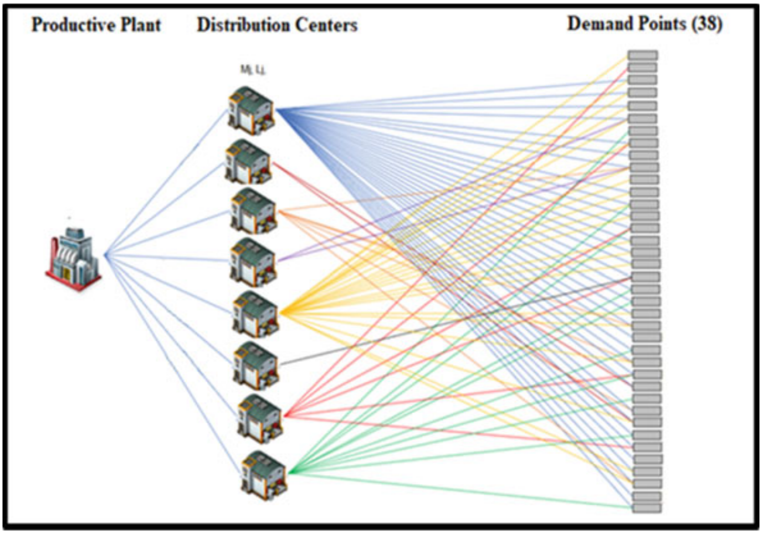


Fig. 3 Current distribution network. *Source* Own elaboration

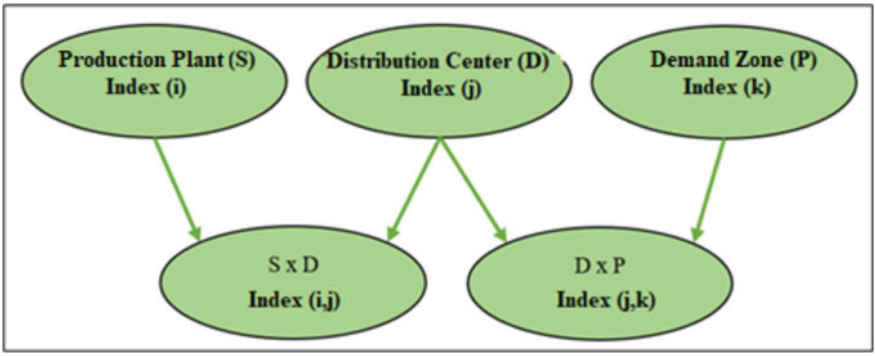


Fig. 4 Sets and indexes configuration. *Source* Own elaboration

$$+\sum_{j \epsilon D} \text{cFixedD}(j) + \sum_{j \epsilon D} CostHcD(j) \tag{3}$$

The model restrictions are detailed below:

(a) The first group represents the respective quantities shipped of the four SKUs, which cannot exceed the production capacity of each one, symbolized in Eqs. (4–7).

$$\sum_{j \epsilon D} \alpha SD(i, j) \leq capacityS\alpha(i) \forall (i) \epsilon S \tag{4}$$

$$\sum_{j\epsilon D}\beta SD(i,j) \leq capacityS\beta(i)\forall(i)\epsilon S \tag{5}$$

$$\sum_{j\epsilon D}\gamma SD(i,j) \leq capacityS\gamma(i)\forall(i)\epsilon S \tag{6}$$

$$\sum_{j\epsilon D}\varepsilon SD(i,j) \leq capacityS\varepsilon(i)\forall(i)\epsilon S \tag{7}$$

(b) The second group refers to the total quantity shipped of the four SKUs, which must be less than or equal to the total storage capacity per distribution center (Eq. 8).

$$\sum_{i\epsilon s}(\alpha S + \beta S + \gamma S + \varepsilon S)(i,j) \leq \text{CapacityD}(j)\forall(i)\epsilon S \tag{8}$$

(c) The third group refers to the conservation of flows between the production plant, the distribution centers, and the demand zones at the SKU level (Eq. 9)

$$\begin{aligned}&\sum_{i\epsilon s}(\alpha S + \beta S + \gamma S + \varepsilon S)(i,j)\\ &= \sum_{j\epsilon D}(\alpha D + \beta D + \gamma D + \varepsilon S)(j,k)\forall(i)\epsilon S\forall(j)\epsilon D\end{aligned} \tag{9}$$

(d) The fourth group stipulates that the volume sent from each distribution center to the demand zone must be equal to the volume demanded at each point, at the SKU level (Eq. 10).

$$\begin{aligned}&\sum_{j\epsilon D}(\alpha D + \beta D + \gamma D + \varepsilon D)(j,k)\\ &= \sum_{k\epsilon P}(demandP\alpha + demandP\beta + demandP\gamma\\ &\quad + demandP\varepsilon)(j,k)\forall(i)\epsilon S\forall(j)\epsilon D\end{aligned} \tag{10}$$

(e) The fifth group shows the specific restrictions defined by the company: closing distribution centers J2 and J6 (Eq. 11); and keeping open distribution centers J1 (Eq. 12) and J3 (Eq. 13), which have the minimum annual operating volumes.

$$\sum_{j=2,6\epsilon D}(\alpha D + \beta D + \gamma D + \varepsilon D)(j,k) = 0\forall(j)\epsilon D \tag{11}$$

$$\sum_{j=1\epsilon D}(\alpha D + \beta D + \gamma D + \varepsilon D)(j,k) \geq 2331\forall(j)\epsilon D \tag{12}$$

$$\sum_{j=3\epsilon D} (\alpha D + \beta D + \gamma D + \varepsilon D)(j, k) \geq 1130 \forall (j) \epsilon D \tag{13}$$

The execution of the model is based on three proposals. The first reflects the aim of reducing operating expenses without tactical restrictions. The second incorporates specific restrictions on the operation of certain distribution centers. Finally, the third is a hybrid in which a strategic decision is incorporated into the theoretical model.

7 Mathematical Model Results

Using the MLP in Excel with the Open Solver tool, we analyzed the following scenarios:

- A 50% expansion of the main distribution center to reduce primary distribution by eliminating movements of finished products and avoiding its storage by dispatching it directly from the refiner. Only those distribution centers yielded by the linear scheduling yielded, because of cost minimization, were considered. Under this scenario, only five distribution centers should operate, and one would absorb the demands of the entire northern zone. Moreover, demand in the southern zone will also be served mainly by this center and partially by another of the four remaining distribution centers. The first model results indicate an annual saving between US $810,000 and the US$1,081,000, and a total saving of $3,700,000 between 2022 and 2026. The model represents an overall saving of 13.1%, 79% of which comes from primary distribution, reflecting that the model seeks not only volume optimization between distribution centers but also route optimization.
- The second scenario reflected the strategic aim of increasing consumer products. Given the strong growth in these areas, two distribution centers were kept: one in the north and another in the south. Finally, the scenario proposed the closure of one of the distribution centers in the east—that with the least demand—and its sales handed over to another of the centers. The results are an annual saving of over $730,000 and a total saving of $4,000,000 over the period. The savings represent approximately 9.4% of the current model, 70% of which comes from primary distribution due to increased products sent from one of the distribution centers. The second-greatest category of savings is storage due to the closure of two of the distribution centers. Likewise, a 3% increase in secondary distribution is observed due to these two decisions.

7.1 Financial Evaluation

For the economic analysis, the expansion and implementation of the company's current distribution center were considered within the investment. The project execution year was 2021 (year 0), and for Years 1–5, the primary and secondary transportation costs, storage, in & out costs, and headcount were considered cash flow. The savings obtained from the redesign of the distribution network resulted from the expansion of the company's distribution center, the closure of two distribution centers, and the optimization of routes.

The economic evaluation for 2021 shows that the NPV of the proposed project is $2,311,411, the IRR is 79%, and the recovery period is 1.37 years. These results are the consequence of a proposal based on strategic decisions and subjective inputs in pursuit of quantitative results adjusted to reality. The design and implementation project for a distribution center located in a strategic area in the eastern part of Peru involves expanding its storage capacity to optimize its distribution network, complying with quality requirements such as standard operating systems, and assuring the level of service. As a direct consequence, a reduction in operating costs will be achieved in the distribution network, and the ability to meet growing demand at the national level will emerge as an opportunity.

8 Conclusions and Recommendations

8.1 Conclusions

In this study, we explored ways of improving production costs and seeking greater efficiencies in operating expenses, part of the responsibility for which falls on supply chain management. We used linear programming to adjust the supply chain to market demands and support strategic business decisions to evaluate project execution. A key strategy of the company we studied is prioritizing its line of consumer products, reducing its operating costs, and being more competitive in the market.

We also proposed ways for the company to restructure its distribution network in the short and long term without affecting the level of service. We used the center of the gravity model to group more than 500 customers at 25 demand zones. Our final proposal considers the company's strategic decisions without neglecting cost reduction; that is, it aims to strike a balance between the first and second evaluated scenarios. In the first case, the model focused solely on searching for efficiencies. As the company's financial performance has weakened in recent years, it needs an alternative that improves its profitability. Accordingly, the financial results yielded by the first model are greater. The second proposal conforms to the company's exploration of which distribution centers to retain. Therefore, the saving is 28% lower than that obtained through the first proposal. In this scenario, two distribution centers are forced to remain open so as not to lose coverage and improve the level of service, despite not being the optimal alternative. On the other hand, the model recommends the closure of another two distribution centers to offset the expansion of the plant.

The economic-financial evaluation of expanding the plant's distribution center by 50% yielded the following financial results: a TIR of 79% and an NPV of $2,311,411. Thus, the project feasibility is reflected in a new, optimized distribution network with higher yields.

Finally, this chapter presented the critical business processes of procurement, fulfillment, production, warehouse management, and material planning in terms of how they impact the organization with the support of SAP ERP.

8.2 Recommendations

The expansion of the plant's distribution center requires investment and changes in the supply network processes. Therefore, it is necessary to analyze the ten knowledge areas of project management and assign a project manager from the beginning of the process to guarantee fulfillment of the project in terms of level, cost, time, and scope.

In the long term, it is recommended that once demand has increased along with storage capacity, the first option of continuing to expand the plant distribution center be considered. Primary distribution accounts for 70% of logistics costs; therefore, working from that point will allow for greater efficiency. It is advised that any change in the supply chain network design prioritize the company's strategic objectives. Therefore, the final proposal only considers opening one other distribution center, which was chosen considering the demand zone with the highest growth (150%). The rest of the changes must focus on optimizing efficiencies since, as a consumer goods company, price competitiveness is a necessity.

Given the complexity of the data used in this study and the number of variables that compromise the decision-making, the application of tools such as Open Solver is recommended. Likewise, it is essential to define the data sets, variables, and parameters clearly. As part of project development, senior management must participate in communicating progress and securing the commitment of company employees. The expansion of the plant's distribution center has repercussions for the entire organization but has the most significant impact on the commercial and supply areas. Thus, during the implementation of the new distribution scheme, optimal coordination is essential to ensure that customers are not affected by the changes made.

References

ADEX: Perú Exporta Boletín Semanal. ADEX, Lima (2020)

Baldwin, R., Weder di Mauro, B.: Economics in the Time of COVID-19. CEPR Press, London, United Kingdom (2020)

Ballou R.H.: Logística: Administración de la cadena de suministro. Pearson Education (2004)
Banco Mundial: La economía en los tiempos del Covid-19-Informe Semestral de la región América Latino y el Caribe. BIRF AIF (2020)
Situación Perú. Cuarto trimestre 2020. Lima: BBVA Research. Brunelli, M.: Introduction to the Analytic Hierarchy Process. Springer, London (2015)
Brunelli, M.: Introduction to the Analytic Hierarchy Process. Springer, London (2015)
Cámara de Comercio Industria y Turismo de Ucayali: Cámara de comercio industria y turismo de Ucayali (Mayo de 2020). http://www.camaraucayali.com/index.php
Chopra, S., Meindl, P.: Supply Chain Management, 5th edn. Pearson (2013).
Fondo Monetario Internacional: Perspectivas de la economía mundial al día. IMF (2020a). https://www.imf.org/es/Publications/WEO/Issues/2020/01/20/weo-update-january2020
Fondo Monetario Internacional: Informe de perspectivas de la economía mundial (2020b)
Fort, R., Borasino Deustua, E.: ¿Agroindustria en la Amazonía? Posibilidades para el desarrollo inclusivo y sostenible. GRADE, Lima (2016)
IMF: https://www.imf.org/es/Publications/WEO/Issues/2020/04/14/weo-april-2020
Index Mundi: Index Mundi. Obtenido de Index Mundi (2019). http://www.indexmundi.com/agriculture/?commodity=palm-oil
Investing.com: Global sales volume of palm oil in 2020. Investing.com. Web site (2020) https://www.investing.com/commodities/crude-palm-oil
Islam, S.: Linear Programming. Kabir Publications, Dhaka (2008)
Jacobs, F.R., Chase, R.B., Aquilano, N.J.: Operations Management for Competitive Advantage. Mc-Graw Hill, Boston 64: 70 (2004)
Lindo Systems INC.: Optimization Modeling with LINGO. Lindo Systems INC., Chicago (2003)
Mahmoudi, A., Liu, S., Javed, S.A., Abbasi, M.: A novel method for solving linear programming with grey parameters. J. Intell. Fuzzy Syst. **36**(1), 161–172 (2019)
Malaysian Palm Oil Board: Evolution of the Palm Oil World Price During 2020. MPOB Portal, Malaysian (2020)
Ministerio de Desarrollo Agrario y Riego: Perfil productivo y competitivo de los principales cultivos del sector (2020). https://siea.midagri.gob.pe/portal/siea_bi/index.html
Ministerio de Economía de Finanzas: Gob.pe (2020). https://www.gob.pe/institucion/mef/noticias/142592-plan-economico-para-la-contencion-y-reactivacion-economica-frente-al-covid-19-ha-implementado-medidas-por-s-67-199-millones
Ministerio de Transportes y Comunicaciones: MTC Digital (2007). https://www.gob.pe/institucion/mtc/normas-legales/10026-021-2007-mtc
Puente Riofrío, M., Gavilánez Álvarez, Ó.: Programación lineal para la toma de decisiones. Escuela Superior Politécnica de Chimborazo, Riobamba (2018)
Saaty, T.L.: Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World. RWX Publications, Pittsburgh (2012)
Service Congressional Research: Trade Statistics and Outlook. Washington DC (2020)
Stadtler, H., Kilger, C., Meyr, H.: Supply Chain Management and Advanced Planning. Springer, Berlin (2015)
Trading Economics:. Palm Oil (2020). https://tradingeconomics.com/commodity/palm-oil?user=lijun
Vanderbei, R.J.: Case studies in trajectory optimization: trains, planes, and other pastimes. Optim. Eng. **2**(2), 215–243 (2001)
Watson, M., Lewis, S., Cacioppi, P., Jayaraman, J.: *Supply Chain Network Design: Applying Optimization and Analytics to the Global Supply Chain.* Pearson Education (2013)

Product and Content Management Through QR Codes as an Efficient Strategy in E-commerce

Gerardo Reyes Ruiz

Abstract New technologies have changed the way in how products are offered today. In this sense, the Internet and social networks have played a preponderant role in spreading any product more efficiently and dynamically. Simultaneously, having a smartphone and a high-speed wireless network is no longer a luxury or a temporary fad but rather necessary for new generations. These technological advances and new marketing trends have not gone unnoticed by medium and large stores. In this context, e-commerce is a modality that allows adding these new technologies to sell products and services through the Internet, making it a tool that allows discovering new uses, forms, and consumption habits. E-commerce allows customers to provide products and services with the highest quality; for this, it is necessary to implement QR codes capable of creating a differentiating user experience where products are displayed in the best possible way and accompany them of content valuable to consumers. In this way, it is intended to promote the efficient and rationalized use of all the resources that companies have and at the same time promote the use of new technologies as a strategic enabler and competitive differentiator so that they exceed their business objectives.

Keywords E-commerce · QR codes · New technologies · Products and services · Marketing

1 Introduction

In recent decades there have been significant changes both in people's consumption and in the field of called new technologies (Singh et al. 2021). On the one hand, we have witnessed that some brands have gradually been positioning their products

G. Reyes Ruiz (✉)
Center for Higher Naval Studies (CESNAV), Naval University, Cd. de México, Cd. de México, México
e-mail: greyesruiz@hotmail.com

Calz de La Virgen, Coapa Ex-Ejido de San Pablo Tepetlapa, 04849 Coyoacán, Ciudad de México, México

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_17

in markets that are more competitive every day and, on the other hand, new technologies have shown dizzying advances, which have allowed the creation, precisely, new consumer markets (Grubor and Milovanov 2017). With the appearance of the Internet, our life underwent more than apparent changes; however, it has been new technologies, which make use of the Internet, which currently allow us to have a more comfortable, pleasant, and safe life. In other words, our daily lives have also been transformed with the proliferation of new technologies, particularly after living through the COVID19 pandemic (Sharma and Bashir 2020; He et al. 2021).

Let us look at some examples; there are currently countless establishments around the world that allow you to make purchases of all kinds of products or services, from the comfort and security of your home, just with a phone connected to the Internet or with access to a data plan (Reyes et al. 2016; Forecast GMDT 2019). At present, countless establishments focus on or have the service of carrying purchases, which are generally carried out through a mobile device with internet access, to the home's door (Bulearca and Tamarjan 2010).

In the same way, and with a smartphone connected to the Internet, we can make multiple payments for services, bank cards, and money transfers. From the comfort and safety of the home: of course, banking institutions have been facilitators and promoters of these changes in order, among other things, to create a more comfortable and safe life (Shaikh and Karjaluoto 2015; Fenu and Pau 2015).

These examples help us to establish that contemporary human beings have become a codependent entity of new technologies, regardless of whether any technological innovation satisfies one of their specific needs. That is to say, the life that touched us in this twenty-first century is, by far, more bearable than the life of just 100 years ago. This is undoubtedly due to the leaps and bounds with which science and technology have advanced (Lee and Daiute 2019). Therefore, the benefits of technological advances for a contemporary human being are also more than evident.

Without a doubt, we are currently immersed in a world of information (Hugill 2016). Indeed, this is due, to a great extent, to the fact that the approach and knowledge of new technologies are becoming easier and more accessible for all people. However, these technological changes are increasingly rapid, and it is clear that the interaction between technology and humans has changed dramatically over time (Elsobeihi and Abu Naser 2017).

In other words, so much information is handled today that contemporary human beings must rapidly assimilate many technological developments instead of having them adapted to their needs. As a consequence of this interaction, it can be said that the current dynamics of the product or service markets have led us, among other things, to be immersed in a global society with cutting-edge technologies (Ameen et al. 2021).

Similarly, current marketing trends have also had to adapt to impending technological changes, since currently, it is not enough to implement marketing strategies that only focus on displaying a product on the side of a store or through from any other conventional medium such as television, radio, some magazines and printed catalogs (Rust 2020). That is, how products or services are presented and sold to the final consumer has gradually changed over time (Willman-Iivarinen 2017; Nurul Aqila et al. 2016; Lee et al. 2010).

Nevertheless, an important factor to consider is that current marketing strategies, which have survived a globalized world and know how to catch up with technological advances, largely depend on the purchasing habits of the people living in a country (Pang et al. 2009).

The significant impact of the Internet and its adoption through new technologies have also transformed the way people interact: now communications are more impersonal but faster, more efficient, and secure. The response of new technologies was evident at the beginning and throughout the time that the COVID19 pandemic has lasted worldwide (Toussaert 2021; Lee and Trimi 2021).

In this context, the efficiency of mobile devices, and in particular of smartphones (Yesilyurt and Yalman 2016), has reached a level of dependence for people who are currently a necessary and indispensable product with which people are communicated or used you can make your purchases online, and not so much in a comfortable way but rather in a secure way (Agrebi and Jallais 2015).

Furthermore, mobile devices, mainly through social networks, have become an extremely important and sensitive means to introduce and/or disseminate a product or service more efficiently and dynamically (Lindsey-Mullikin and Borin 2017; Dolega et al. 2020). Companies looking for new and novel ways to sell their products or services have not ignored the many uses of these innovative applications.

Of course, large and even medium-sized companies have not been and cannot be indifferent to technological advances, marketing trends, and, obviously, new sales strategies, particularly those carried out over the Internet (Yu 2012). Companies that invest in new technologies to publicize their products, expand their market, and even position some of their products must be very clear about the sales strategies they will use to achieve their objective (Wijayanto et al. 2014).

Otherwise, it is very likely that they will incur unnecessary expenses or that consumers will not well receive their products. Undoubtedly, a primary objective in the sales process for a product or service is to awaken the consumer's desire to purchase. In this context, new sales strategies must consider the entire consumer process. They need to identify how many and which goods are demanded by their consumers so that the finished product or service can be to their liking and have the intention of buying it (Agmeka et al. 2019).

It is also vital that these sales strategies identify the primary needs of their consumers; from how to reach them, through the profitability of the product and even knowing if the final product or service can be paid for by the consumer or if it is in their total interest (Schwarz and Tan 2021).

The last generations of consumers have witnessed dizzying changes both in the so-called new technologies and in the consumption habits and forms of payment of some products (Dibrova 2016). Scientific and technological development and technology transfer have contributed to multiple advances, which have supported new sales strategies (Ramli 2017; Stonehouse and Snowdon 2007; Shukla et al. 2017; Khan et al. 2014).

These new sales strategies have been developed to present to consumers, in a much more accessible and attractive way, a finished product or service that is already on the market, that is about to enter a new market segment or that its innovation will allow you to create, precisely, a new consumer market (Jagpal and Spiegel 2011). However, new technologies, seen as an innovation process, cannot in any way be considered a synonym of growth and business progress. Over time, the companies that managed to survive these rapid technological developments had to face these imminent changes and, consequently, adapt their products or services, with new sales strategies, to markets that are more competitive every day (Rice 2013).

On the other hand, companies that did not adapt or did not understand these multiple technological changes and unfortunately could not adopt the new sales strategies found themselves in dire need to withdraw some of their products or services from the market. Some companies with a long tradition in the market had to temporarily or permanently close their operations (Bai and Tian 2020).

As mentioned above, new technologies, particularly those adapted to the Internet, played a leading role globally during the COVID19 pandemic (Sipior 2020; Park et al. 2020). In this stage of crisis, multiple applications emerged that allowed people to stay connected through videoconferences (Zoom, Google Meet, Cisco Webex Meetings, Skype, among others), make all kinds of purchases (both products and services) from the comfort of your home (Amazon, Chedraui, Costco, The Green Cornen, Superama, Petco, OfficeMax, Postmates and Delivery.com). Some of these applications became very popular because they brought these purchases to the door of the home (Uber Eats, Rappi, Didi Food, DoorDash, GrubHub, etc.), carry out all kinds of banking transactions with a smartphone (Paypal, Venmo, Google Wallet, Payoneer), hire a streaming service (Netflix, Amazon Prime, Disney+, HBO, Tubi, Discovery).

In this context, the sale and purchase of products and services made through the Internet (e-commerce) had, and continues to have, considerable growth worldwide. Undoubtedly, this behavior of consumers was favored because they avoided, as far as possible, getting and suffering from the symptoms of COVID19 by having direct contact with another person (Kalgotra et al. 2021).

In other words, the Internet became the best ally; became the default shopping channel. What has become clear is that new technologies are a critical factor so that people do not risk the most valuable thing, their lives. In this world scenario, consumers had to learn to use numerous applications, generally through a mobile device, to satisfy their basic needs through internet purchases (Anvari and Norouzi 2016).

For its part, e-commerce or internet commerce is commerce carried out electronically, where the purchase and sale of products or services are carried out through the Internet (Shambhu and Prasanna 2021; Phillips 2016; OECD 2019; Kutz 2016). However, e-commerce is not limited only to the Internet, since it can also be done through intranets (Turban et al. 2018), and neither is e-commerce limited to the purchase or sale of products or services, since you can also transport, trade data, goods, information, communication, among others (Radovilsky 2015).

In this way, e-commerce became a top-rated sales channel that offers products or services to customers. This channel, now a large global market, originated with the sale of electronic devices and small products, which could have easily been transferred between the seller and the buyer. Amazon, the most popular e-commerce provider, started its online business selling books (Buchanan and McMenemy 2012).

Consequently, offering goods that exist only in electronic form, such as software, was even more natural. Therefore, the rapid growth of this online sales channel resulted in a greater diversity of products to be sold over the Internet. In modern times, there are many products or services, even large items such as furniture or cars, that can be sold or bought in electronic stores. In this dynamic, most likely the only thing that changes is the shipping method to deliver the product to the customer.

Undoubtedly, some critical factors that influenced this rapid expansion of e-commerce have been: (1) a low barrier to entry of financing for distributors; (2) an explosive growth of mobile devices; (3) an apparent expansion of social networks; (4) an excessive growth of users on the world wide web; and (5) easy access to the Internet (Cabot 2018).

Now let us see some data related to e-commerce worldwide: The increase in internet users has been an important factor for the growth of e-commerce worldwide since, based on the figures reported by Internet World Stats (2021), Internet users went from 3.696 million (with a world penetration rate of 49.5%) in December 2015 to 5.053 million (with a world penetration rate of 64.2%) in December 2020.

This growth in global connectivity to the Internet is positive for the e-commerce industry because all new users are potential customers to buy online. For its part, the number of e-commerce buyers in the world went from 1520 million in 2016 to 2050 million in 2020 (Statista 2021), which represented a variation of 34.9% for this period. Undoubtedly, e-commerce is a representation of how digital transactions continue to shape the behavior and purchasing practices of people around the world.

In this context, online retail sales in the world went from USD 1845 billion in 2016 to USD 4206 billion in 2020 (Statista 2021), which represented a variation of 128% during the 2016–2020 period. In other words, in five years, the monetary figures associated with this type of e-commerce increased five-eighths worldwide. This implies that sales growth through e-commerce is also associated with increasing the number of internet users who appreciate the benefits of online purchasing concerning traditional media.

E-commerce has changed the way people shop. This type of commerce has changed the way companies carry out their processes, from how they design, produce, deliver their products or services to the way consumers trust suppliers (Laudon and Laudon 2019). Undoubtedly, e-commerce is here to stay, especially in times of pandemics such as the current COVID19 (Kissler et al. 2020).

According to Digital 2021: Global Digital Overview (Hootsuite 2021), consumers worldwide made, through e-commerce during 2020, approximately 347 billion purchases, which is equivalent to 44.5% of purchases worldwide. Furthermore, during the COVID19 pandemic, during 2020, the total value of the global B2C (Business to Consumer) e-commerce market was approximately 2.44 trillion US dollars (Hootsuite 2021). As a consequence of this dynamic in B2C e-commerce

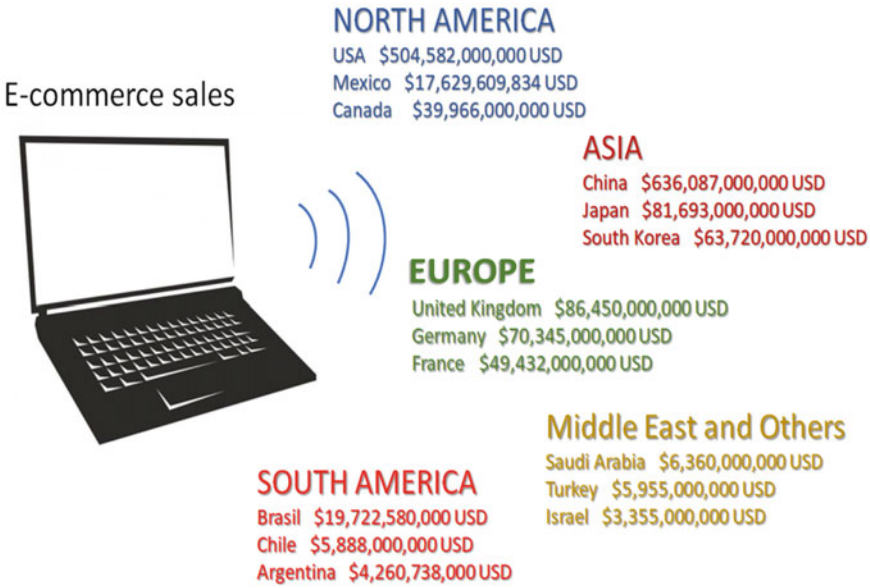


Fig. 1 Impact of e-commerce through global sales in 2020. *Source* Author's elaboration

worldwide, the use of road transport for product distribution also increased (Huang et al. 2018). To conclude with this section, Fig. 1 presents the impact of world sales through e-commerce during 2020 (Linio 2021).

2 Background and Types of E-commerce

Every company must be evident that to survive in an environment where there are multiple products or services similar to yours, and it is of the utmost importance to be different. Michael Porter (1985), one of the pioneers in strategy issues, commented that only two sources of competitive advantage could be identified: (a) offering a similar product (service) at a lower cost or, (b) offering a product (service) different, but at a higher price. This author also states that the first competitive advantage entails a low-cost strategy while the second competitive advantage necessarily leads to a differentiation strategy. However, creating a different product is not as simple as it sounds.

This is because a different product implies, among other things, quality in the product itself. It requires relatively high levels of investment (generally for research and development), innovation, operating costs, labor remuneration, and promotion (Balsam et al. 2011; Nie et al. 2018). These high levels of promotion are allowed because they provide high-profit generation (Holcombe 2009). It is essential to mention that in a market segment, multiple brands are identified that are offered by different companies. A different product or service indeed entails, among other things, important aspects of innovation, high advertising costs, and a considerable investment in research and development (Trout and Rivkin 2008).

However, we consider that it is precisely at this point where the advantage of showing a product (service) through a new sales strategy takes on great importance, which aims to show any product (service) in a more interesting and novel way, regardless of the quality of the product or its intrinsic properties (Guo et al. 2018).

Consumers currently have great options for the same type of product (without loss of generality, from now on we will refer only to the concept of "product" although the term "service" will be implicit), which can even create preferences brand in the mind of the customer (Kumar and Steenkamp 2007).

In the first instance, this behavior aims to increase the income of companies and, later, increase consumer trust and loyalty (Rubio et al. 2015). It is important to ask: why does a consumer choose a specific product in this context? There are indeed multiple factors for a consumer to decide to buy a product (Woo 2015; Turkyilmaz and Uslu 2014), but it is also true that a factor to take into consideration to justify the success and preference of a product is its image or the way it is presented (Kim et al. 2020; Cassani et al. 2020).

This abstract concept can lead the consumer to generate certain perceptions of the product and its presentation (Manzur et al. 2011; Aghekyan-Simonian et al. 2012). These perceptions should in no way be taken lightly, because the rejection of a product, or even a brand, is because: (1) the consumer has had a negative experience with said product or; (2) the consumer has some negative attitudes, even generated by comments from other consumers, towards a product (Winchester and Romaniuk 2008; Lee et al. 2017).

However, we consider that for the image of a product, the way it is presented to the consumer is critical, that is, how the product and its characteristics are presented. For this reason, we are convinced that the strategy of presenting a product, regardless of all its qualities and characteristics, through a new and innovative, economic, and attractive strategy, can serve to position and increase its sales in a market segment.

On the other hand, and as mentioned above, the Internet has changed how we interact in modern societies, and it has even changed the way we currently use our knowledge. Simultaneously, mobile devices gradually became an essential product for a person to communicate or to carry out multiple transactions online. Currently, and anywhere globally, having a smartphone and a wireless network is no longer a luxury or a temporary fad; on the contrary, it has become a necessity, particularly for the new generations.

The way that much of the world's transactions currently take place, including the purchase of a product by retail consumers, is undoubtedly online (Hootsuite 2021). E-commerce classification helps to understand this diversified field. In general, electronic sales and purchases can be Business to Consumer (B2C) or Business to Business (B2B). However, it is important to know the different ways in which this electronic commerce, or types of e-commerce, is carried out. Below we show,

Table 1 Types of e-commerce based on the nature of the transactions and the relationships between the participants

E-commerce	
Business to business (B2B)	Direct delivery
Business to consumer (B2C)	Consumer to consumer (C2C)
Consumer to business (C2B)	Collaborative commerce
Intra-business EC	Electronic government

Source Author's own elaboration

according to Turban et al. (2018), the main classification of e-commerce is based on the nature of the transactions and the relationships between the participants (see Table 1).

3 Traditional Approach to E-commerce

3.1 Issues, Controversies, Problems

Mobile internet traffic is a vast and unavoidable phenomenon. Almost all transactions carried out worldwide could be carried out through a mobile network (social media services, e-commerce, banking, etc.), that is, almost all transactions. Our daily lives can be easily done just by using a mobile device. In this universe of online transactions, and since consumers differ widely, it is difficult to know which product elements work best and which should be abandoned or improved.

However, the quality information associated with a product is necessary and important for consumers to value it and better understand those products they want to buy (Nor Asshidin et al. 2016). Therefore, this information is a preponderant factor for consumers to decide whether they prefer products online (Lin et al. 2018). Of course, the online consumer's decision is very important for the success of e-commerce (Sharma et al. 2019).

In this sense, generally, consumers see photographs of the products they search on the Internet in a static and boring way (see Fig. 2). In addition, if they need to know more information about the product of their interest, they have to click on multiple links to know more details of the product they are analyzing.

Figure 2 shows the traditional way of presenting a product, which can be through an internet page or interactive catalogs with static designs that do not use objects focused on a better perception of the product by the consumer. With the use of an App, a hologram of the finished product can be presented in specific places where the said product could not generally be placed.

For example, augmented reality is intended to surprise the customer and obtain their full attention and interest: one of the main objectives, and perhaps the most important, of the sale of products with the use of these new technologies is to amaze and impact the customer and then motivate him to purchase the final product, the same

Fig. 2 An example of traditional e-commerce. *Source* Author's elaboration

that he previously viewed through an App (generally with a mobile phone). Large and even midsize product brands have not ignored modern e-commerce strategies and growing technological advances.

This behavior, in turn, has allowed some companies or manufacturers to decide to introduce their brands to the market. In this context, Quick Response codes, known as QR (Hill and Whitty 2021; Denso Wave Incorporated 2021), are a reliable and fully customizable tool that allows adding any type of information associated with the product that is displayed through a web page, thus which makes it a novel technology to discover new uses, forms and consumption habits but, above all, it allows a product to be displayed in an interesting, novel and simple way (Pantano and Servidio 2012). The information shown by means of a QR code, which is easily identified if presented next to the product, is intended to surprise the customer and obtain their full attention and interest (Mostafa 2015).

Of course, the sale's primary objective when using this type of new technology is to awaken the consumer's desire and then motivate him to purchase the product that he has already viewed through an App, usually through a mobile phone (Ozkaya et al. 2015).

This approach undoubtedly originates a novel sales strategy that very few companies currently use (Sen et al. 2019). Perhaps the latter is because companies assume that its cost is high; however, this technology is highly affordable and has great potential to show a product more attractively and interestingly for the consumer (Hossain et al. 2018).

In other words, the aim is to present only the information that is important to the consumer and is of complete interest to the consumer and that does not feel bombarded with advertising: Currently, a type of marketing is being developed, known as Inbound Marketing, which aims to undo all that information that is not important to the consumer (Patrutiu-Baltes 2016; Halligan and Shah 2014). However, this type of marketing focuses on the type of information, but not the form, that is presented to the consumer.

It is precisely at this juncture where QR codes make sense as a new sales strategy to make how a product is presented to the consumer in an online store more attractive and interesting (Aghekyan-Simonian et al., 2012). This is because QR codes make it easy to add all kinds of technologies that allow adding, through an image, audio, or video, more interesting and novel information about the product, such as Increased Reality, Virtual Reality, 360° images, music, etc. (Tustain 2018; Orlosky et al. 2017; LaVoila et al. 2017).

Our proposal, as a new sales strategy, will use the relatively new technology called QR codes, through which it will be possible to visualize, through a mobile device, in a virtual way, and with 3D objects, a more detailed panorama of the finished product than a company has available in some of its department stores (Honkamaa et al. 2007; Buchanan and McMenemy 2012). Companies that have a page on the Internet where they present their products can adapt both their page and the way of displaying their products so that, through QR codes, the consumer interacts from anywhere in the world.

On the other hand, companies that do not have an internet page to present their products can opt for a catalog that is expressly designed with attractive colors and images for the user. This catalog can be available in any section where their products are offered. The catalog can be made up of images of the final products, and on one side of each image will be the QR code, which will allow the product to be presented, with the application of a smartphone, through 3D images or display any information in a multimedia file (Reyes et al. 2016).

This procedure can also be performed using a computer camera: the web camera identifies the marker, and immediately afterward, the superimposed image and all the information that is of total interest to the consumer is displayed on the computer screen, which can be downloaded from a website previously designed for that purpose. The superimposed image (2D or 3D) is crucial because it captures the most significant consumer attention.

This image must be attractive to the eye since it will represent the content and use of the finished product, show its existence in inventories, track the location of the sale, request the consumer's email for more information, request the evaluation of the product (via an online survey or email) and even providing a purchase button (commonly known as a shopping cart).

In other words, and regardless of whether the product is presented on an internet page or in a catalog, the objective of our proposal is that, in addition to the product, a QR code is presented that is detonated using an image or marker. This QR code will allow, when scanned by a webcam or a mobile device, to view 2D or 3D images, multimedia files, etc. the product and display all kinds of information associated with it so that it can be consulted by an undetermined number of consumers (Fridhi and Frihida 2019).

4 Solutions and Recommendations

Within the sales process through the Internet, different needs can be observed. For example, the furniture to buy is according to the decoration, that the product meets their needs, that motivate the consumer's desire to purchase or enhance the purchase. It is necessary to visualize the consumer's process since the main objective is to demand some goods that are to his liking. The perception of a product, through its image, can in no way be taken lightly, since the preference of a product, or even a brand, can occur because the customer has had a pleasant experience with said product or because the customer has some attitudes positives, even generated by comments from other consumers, towards a specific product.

At this point, we are convinced that in order to establish a better sales strategy, even for each market segment established by a group of consumers with heterogeneous consumption habits, a faster, more direct, and efficient interaction is necessary and even indispensable, the which can be carried out by implementing the QR codes on one side of the product that is being shown by a device with internet access (Zendjebil et al. 2008): fast because it only depends on the speed with which the transmission of the data; direct because it allows and facilitates interaction with the consumer through a mobile and efficient device because it shows, dynamically and attractively, the characteristics and all the specific information of the product that is for sale, you can even see all this in real-time (Wara and Dugga 2019).

On the other hand, contemporary consumers are increasingly responsible for what they buy; for example, they are currently interested in visualizing the product in more detail. They are interested in being informed about its composition or how it affects the ecology. Due to this, companies have to migrate towards new technologies to attend to the new ways of choosing and selecting a product, that is, how to sell their products.

Likewise, it is essential to change the culture of offering products because technologies have already proposed and improved new markets (such as internet sales or automated points of sale). The sales strategy through QR codes will personalize the products, thus offering quality and convenience in purchases. In this sense, the knowledge and comparison of brands with others, of which there may already be knowledge, can make certain brands better known and selected precisely for the innovative way they are being presented.

4.1 Hardware Requirements

The system's design that we propose must foresee the type of hardware and software required for the execution of the system. In this system, the following is proposed:

- Photographic cameras, usually contained by mobile devices connected to the Internet. With this, both the QR code and the marker are detected.

- Device screen (usually the mobile device) with which to interact with the system. This screen shows the three-dimensional image of the product, the information, and the characteristics that are intended to be shown to the consumer.
- Audio, also provided on mobile devices, since in many cases, the images come with sound, usually in a podcast.

The recent evolution of mobile hardware has allowed QR codes to be the "triggers" to reproduce multiple applications and tools on physically small units such as smartphones or tablets. These devices contain all the necessary components to present the consumer with all kinds of information about a product, such as high-resolution cameras and displays, accelerometers, GPS, wireless connectivity via WLAN, and radio links (Honkamaa et al. 2007).

For the execution of this product sales system, using QR codes, a camera is used, which produces a point of view to show all the information related to the product and that will be superimposed on a marker (see Fig. 3). In addition, information display events such as its price, existence, composition, etc. can be "triggers" which will be helpful for the consumer because they will be able to compare the products of their interest with other well-known brands even displayed on display the same shelf.

By comparing and obtaining the advantages of the products, the consumer is expected to be inclined to buy the products that quickly and efficiently show him better information. In addition, in this interaction, you can go to the product's official site, social networks such as Facebook or Twitter, and even purchase through these means. Interaction can be done through buttons with overlapping icons, which show the objects or links associated with the product when pressed.

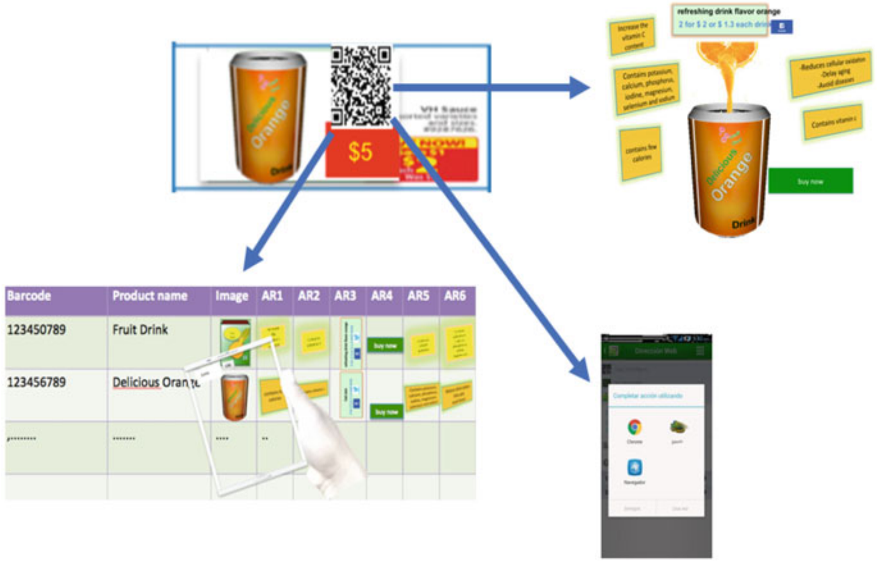


Fig. 3 Reading the QR code. *Source* Author's elaboration

4.2 System Architecture

The first action that begins with the system's design is the determination of the system's architecture, which is the hierarchical structure of the program modules, the way its components interact, and the data structure used by its modules. (Bass et al. 2012). There are several architectural styles of software; however, due to the nature of the system that is proposed to be built, the one that should be modeled is the Service Oriented Architecture (SOA) type, which is an architecture paradigm to design and develop distributed systems and has been created to provide ease and flexibility of integration with linked systems, as well as establish direct alignment with business processes, thus reducing implementation costs. Other advantages of this system are: (1) it implements the innovation of services to consumers and (2) it has an agile adaptation to changes, including early reaction to competitiveness (Bianco et al. 2007).

The main characteristic of SOA is that the information systems of a company are built on a set of computer standards with the aim that all of them, even those made with different technologies, can operate in an integrated way and without dependencies between them. SOA represents a model where a logical unit is decomposed into several smaller units; In this architecture, the services can be used by other services or other programs (Erl 2017). The architecture of the product sales system, using QR codes, is shown in Fig. 4.

In this product sales system, the following components should be considered: image design, product repository, online shopping, Internet, web system, creation of QR codes, and bookmarks. The programming paradigms for this type of architecture

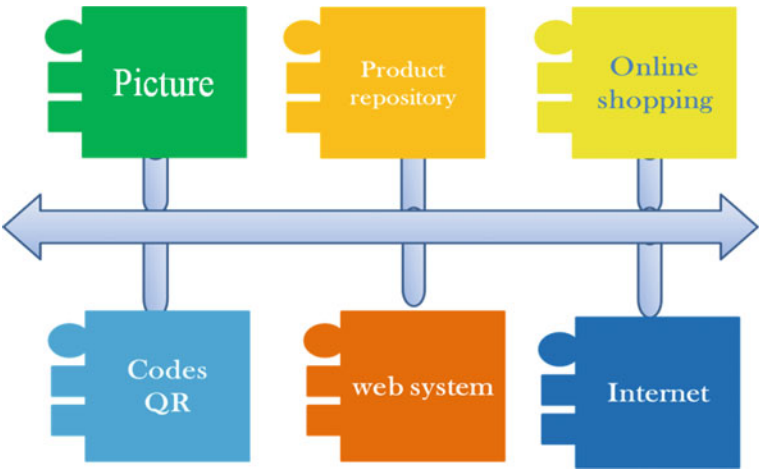


Fig. 4 SOA of the product sales system through QR codes. *Source* Author's elaboration

require a structure that integrates different modules to be interconnected and simultaneously operate individually; This characteristic is called "low level of coupling of services".

To graphically show the architecture of this system, it is necessary to construct a diagram to show its operation from the precise moment the consumer visualizes a product until he finishes using the system: a technique that can be used is known as "Activities diagram" (see Fig. 5).

The interfaces to be used must be of a standard type, which will allow services of different technologies, and even dissimilar data formats to exchange information without resorting to delimited interfaces (OASIS 2021).

5 Design and Construction of QR Codes

Agrebi and Jallais (2015) pointed that the greater the perception regarding the ease of use, the greater the intention of people to use the telephone and make purchases. Based on this, it can be indicated that it is attractive and novel when the consumer uses their mobile device to view a product through a web page in 2D, 3D or AR. The plus of these web pages when adding an internet sales system is that it stimulates people to perceive them as of enjoyment and to make purchases of hedonic and utilitarian products through them. This interaction with the user allows more and more companies to promote their products through this modality, which includes the case of products offered through e-commerce. In this way, the creation of the QR codes is as follows.

5.1 QR Code

The QR code (see Fig. 6) is a two-dimensional image that stores information in a dot matrix or a two-dimensional barcode created in 1994 by the Japanese company Denso Wave, a subsidiary of Toyota (Denso Wave Incorporated 2021). There are different QR code readers (see Table 2), among them some are free to use and ready to be downloaded via the Internet; even new smartphones are already equipped with this type of software: In these QR codes, you can store text, a website address, a phone number or even a social network domain such as Facebook or Twitter. This type of two-dimensional code is used in these sales systems so that the consumer can locate the corresponding application quickly and precisely by the camera directed towards the QR code.

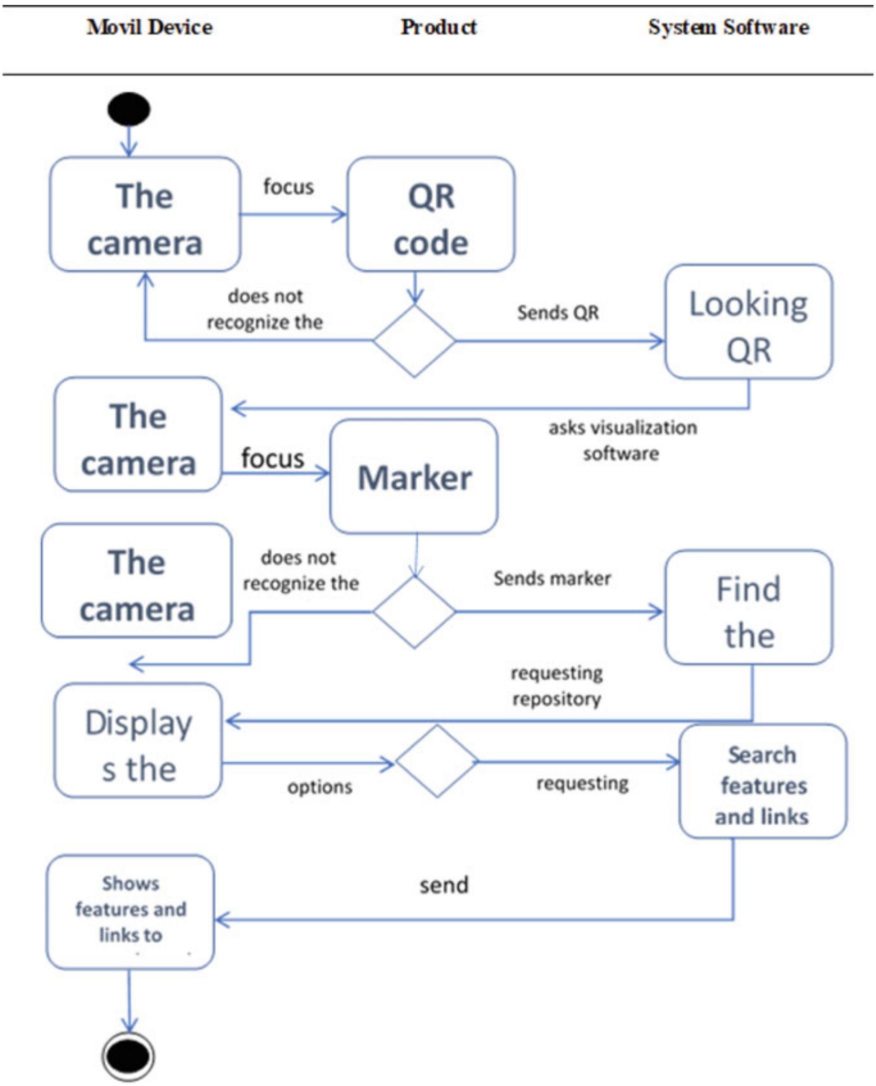


Fig. 5 Activity diagram of the catalog sales system for own-brand products. *Source* Author's elaboration

5.2 *Marker*

It is a 2D image that allows the information associated with it to be easily extracted thanks to its predefined color and shape characteristics. (Uchiyama and Marchand 2012) In this sense, the marker is used as a trigger, which "fires" at the moment it is detected by the mobile device's camera, to show 3D or multimedia virtual objects as

Fig. 6 QR code reader. *Source* Author's own elaboration

Table 2 QR code reader apps

QR code reader	Operating system
ScanLife/BIDI	iOS, Android, BlackBerry, Symbian, Java
QR Droid/QR Zapper	Android/iOS
QRafter	iOS
RedLaser	iOS, Android, Windows Phone
Tingiz	Android
Scan	iOS, Android, Windows Phone
Barcode Scanner	Android
i-nigma	iOS, Android, BlackBerry, Windows Phone
1QR	Android
Beetag Reader	Windows Phone 7, Android iPhone, Bada BlackBerry, BlackBerry Touch, J2me, PalmOS 5.x, Symbian S60 2nd–Symbian S60 3rd, Symbian S60 5th, Symbian UIQ2, Symbian UIQ3, Windows Mobile 5, 6, 6.5
UpCode Reader	Nokia with Symbian
QuickMark Reader	System iOS, Android, Windows Phone/Mobile and Symbian
Kaywa Reader	Java like Motorola, Samsung or Sony Ericson

Source Author's own elaboration

well as to show links to the product characteristics, information from linked websites and, in some cases, facilitates and motivates the purchase of the product. Markers can be built with a drawing program; these markers require some specific characteristics to be recognized efficiently.

Once the marker has been designed, it is exported as an image, in any format, to display it together with the product shown on the web page (print it in the product catalog or even in the packaging of the product to consult). A marker contains a black outline (frame) for the camera to detect. Within this outline (frame), a black and white pattern is defined that is encoded as marker identification. These types of markers have been developed with different forms of identification, which restrict the representation of the marker in order to improve the stability and scalability of recognition through a mobile device.

After creating the marker, we proceed to generate all the information that will be added to the product when the mobile device's camera focuses on the marker. This information, which can be a 3D virtual object, is designed with a wide variety of specialized software used to create innovative content and awaken, in turn, the interest and desire of the consumer to buy. For the scope of this work, the construction of the 3D object is not detailed because each design software has different characteristics; however, Fig. 7 shows the result of a product when it is associated, through QR codes, with a or several Apps.

Fig. 7 Apps associated with a product through QR codes. *Source* Author's own elaboration

6 Future Directions of Research

New technologies, rather than being fashionable, are increasingly close to people, and using them obtains various benefits. An example is the sale of products online, which uses other technologies to publicize its products better and, in this way, increase sales. In addition, these technologies seek a way to make the product more attractive through multimedia files to generate in people the desire to have it in their hands.

How many times have people dreamed of observing the details (such as the colors, dimensions, their music, their operability, their movements, etc.) of their favorite toys before buying them or the items in operation before opening them. Even wanted to see the clothes in various colors and try on ornaments without removing them from the wrapper. This, generally, was done after purchasing the product, that is, until the moment in which the person appreciated the product when they tried it on in front of a mirror and observed if that product was to their total liking. Because flat images do not stimulate emotion or the desire to own the product, companies are increasingly using new sales strategies to make people's wishes come true, thereby increasing people's preference for your products, which will be reflected in an increase in your sales.

Currently, the world is invaded by mobile devices. According to data from Hootsuite (2021), in January 2021, there were 5.22 billion people with a mobile phone, which represented a penetration level of 66.6% worldwide. Likewise, the penetration level of social networks was 53.6% (4.2 billion people in the world). This is a great reason to add new technological elements to the products offered on the web pages; elements that encourage the consumer to enter an avant-garde world of buying and selling and, for this reason, technological resources must be generated that are novel and innovative so that users can use them quickly. In addition, these technological resources must be designed, built, and sold with the software used daily. Furthermore, these technological resources must be indispensable in those programs used with devices that are very frequently used by the user, in this case, such as so-called mobile devices.

Taking into account that computer systems have evolved from the moment in which factors such as the mobile platform, the growing use of big data for business, and the vast use in cloud computing have been added (Laundon and Laudon 2019), it is necessary to look for technologies that make more effective use of the Internet and mobile devices that meet consumer requirements.

To be at the forefront of these sales issues, our choice must be improved when using information resources that are, to a large extent, invention and improvement of information and communication technologies, that is, those systems that involve new technologies with characteristics and capabilities in information management.

Although technological resources and tools that use QR codes have already been developed, it is necessary to introduce more of these resources in e-commerce. These new systems are proposed to help consumers and sellers show what they want to express themselves with the display of a product. In other words, the abstract must be extracted from a product in order to show it to the consumer, which, without a

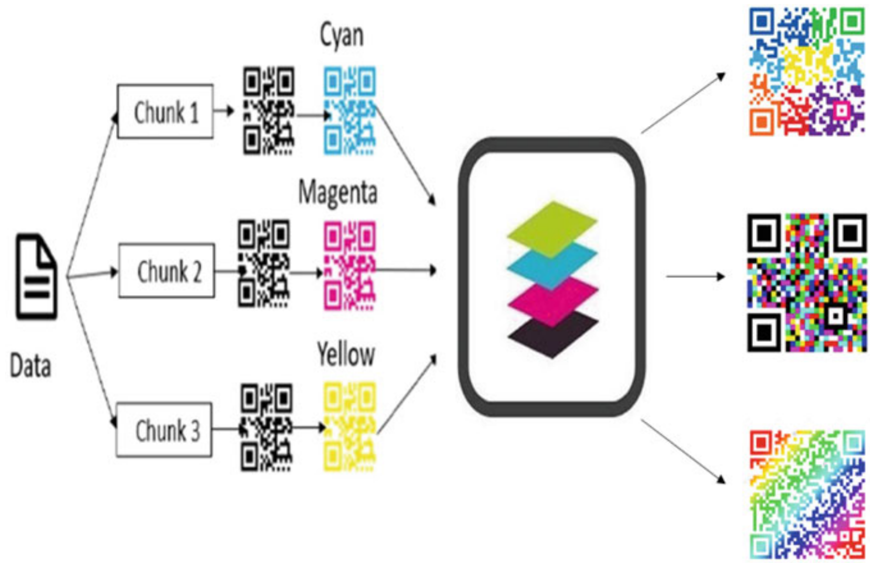


Fig. 8 Multi-level QR codes. *Source* Own elaboration based on Badawi et al. (2019)

doubt, can be achieved with quite accessible elements, such as multimedia elements. In this context, and to continue using QR code technology, it is proposed to use multi-level QR codes (see Fig. 8). These multi-level codes contain multiple layers of information, which, independently, can function as a simple QR code. Among the many advantages of using multi-level QR codes, the following stand out: increasing the use of information with a single code, encrypting multiple information channels, simultaneously using multiple apps, they can be used as multiple security codes, interlacing information, decreasing the use of simple QR codes, motivate the creation, adaptation, and use of new technologies, among others. Furthermore, with these multi-level codes, new sales strategies would, in turn, be generated.

The information that is added to the image of the product, using a multi-level QR code, can be information that is downloaded from a website (text, images, sound, video or multimedia files, augmented or virtual reality, etc.) or content from a 3D presentation of the product its correct use, its construction through a manual or video, the location of the sale, stock in the store, the contact email, a purchase button, set aside the product, follow-up on the purchase or shipment, among others.

On the other hand, this type of new technology allows connection with others that can achieve a new shopping experience for the consumer. For example, the shopping experience through mobile commerce (m-commerce), which includes information services (Google, yellow pages, the cloud, etc.), multiple transactions, location-based services (such as reception discounts, coupons at a local store, taxis, etc.), support services, emergency services, entertainment, etc. All these aspects can be carried out in real-time, which will depend, logically, only on the speed at which the data is transmitted.

In this context, products that associate a multi-level QR code can be a vital component of this type of commerce. By using these codes, the mobile device's camera would be used as an interaction device. Therefore, and through this simple mechanism, the user could view with a mobile device all the information that is found on the Internet and that is associated with the displayed product.

7 Conclusions

Multiple scientific and technological advances have supported new internet sales strategies, commonly known as e-commerce. In order to present potential customers with a finished product, which is already for sale in the market or is about to enter a new market segment, some of these new e-commerce strategies are developed in a way more accessible and attractive. In this context, the new e-commerce strategies have shown that, over time, how products are presented but, above all, are sold to the consumer has also changed.

Consequently, currently, it is no longer enough to adopt a sales strategy that presents a specific product on the sideboard or through any other conventional means to sell it. The use of the Internet has revolutionized the way people interact: now communications are faster and more efficient. In the same way, the development of mobile devices has reached a level of dependency for the human being that currently is a necessary product, and almost indispensable, for a person to be communicated or to make purchases online. In the splendid scenario of online shopping, awakening the consumer's desire to buy is undoubtedly one of the main objectives in the complex process of selling any product.

Therefore, the main objective of using e-commerce, based on new technologies, is to surprise the customer and, as a consequence, obtain their entire interest and attention towards the product that the customer is observing through these new technologies. In this sense, new technologies are an ideal means to awaken the consumer's desire and motivate him to purchase the displayed product, generally through an App with a mobile device.

Even though this new approach allows generating an innovative sales strategy, many companies, despite being familiar with it, are very few who use it and even fewer who dare to develop an application specifically for one or some of them. This is undoubtedly due to the high cost of companies implementing a new technology, which is not necessarily the case.

Information systems are codes built to help people make decisions easily, accessible, and fast way. These decisions would be oriented to different areas ranging from acquiring new knowledge, medicine, tourism, etc., to other areas that include the sale-purchase of products and the offering of products to consumers in a more novel and innovative way.

At present, there are multiple examples of these systems that provide this type of facility to consumers by way of offering products and services, such is the case of the selection of places in a cinema, theatre or auditorium, to name a few examples, and where your options also contain the date and time. Other types of online sales systems can be flight reservations or bus travel reservations, where sales also change and adapt to consumers' daily actions and needs.

This could be seen during COVID19; that is, e-commerce sales were the first response to offer the consumer, more innovatively and efficiently, products and services through the Internet what was offered daily through catalogs, magazines or just on the shelf.

The sales strategy, through QR codes, that we propose in this book chapter offers a very accessible format to interact with the consumer through a previously designed internet page. We believe that this e-commerce strategy can be acquired by companies interested in selling their products online at a reasonably affordable price. Without a doubt, our proposal's advantages are its adaptability, since it can be quickly adapted to all types of products. This new e-commerce strategy can be offered by including a software update service and an extra-oriented service to technical support.

QR codes make it possible to relate this e-commerce strategy with other new technologies, social networks, and multiple apps for mobile devices that, in turn, serve to generate more innovative environments (such as augmented reality, virtual reality, or mixed reality). This novel approach to e-commerce allows showing all kinds of products in an original and novel way. In addition, we are convinced that this e-commerce strategy will favor and position any product that a company selects to show it from a different perspective. There is much to do with QR codes; however, the priority is to bring this new technology closer to companies that bet on cutting-edge e-commerce. Currently, very few companies use and know this technological tool because they consider it expensive.

We also consider that this book chapter has the massive consumer market as its horizon, mainly because many products are still offered through the traditional way (radio, television, print media) but are not offered in a specific segment of the market.

At present, there are still many products that are offered simultaneously to large numbers of consumers, who make up a whole target population and who are also waiting to acquire a product in a new way that attracts their attention. Around the world, companies stand out that, regardless of their sales strategy, they are responsible for providing consumers with quality products.

Furthermore, if these companies undertake to promote the use of new technologies as a strategic precursor and competitive differentiator, then they will be prepared to face the challenge that modernity has prepared for them to achieve market positioning of their products: to exceed their objectives of the business through new e-commerce strategies.

For all of the above, we are convinced that any company interested in offering its products through this novel e-commerce strategy will benefit from a sustained increase in sales. This novel e-commerce strategy is aimed at companies that have products and that have a certain interest in positioning, distributing, or making them known in markets that every day demand a higher level of innovation and creativity.

Undoubtedly, companies interested in implementing new e-commerce strategies for their products will have a greater probability of reaching higher sales levels since by creating and implementing new technologies and supporting the progress of their environment, they allow a glimpse of new technological horizons. These new e-commerce proposals are made available to consumers, who will generate new needs for the correct application of the products they purchase in the not too distant future. Above all, infinite opportunities will open up for technological innovation.

In other words, the new ways of presenting a product, providing a particular visual and creative interaction generated through QR codes, will facilitate and allow a considerable increase in e-commerce worldwide. Therefore, this strategy allows to potentiate the advantages in terms of customer service, since by interacting with them through the visualization offered by the multiple apps, triggered by QR codes and with access from any device mobile, it is intended to provoke a different turn to the advertising that is currently known in e-commerce and, as already mentioned above, to generate new forms of consumer habits.

References

Aghekyan-Simonian, M., Forsythe, S., Kwon, W.S., Chattaraman, V.: The role of product brand image and online store image on perceived risks and online purchase intentions for apparel. J. Retail. Consum. Serv. **19**, 325–331 (2012). https://doi.org/10.1016/j.jretconser.2012.03.006

Agmeka, F., Wathoni, R.N., Santoso, A.S.: The influence of discount framing towards brand reputation and brand image on purchase intention and actual behaviour in ecommerce. Procedia Comput. Sci. **161**, 851–858 (2019). https://doi.org/10.1016/j.procs.2019.11.192

Agrebi, S., Jallais, J.: Explain the intention to use smartphones for mobile shopping. J. Retail. Consum. Serv. **22**, 16–23 (2015). https://doi.org/10.1016/j.jretconser.2014.09.003

Ameen, N., Hosany, S., Tarhini, A.: Consumer interaction with cutting-edge technologies: implications for future research. Comput. Human Behav. **120** (2021). Article 106761. https://doi.org/10.1016/j.chb.2021.106761

Anvari, R.D., Norouzi, D.: The impact of e-commerce and RandD on economic development in some selected countries. Procedia Soc. Behav. Sci. **229**, 354–362 (2016). https://doi.org/10.1016/j.sbspro.2016.07.146

Badawi, B., et al.: A smart fuzzy auto suggestion system for a multilayer qr code generator. J. Theor. Appl. Inf. Technol. **19**(13), 3585–3603 (2019)

Bai, Q., Tian, S.: Innovate or die: Corporate innovation and bankruptcy forecasts. J. Empir. Financ. **59**, 88–108 (2020). https://doi.org/10.1016/j.jempfin.2020.09.002

Balsam, S., Guy, D.F., Arindam, T.: The impact of firm strategy on performance measures used in executive compensation. J. Bus. Res. **64**(2), 187–193 (2011). https://doi.org/10.1016/j.jbusres.2010.01.006

Bass, L., Clements, P., Kazman, R.: Software Architecture in Practice, 3rd edn. Addison-Wesley Professional, USA (2012)

Bianco, P., Kotermanski, R., Merson, P.: Evaluating a Service-Oriented Architecture (CMU/SEI-2007-TR-015). Recovered from the Software Engineering Institute, Carnegie Mellon University website: http://resources.sei.cmu.edu/library/asset-view.cfm?AssetID=8443 (2007)

Buchanan, S., McMenemy, D.: Digital service analysis and design: the role of process modelling. Int. J. Inf. Manage. **32**(3), 251–256 (2012). https://doi.org/10.1016/j.ijinfomgt.2011.11.008

Bulearca, M., Tamarjan, D.: Augmented reality: a sustainable marketing tool? Glob. Bus. Manag. Res. **2**(2–3), 237–252 (2010)

Cabot, J.: WordPress: a content management system to democratize publishing. IEEE Softw. **35**(3), 89–92 (2018). https://doi.org/10.1109/MS.2018.2141016

Cassani, L., et al.: Emotional response evoked when looking at and trying a new food product, measured through images and words. A case-study with novel fruit and vegetable smoothies. Food Qual. Prefer. **84** (2020), Article 103955. https://doi.org/10.1016/j.foodqual.2020.103955

Denso Wave Incorporated: Website. Recovered from http://www.qrcode.com/ (2021)

Dibrova, A.: Virtual currency: new step in monetary development. Procedia Soc. Behav. Sci. **229**, 42–49 (2016). https://doi.org/10.1016/j.sbspro.2016.07.112

Dolega, L., Rowe, F., Branagan, E.: Going digital? The impact of social media marketing on retail website traffic, orders and sales. J. Retail. Consum. Serv. **60** (2020), Article 102501. https://doi.org/10.1016/j.jretconser.2021.102501

Elsobeihi, M.M., Abu Naser, S.S.: Effects of mobile technology on human relationships. Int. J. Eng. Inf. Syst. **1**(5), 110–125 (2017)

Erl, T.: SOA Design Patterns. Pearson, USA (2017)

Fenu, G., Pau, P.L.: An Analysis of features and tendencies in mobile banking apps. Procedia Comput. Sci. **56**, 26–33 (2015). https://doi.org/10.1016/j.procs.2015.07.177

Forecast GMDT: Cisco visual networking index: global mobile data traffic forecast update, 2017–2022. Recovered from https://www.cisco.com/c/en/us/solutions/service-provider/visualnetworking-index-vni/index.html (2019)

Fridhi, A., Frihida, A.: GIS 3D and science of augmented reality: modeling a 3D geospatial environment. J. Soft Comput. Civ. Eng. 3–4, 78–87 (2019). https://doi.org/10.22115/SCCE.2020.212254.1148

Grubor, A., Milovanov, O.: Brand strategies in the era of sustainability. Interdiscip. Descr. Complex Syst. **15**(1), 78–88 (2017). https://doi.org/10.7906/indecs.15.1.6

Guo, B., Wang, J., Wei, S.X.: RandD spending, strategic position and firm performance. Front. Bus. Res. China **12** (2018). Article 14. https://doi.org/10.1186/s11782-018-0037-7

Halligan, B., Shah, D.: Inbound Marketing: Attract, Engage, and Delight Customers Online. Wiley, USA (2014)

He, W., Zhang, Z.J., Li, W.: Information technology solutions, challenges, and suggestions for tackling the COVID-19 pandemic. Int. J. Inf. Manag. **57** (2021). Article 102287. https://doi.org/10.1016/j.ijinfomgt.2020.102287

Hill, G.N., Whitty, M. A.: Embedding metadata in images at time of capture using physical quick response (QR) codes. Inf. Process. Manage. **58**(3) (2021). Article 102504. https://doi.org/10.1016/j.ipm.2021.102504

Holcombe, R.G.: Product differentiation and economic progress. Q. J. Austrian Econ. **12**(1), 17–35 (2009)

Honkamaa, P., Jäppinen, J., Woodward, C.: A lightweight approach for augmented reality on camera phones using 2D images to simulate in 3D. VTT. MUM '07: Proceedings of the 6th International Conference on Mobile and Ubiquitous Multimedia (2007). https://doi.org/10.1145/1329469.1329490

Hootsuite: Digital 2021: global digital overview. Recovered from https://datareportal.com/reports/digital-2021-global-overview-report (2021)

Hossain, Md.S., Zhou, X., Rahman, Mst.F.: Examining the impact of QR codes on purchase intention and customer satisfaction on the basis of perceived flow. Int. J. Eng. Bus. Manage. **10**, 1–11 (2018). https://doi.org/10.1177/1847979018812323

Huang, Y., Savelsbergh, M., Zhao, L.: Designing logistics systems for home delivery in densely populated urban area. Transp. Res. Part B **115**, 95–125 (2018). https://doi.org/10.1016/j.trb.2018.07.006

Hugill, P.J.: The power of knowledge: how information and technology made the modern world. J. Hist. Geogr. **52**, 123–124 (2016). https://doi.org/10.1016/j.jhg.2015.06.007

Internet World Stats: Website. Recovered from https://www.internetworldstats.com/emarketing.htm (2021)

Jagpal, S., Spiegel, M.: Free samples, profits, and welfare: the effect of market structures and behavioral modes. J. Bus. Res. **64**, 213–219 (2011). https://doi.org/10.1016/j.jbusres.2010.02.001

Kalgotra, P., Gupta, A., Sharda, R.: Pandemic information support lifecycle: evidence from the evolution of mobile apps during COVID-19. J. Bus. Res. **134**, 540–559 (2021). https://doi.org/10.1016/j.jbusres.2021.06.002

Khan, R.T., et al.: Synthesis of constructs for modeling consumers' understanding and perception of eco-labels. Sustainability **6**, 2176–2200 (2014). https://doi.org/10.3390/su6042176

Kim, S., Baek, T.H., Yoon, S.: The effect of 360-degree rotatable product images on purchase intention. J. Retail. Consum. Serv. **55** (2020). Article 102062. https://doi.org/10.1016/j.jretconser.2020.102062

Kissler, S.M., Tedijanto, C., Goldstein, E., Grad, Y.H., Lipsitch, M.: Projecting the transmission dynamics of SARS-CoV-2 through the postpandemic period. Science **368**(6493), 860–868 (2020). https://doi.org/10.1126/science.abb5793

Kumar, N., Steenkamp, J.B.: Private Label Strategy-How to Meet the Store Brand Challenge. Harvard Business School Press, USA (2007)

Kutz, M.: Introduction to E-commerce: Combining Business and Information Technology. Bookboon.com Ltd., United Kingdom (2016)

Laudon, K.C., Laudon, J.P.: Management Information Systems Managing the Digital Firm, 16th edn. Pearson Education Limited, USA (2019)

LaVoila, J.J., et al.: 3D User Interfaces: Theory and Practice. Addison-Wesley Professional, USA (2017)

Lee, C.D., Daiute, C.: Introduction to developmental digital technologies in human history, culture, and well-being. Hum. Dev. **62**, 5–13 (2019). https://doi.org/10.1159/000496072

Lee, S.M., Trimi, S.: Convergence innovation in the digital age and in the COVID-19 pandemic crisis. J. Bus. Res. **123**, 14–22 (2021). https://doi.org/10.1016/j.jbusres.2020.09.041

Lee, W.-I., Cheng, S.-Y., Yu-Ta, S.: Effects among product attributes, involvement, word-of-mouth, and purchase intention in online shopping. Asia Pac. Manage. Rev. **22**(4), 223–229 (2010). https://doi.org/10.1016/j.apmrv.2017.07.007

Lee, W.-I., Cheng, S.-Y., Shih, Y.-T.: Effects among product attributes, involvement, word-of-mouth, and purchase intention in online shopping. Asia Pac. Manag. Rev. **22**, 223–229 (2017). https://doi.org/10.1016/j.apmrv.2017.07.007

Lin, X., Featherman, M., Brooks, S.L., Hajli, N.: Exploring gender differences in online consumer purchase decision making: an online product presentation perspective. Inf. Syst. Front. **21**, 1187–1201 (2018). https://doi.org/10.1007/s10796-018-9831-1

Lindsey-Mullikin, J., Borin, N.: Why strategy is key for successful social media sales. Bus. Horiz. **60**(4), 473–482 (2017). https://doi.org/10.1016/j.bushor.2017.03.005

Linio: Website. Recovered from https://www.linio.com.mx/sp/indice-ecommerce (2021)

Manzur, E., Olavarrieta, S., Hidalgo, P., Farías, P., Uribe, R.: Store brand and national brand promotion attitudes antecedents. J. Bus. Res. **64**, 286–291 (2011). https://doi.org/10.1016/j.jbusres.2009.11.014

Mostafa, A.A.: The effectiveness of product podes in marketing. Procedia Soc. Behav. Sci. **175**, 12–15 (2015). https://doi.org/10.1016/j.sbspro.2015.01.1168

Nie, P., Wang, C., Chen, Y., Yang, Y.: Effects of switching costs on innovative investment. Technol. Econ. Dev. Econ. **24**(3), 933–949 (2018). https://doi.org/10.3846/tede.2018.1430

Nor Asshidin, N.H., Abidin, N., Borhan, H.B.: Consumer attitude and uniqueness towards international products. Procedia Econ. Fin. **35**, 632–638 (2016). https://doi.org/10.1016/S2212-5671(16)00077-0

Nurul Aqila, H., et al.: The Relationship of attitude, subjective norm and website usability on consumer intention to purchase online: an evidence of Malaysian youth. Procedia Econ. Fin. **35**, 493–502 (2016). https://doi.org/10.1016/S2212-5671(16)00061-7

OASIS: Advancing open standards for the information society. Recovered from https://www.oasis-open.org/news (2021)

OECD: Unpacking E-commerce: Business Models, Trends and Policies. OECD Publishing, Paris (2019). Recovered from https://www.oecd-ilibrary.org/science-and-technology/unpacking-e-commerce_23561431-en

Orlosky, J., Kiyokawa, K., Takemura, H.: Virtual and augmented reality on the 5G highway. J. Inf. Process. **25**, 133–141 (2017). https://doi.org/10.2197/ipsjjip.25.133
Ozkaya, E., et al.: Factors affecting consumer usage of QR codes. J. Direct Data Digit. Mark. Pract. **16**, 209–224 (2015). https://doi.org/10.1057/dddmp.2015.18
Pang, J., Keh, H.T., Peng, S.: Effects of advertising strategy on consumer-brand relationships: a brand love perspective. Front. Bus. Res. China **3**(4), 599–620 (2009). https://doi.org/10.1007/s11782-009-0029-8
Pantano, E., Servidio, R.: Modeling innovative points of sales through virtual and immersive technologies. J. Retail. Consum. Serv. **19**, 279–286 (2012). https://doi.org/10.1016/j.jretconser.2012.02.002
Park, S., Choi, G.J., Ko, H.: Information technology–based tracing strategy in response to COVID-19 in South Korea-privacy controversies. J. Am. Med. Assoc. **323**(21), 2129–2130 (2020). https://doi.org/10.1001/jama.2020.6602
Patrutiu-Baltes, L.: Inbound marketing-the most important digital marketing strategy. Bull. Transilvania Univ. Braşov. Series V: Econ. Sci. **9**(58/2), 61–68 (2016). Recovered from http://webbut.unitbv.ro/BU2016/Series%20V/Contents_V_MK.html
Phillips, J.: Ecommerce Analytics. Analyze and Improve the Impact of Your Digital Strategy. Pearson Education Inc., USA (2016)
Porter, M.: Competitive Advantage. Creating and Sustaining Superior Performance. The Free Press, New York (1985)
Radovilsky, Z.: Business Models for E-Commerce. Cognella Academic Publishing, USA (2015)
Ramli, N.S.: A review of marketing strategies from the European chocolate industry. J. Glob. Entrep. Res. **7**(10), 1–17 (2017). https://doi.org/10.1186/s40497-017-0068-0
Reyes, R.G., Olmos, P.S., Hernández, H.M.: Private label sales through catalogs with augmented reality. In: Handbook of Research on Strategic Retailing of Private Label Products in a Recovering Economy (Coordinadoras Mónica Gómez-Suárez y María Pilar Martínez-Ruiz), pp. 275–305. Business Science Reference (an imprint of IGI Global), United Satates of America (2016).
Rice, A.L.: The Enterprise and Its Environment: A System Theory of Management Organization. Psychology Press, London (2013)
Rubio, N., Villaseñor, N., Oubiña, J.: Consumer identification with store brands: Differences between consumers according to their brand loyalty. Bus. Res. Q. **18**, 111–126 (2015). https://doi.org/10.1016/j.brq.2014.03.004
Rust, R.T.: The future of marketing. Int. J. Res. Mark. **37**(1), 15–26 (2020). https://doi.org/10.1016/j.ijresmar.2019.08.002
Schwarz, J.A., Tan, B.: Optimal sales and production rollover strategies under capacity constraints. Eur. J. Oper. Res. **294**, 507–524 (2021). https://doi.org/10.1016/j.ejor.2021.01.040
Sen, S., Rocco, R.A., Ranganathan, S., Brooks, J.R.: Revisiting quick response code technology: corporate perspectives. Int. J. Mobile Commun. **17**(6), 703–726 (2019). https://doi.org/10.1504/IJMC.2019.102722
Shaikh, A.A., Karjaluoto, H.: Mobile banking adoption: a literature review. Telematics Inform. **32**(1), 129–142 (2015). https://doi.org/10.1016/j.tele.2014.05.003
Shambhu, N.S., Prasanna, S.: Influence of conditional holoentropy-based feature selection on automatic recommendation system in E-commerce sector. J. King Saud Univ.-Comput. Inf. Sci. (2021, in press). https://doi.org/10.1016/j.jksuci.2020.12.022
Sharma, T., Bashir, M.: Use of apps in the COVID-19 response and the loss of privacy protection. Nat. Med. **26**, 1165–1175 (2020). https://doi.org/10.1038/s41591-020-0928-y
Sharma, S., Mahajan, S., Rana, V.: A semantic framework for ecommerce search engine optimization. Int. J. Inf. Technol. **11**(1), 31–36 (2019). https://doi.org/10.1007/s41870-018-0232-y
Shukla, M., Dos Santos, R., Fong, A., Lu, C.-T.: DERIV: distributed brand perception tracking framework. J. Big Data **4**(17), 1–23 (2017). https://doi.org/10.1109/ICMLA.2016.0069

Singh, U.S., et al.: A study on the revolution of consumer relationships as a combination of human interactions and digital transformations. Mater. Today: Proc. (2021, in press). https://doi.org/10.1016/j.matpr.2021.05.578

Sipior, J.C.: Considerations for development and use of AI in response to COVID-19. Int. J. Inf. Manage. **55** (2020). Article 102170. https://doi.org/10.1016/j.ijinfomgt.2020.102170

Statista: Website. Recovered from https://www.statista.com (2021)

Stonehouse, G., Snowdon, B.: Competitive advantage revisited: Michael Porter on strategy and competitiveness. J. Manage. Inq. **16**, 256–273 (2007). https://doi.org/10.1177/1056492607306333

Toussaert, S.: Upping uptake of COVID contact tracing apps. Nat. Hum. Behav. **5**(2), 183–184 (2021). https://doi.org/10.1038/s41562-021-01048-1

Trout, J., Rivkin, S.: Differentiate or Die: Survival in Our Era of Killer Competition. Wiley, New Jersey (2008)

Turban, E., et al.: Electronic Commerce 2018. A Managerial and Social Networks Perspective, 9th edn. Springer Nature, Switzerland (2018)

Turkyilmaz, C.A., Uslu, A.: The role of individual characteristics on consumers' counterfeit purchasing intentions: research in fashion industry. J. Manage. Mark. Logistics **1**(3), 259–275 (2014). Recovered from https://www.pressacademia.org/archives/jmml/v1/i3/7.pdf

Tustain, J.: Complete Guide to VR, 360 Degree Photography. Ilex Photo, USA (2018)

Uchiyama, H., Marchand, E.: Object detection and pose tracking for augmented reality: recent approaches. In: 18th Korea-Japan Joint Workshop on Frontiers of Computer Vision (FCV), Feb 2012, Kawasaki, Japan (2012). https://hal.inria.fr/hal-00751704

Wara, A.A., Dugga, S.: Enhancing user experience using mobile QR-code application. Int. J. Comput. Inf. Technol. **3**(6), 1310–1315 (2019). Recovered from https://www.ijcit.com/archives/volume3/issue6/Paper030620.pdf

Wijayanto, I.H., Soeaidy, M.S., Rochmah, S.: Tourism based on the model of strategic place triangle (A case study in Wisata Bahari Lamongan). J. Indonesian Tourism Dev. Stud. **2**(3), 114–119 (2014). Recovered from https://jitode.ub.ac.id/index.php/jitode/article/view/140

Willman-Iivarinen, H.: The future of consumer decision making. Eur. J. Futures Res. **5**(14), 1–12 (2017). https://doi.org/10.1007/s40309-017-0125-5

Winchester, M., Romaniuk, J.: Negative brand beliefs and brand usage. Int. J. Mark. Res. **50**(3), 355–375 (2008). https://doi.org/10.1177/147078530805000306

Woo, V.: Monetary and image influences on the purchase decision of private label products in Malaysia. J. Adv. Manage. Sci. **3**(4), 312–318 (2015). https://doi.org/10.12720/joams.3.4.312-318

Yesilyurt, M., Yalman, Y.: Security threats on mobile devices and their effects: estimations for the future. Int. J. Secur. Appl. **10**(2), 13–26 (2016). https://doi.org/10.14257/ijsia.2016.10.2.02

Yu, S.J.: The dynamic competitive recommendation algorithm in social network services. Inf. Sci. **187**, 1–14 (2012). https://doi.org/10.1016/j.ins.2011.10.020

Zendjebil, I., et al.: Outdoor augmented reality: state of the art and issues. In: 10th ACM/IEEE Virtual Reality International Conference (VRIC 2008), pp. 177–187, Apr 2008, Laval, France (2008). https://hal.archives-ouvertes.fr/hal-00339480

System Dynamics and Graphical Interface for the Supply Process: A Case Study in a Regional Food Packing Company in Mexico

Ernesto A. Lagarda-Leyva

Abstract Small businesses in Mexico require practical data-driven solutions for decision-making. The following case study was conducted in a regional food packing and marketing company in southern Sonora, Mexico. The purpose of this organization was the sale and distribution of products belonging to the basic food basket. On the other hand, the object under study focuses on the supplied link of the supply chain, in which, after observing and performing an organizational analysis through the application of various tools, it was detected the existence of different problems in the inventory management of the organization, mainly due to the absence of inventory policies, lack of indicators and variation in demand, the objective was to develop a graphical interface to evaluate the performance of the supplied link of dry and cold products in different scenarios using system dynamics. To address this problem, it was decided to carry out an investigation into different sources of information regarding the implementation of system dynamics and inventory management. Therefore, it was determined that the methodology to be followed would be system dynamics, which consists of the development of a simulation model of the supply process, in which, to complement it, the decision was made to incorporate sectors corresponding to the EOQ Model. Finally, the graphical interface with the user was developed, in which the interested party can make modifications in the critical variables to observe the behavior of scenarios that would be generated in the face of different policies and thus support decision-making. The main conclusions are about the contributions on the use and application of system dynamics in situations where inventory policies must be considered to maintain the sufficiency of regional products in stock and satisfy consumer demand.

Keywords System dynamics · Supply chain · Graphical interface · Computational algorithms · Stella architect

E. A. Lagarda-Leyva (✉)
Department of Industrial Engineering, Instituto Tecnológico de Sonora, 5 de febrero 818 Sur. Col. Centro, Sonora, Mexico
e-mail: ernesto.lagarda@itson.edu.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_18

1 Introduction

Commerce is the economic activity with the largest number of establishments in the country. In 2003, there were 1,580,587 businesses dedicated to commerce in Mexico. By 2008, there were 1,858,550, which means an increase of more than 17% in five years (INEGI 2019).

According to the resulting data by INEGI, in Wholesale Commercial Enterprises, real income from supply of goods and services increased 0.1%, the active personnel increased 0.2% real average remunerations paid were higher by 0.4% during the penultimate month of 2018. On the other hand, during the same period Retail Trade Enterprises, presented that real revenues from the supply of goods and services increased by 0.4% and the Employed Personnel rose 0.3%, while real average remunerations decreased (−) 0.2% (INEGI 2019).

According to the data generated during the 2009 Economic Censuses, the main municipalities of the State of Sonora allocated 85.1% of economic units and 90.9% of active personnel. This refers to the fact that in the State there were 107,723 existing economic units, in which 738,403 people were employed. The personnel employed in the economic activities of services represented 31.4%, while Commerce had a percentage distribution of 27.0% (INEGI 2015). During the second quarter of 2018, Sonora's tertiary sector manifested an increase of 4.2%. In which the commerce sector, real estate services, and transportation were the ones that presented a higher vitality (Lara 2018).

In the municipality of Cajeme, the employed population in the service sector is 74,833 people, which represents 42%, likewise in the commerce sector, there is an active population of 35,635 which constitutes 20% (INEGI 2015). According to the National Statistical Directory of Economic Units, the number of establishments identified in the Wholesale and Retail Commerce sector is 6700, while in the Services sector, 8696 were detected.

In the commerce sector in Ciudad Obregon, Sonora ranks second in establishments (INEGI 2018). One of the companies within this area is the organization under study which consists of the marketing and distribution of products belonging to the basic food basket. The company is located in the Industrial Park of the city.

The organization under study is a social, inclusive and self-sustainable, highly innovative program that meets the needs of the worker, supporting the local economy, generating a culture of self-consumption in the community, and offering a convenient and economical solution to quality food needs. The company has also adopted eight of the 17 Sustainable Development Goals established by the UN, which essentially consist of putting an end to poverty and hunger, guaranteeing a healthy life, and promoting the well-being of all with the help of sustainable cities and communities that seek to improve sustained economic growth.

The object under the study of this project focuses primarily on the cold and dry products of the supplied link, whose function goes from the reception of the products to the storage of each one of them according to its corresponding warehouse. However, sometimes the company has to go for the products with the suppliers.

Currently, the organization under study presents several opportunities in the supply process of cold and dry products. This link is of utmost importance since thanks to it the raw material required for the production process of the different food containers and the products that are sold wholesale and that will be distributed to consumers is obtained.

The company may be affected by external variables because the work model it manages seeks to market regional products. The deficient inventory system that they control can cause various problems because they do not have an inventory policy that indicates when and how much they should order from suppliers. The variation in demand (3894.5 and 36.1 kg), the lack of inventory, and the variability of suppliers (currently 20) are some of the causes of the present problem since sometimes the organization must order the products required by consumers on the same day they are requested. One of the performance indicators that are important to measure for this study due to its variability is inventory turnover, which in dry products (19 products) with the unit of measurement in kilograms is 10.30% (16) and in products measured in liters is 72.72% (3). Likewise, inventory turnover was calculated for cold products whose units of measurement are kilograms and liters, resulting in 80.87% (54) and 100% (3) respectively.

Although the company's suppliers are regional and have the opportunity of shorter delivery times, there is the possibility of not having the demanded merchandise and consequently, the requested order could not be fulfilled. Therefore, with the information presented, it can be seen that the company is affected to make momentary decisions based on the demand, so it makes emergency purchases and does not allow the efficient evaluation of the supplier, in addition to recurring complaints from customers when changing the presentation or quantities of the product that was originally requested.

2 Literature Review

From the conceptual perspective, emphasis is placed on the concepts used in this case study. Value stream map is a concept defined by Womack and Daniel (1996) as a:

> A value stream "map" identifies every action to design, order, and make a specific product. Each step is then sorted into three categories: (1) those that add value, (2) those that add no value but are currently necessary, and (3) those that add no value and can be eliminated. After the third category has been eliminated, the second category should be addressed through flow, pull, and perfection techniques.

Jing et al. (2021) investigate the effect of value stream mapping on procurement effectiveness as a case of study, the whole procurement process, procurement plans, audit, procurement, transportation, inspection, storage, classifying and receiving materials using value stream map. According to this, wastes and non-value activities in the procurement process can be easily found and the improvement methods in two perspectives: (1) the procurement value stream mapping enriches improvement methodology of procurement management; and (2) the P-VSM methodology enlarges the application scope of lean tools on one side.

Balaji et al. (2020) offer in their research a relationship a Dynamic Value Stream Map connected with Internet of Thing; value stream mapping remains a popular visualization tool in the hands of the Lean Manager who seeks to produce more with less. However, value stream mapping (VSM) tends to be static and skill dependent. With the advent of Industrial Internet of Things (IIoT), there could be a paradigm shift on how VSM could be leveraged for maximizing results.

On the other hand, system dynamics is defined as a methodology designed to analyze and simulate problems in real-time to understand the behavior of the system through interactions that will determine changes in the system (Aracil 1995). The methodology was developed by Jay W. Forrester and thus generated an important contribution to the study of complex systems, where it is possible to study their behavior through certain characteristics of feedback to achieve integration in the information flows of the system (Angerhofer and Angelides 2006).

Jay Forrester, the creator of the system dynamics methodology, defines it as that which studies data feedback characteristics—mainly within industrial activities to prove how organization structure, policy broadening, and delays (in both actions and decisions) interact and impact the success within the organization. Its subject matter is based on examining the interactions among companies' information flows, money, orders, materials, staff, and equipment. Moreover, system dynamics provides a single structure to group the functional areas of top management (Forrester 1981). From another perspective, Sterman (2000) establishes system dynamics as a method used to optimize learning within complex systems; it is a method to develop decision-making simulators using specialized computer software. The purpose is to know the dynamic complexity within a system, understand the source of policy resistance, and design more effective strategies.

On the other hand, Agudelo and López (2018), define system dynamics as a tool for inventory management analysis, since it allows presenting good results as long as the models are established most appropriately, relating the variables and observing their behavior over time, using feedback that study a given problem. The importance of the feedback loops of the systems is emphasized since this guarantees that the system has flow and is dynamic. Dynamic simulation is a method used to model and analyze the performance of systems that contain certain linkages between the resulting variables, and also include delays and feedback loops. These types of characteristics are implied in social systems because their behavior is usually unpredictable and variable.

Complex systems are based on system thinking, which has been studied by different authors from Senge et al. (2006) to use mathematical models to explain ecosystem dynamics through the relationship cause-effect (Forrester 1990; Sterman 2000; Lagarda 2019). Likewise, these cause-effect relationships take place using simulators to observe possible future scenarios that allow assessing decision-making beforehand and based on quantitative models (Schwartz 1996; Lagarda-Leyva and Ruiz 2019; Lagarda-Leyva 2019; Aracil and Gordillo 1997).

The graphical user interface is referred to as the component and software of a computer that a person can control and understand. The user interface has two elements: input and output, the first consists of knowing how the user must transmit his requirements to a computer, through the mouse, voice, keyboard, etc. The output involves how the computer will deliver the results to the interested parties. The output devices commonly used are screen and sound (Galitz 2007). The graphical user interface (GUI) is where the relationship between the computer and the user begins. As soon as one begins to intervene with a computer, the person also begins to get involved with the interface. For this reason, the design of the GUI is an aspect of great importance, since, thanks to it, one can complete the activities more simply (Albornoz et al. 2017).

On the other hand, eight empirical studies were selected where applications of the system dynamics methodology have been made to observe the behavior of inventories, the different contributions are an important reference for the determination of variables and information in the development of the proposed case study. The selected cases are cited below, mentioning their main contribution.

The research of Echeverri et al. (2010) show a case study related with the impact on the decisions of the supply chain of a company that manufactures aquatic sportswear using system dynamics of the supply chain of the company Creaciones Nadar S.A. The main result obtained from this study was the simulation of different scenarios to define policies and parameters with the best benefits.

Vergara et al. (2010) carried out a study of the effects of variation in demand and inventory policies in the supply chain, to visualize the effects of ordering strategies based on lot size and reorder point, including constant and time-varying demand. The result of the simulation of the different scenarios was a model to know the behavior of the demand to predict possible stock-outs of merchandise, considering that small changes in demand can cause amplified collateral effects throughout the supply chain.

The development of a system dynamics model for inventory management demonstrates that with variable interaction formulations it is possible to obtain results that allow solving common problems related to inventory management, such as replenishment points and optimal order quantity. The results obtained from the simulation show that system dynamics is an effective tool for decision-making in inventory systems since it allows the formulation of dynamic models that represent the inventory process involving different market and operation variables (Liévano and Villada 2014).

On the other hand, Causado (2015) conducted an inventory model for economic control of orders in a food marketing company, intending to propose to improve the inventory system for a food marketing company to achieve a reduction in inventory costs and an increase in the economic benefit of the company, through planning, control of purchases and sales of products. The results obtained by applying the ABC method showed that eight products are the most profitable for the food marketing company. Also, the results of the Economic Order Quantity EOQ model show the demands of each Class A product, its respective cost of placing an order S, the Q*, the total annual cost G (Q*), the number of orders to be placed, and the reorder point R.

Escobar et al. (2017), conducted the inventory management study for distributors of perishable products to determine the inventory policy with safety stock of a probabilistic model that helps maximize the expected daily profit, considering that the products are perishable, so they can only be stored for a maximum number of days. Batero and Orjuela (2018) analyzed the literature review on routing and inventory problems in perishable supply chains, during 2004 and 2017.

As a result of the research study, it was found that most of the proposed algorithms are heuristic in nature. Due to the computational issues involved in the problem, metaheuristics and metaheuristics incorporated with exact methods are used. These are particularly applicable to food, drugs, and human blood. The limitations that differentiate them from other types of IRP are those of shelf life and spoilage.

Another study is the evaluation of the performance of the freshwater white shrimp supply chain, in which the system dynamics methodology was used to evaluate the performance of the white shrimp cold supply chain to support decision making. Three different scenarios were simulated to determine the quantities in kilograms of shrimp obtained from harvesting to the total captured (Lagarda-Leyva et al. 2016).

Finally, the model of wheat collection and distribution, Dynamics of the Shipping Process to International Markets: Case Study, was carried out to build a dynamic interface that would allow observing the quantitative scenarios in the distribution link, using the system dynamics methodology of the different scenarios with a dynamic and visual interface for the user that allows observing each of the quantitative scenarios associated with the amount of wheat that moved from the wheat collection centers to the national and international market (Lagarda 2019).

3 Materials and Procedure

3.1 Materials

The object under study focuses mainly on dry and cold products with variability in their rotation in the supply chain supply link of a food marketing company in southern Sonora.

For the development of the project under study it was necessary to resort to different resources, which are described below:

1. Stella Architect Software: Computer simulation software developed by Isee Systems.
2. Vensim PLE software: Industrial power simulation software used to improve the performance of real systems. This software was used only for the realization of the causal diagram.

For the development of the graphic interface, computational algorithms based on numerical methods such as Euler or Runge Kutta are used; different types of software are used for the construction of system dynamics models, some of which have greater advantages than others in terms of their scope. The software used in this project were two: (1) Vensim PLE plus from the company Ventana Systems; (2) Stella Architect from the company ISEE Systems. Although there are other types of software such as I Think, Arena, among others.

The advantage offered by Vensim PLE Plus is the ease of construction of causal diagrams and definition of each of the reinforcing or balancing loops, the construction capacity is wide, which allows the development of models with a finite number of variables. Likewise, flow and level diagrams can be constructed, as well as scenario simulation.

On the other hand, Stella Architect software offers the additional advantage of Vensim PLE Plus, but with the advantage of incorporating the design of graphical interfaces based on commands (run, pause, stop, restore all, among others), allowing the incorporation of graphs, data tables, performance indicators, among others. It is a space for communication with users who, without knowledge of System Dynamics or Stella Software, can run the model and interpret the information based on their experiences.

It is important to highlight that in addition, computational algorithms based on differential equations are generated, such as the abstract shown below, the algorithm used in this model was the fourth order Runge Kutta.

```
wholsale_cold_products_decision_sum+"Discrepancy_cold_
products_(hr)" {UNIFLOW}
            UNITS: kg/hr
    OUTFLOWS:
        Output_1 = CONVEYOR OUTFLOW
            UNITS: kg/hr
Cold_products_Suppliers(t)   =   Cold_products_Suppliers (t -
dt)  +  (Cold_products_inputs - Demand_of_cold_products) * dt
{NON-NEGATIVE}
    INIT Cold_products_Suppliers = 0
    UNITS: kg
    INFLOWS:
        Cold_products_inputs = cold_supply_orders {UNIFLOW}
            UNITS: kg/hr
    OUTFLOWS:
       Demand_of_cold_products = wholesale_cold_products_decision
_sum+"Discrepancy_cold_products_(hr)" {UNIFLOW}
            UNITS: kg/hr
Cold_Storage(t) = Cold_Storage(t - dt) + (Cold_storage_supply
- "Outflow_to_Warehouse_(wholesale)" - "Outflow_to_Warehouse
_(retail)") * dt {NON-NEGATIVE}
    INIT Cold_Storage = 0
    UNITS: kg
    INFLOWS:
        Cold_storage_supply  =  IF(Output_from_discharge>436.8)
THEN Output_from_discharge ELSE 0 {UNIFLOW}
            UNITS: kg/hr
    OUTFLOWS:
        "Outflow_to_Warehouse_(wholesale)"    =    "Sum_DD/hr_
(cold_Wholesale)" {UNIFLOW}
```

```
            UNITS: kg/hr
        "Outflow_to_Warehouse_(retail)" = "Discrepancy_
cold_products_(hr)" {UNIFLOW}
            UNITS: kg/hr
"Cold_Storage_(refrigerator)"(t) = "Cold_Storage_(refrigerator)"
(t - dt) + (Supply_to_Warehouse - "Outflow_refrigerators_products_
to _Warehouse_(wholesale)" - "Outflow_refrigerator_products_
to_Warehouse_(retail)") * dt {NON-NEGATIVE}
    INIT "Cold_Storage_(refrigerator)" = 0
    UNITS: kg
    INFLOWS:
        Supply_to_Warehouse = IF(Output_from_discharge<436.8)
THEN Output_from_discharge ELSE 0 {UNIFLOW}
            UNITS: kg/hr
    OUTFLOWS:
        "Outflow_refrigerators_products_to_
Warehouse_(wholesale)" = "Sum_DD/hr_(cold_Wholesale)" {UNIFLOW}
            UNITS: kg/hr
        "Outflow_refrigerator_products_to_Warehouse _(retail)"
= "Discrepancy_cold_products_(hr)" {UNIFLOW}
            UNITS: kg/hr
```

3.2 Procedure

3.2.1 Development of Causal Diagram and Formulation of Dynamic Hypotheses

In this step, each of the elements involved in the supplied link was determined, as well as the relationship between them, to have greater clarity of the problem and thus proceed to become variables and parameters. Likewise, limits and feedback loops were included, which generates a higher degree of formalization. All this was executed based on the information accumulated in the previous step and with the support of the Vensim software. On the other hand, the different dynamic hypotheses were raised considering the information collected in the various theories analyzed to provide an endogenous approach. Therefore, with the identification of the variables and parameters involved in the process, the causal diagram and the formulation of the dynamic hypotheses were continued.

3.2.2 Development of Flow and Level Diagrams

With the development of the causal diagram in the previous step, the Forrester diagram was made, in which the variables and critical parameters of the process were included. The diagram was made with the support of Stella Architect software. Also, in this step, the construction of mathematical equations was carried out, which generated the mathematical model.

3.2.3 Model Validation

This step is of utmost importance since a series of tests or simulations were carried out to corroborate the behavior of the model with the values assigned to the different variables and parameters established in the current conditions; the unit consistency test and the extremes test techniques were used. The simulations were carried out to obtain information and validate the model.

3.2.4 Simulation Scenarios

Quantitative scenarios were constructed based on the current model, where values were assigned to the variables and parameters corresponding to each scenario, to observe the behavior of the model according to the scenario studied. Likewise, in this step, the sensitivity analysis was carried out, since it studies the behavior of the variables in the face of different policies that were reflected in the variations of the values of the model parameters. For the execution of this step, the Economic Order Quantity (EOQ) Model was applied, which is of great importance for the subject studied, since it allowed calculating the lot size and the reorder point of the products grouped by families, considering certain circumstances that were adopted for each of the scenarios.

3.2.5 Graphical Interface Development

Finally, the graphic interface with the user was built, in which different screens and support menus related to the variables and critical parameters were shown using Stella Architect software, in which graphic design, buttons, behavioral graphs, performance indicators, support texts, and data tables were added, which the user used to visualize different scenarios and generate communication with stakeholders.

4 Results

4.1 Causal Diagram and Dynamic Assumptions

The execution of this step of the procedure consisted of the development of a causal diagram of the supplied link of the trading company's supply chain, as well as in the construction of different dynamic hypotheses. To create this diagram, it was necessary to carry out a detailed analysis to identify the variables that have the greatest impact on the process. Figure 1 shows the resulting causal loops diagram.

The causal diagram details the most representative variables in the process. Besides, it can be visualized that the process starts from the attention of wholesale

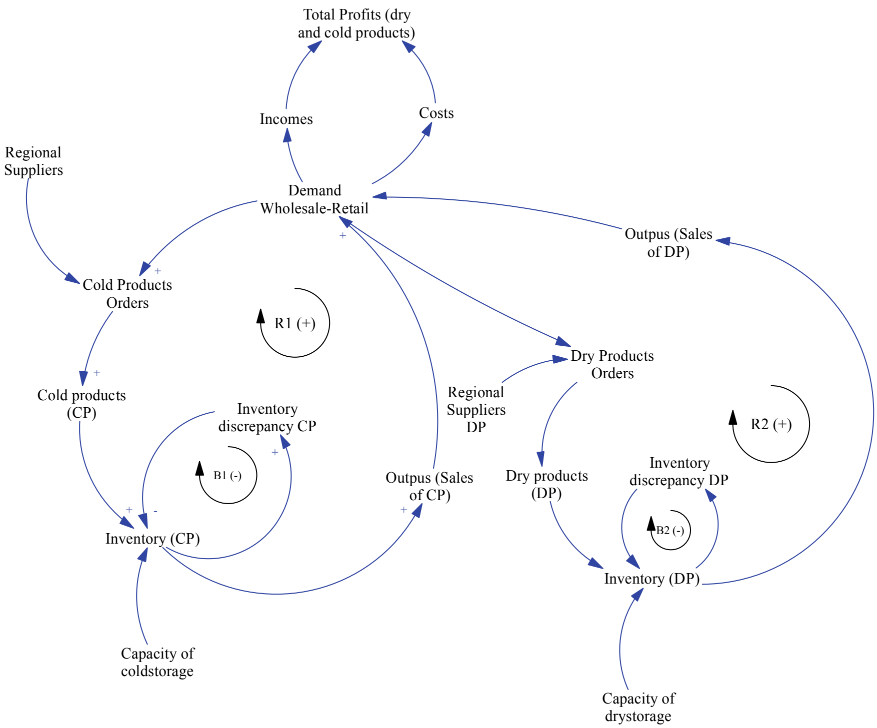


Fig. 1 Causal diagram (dry and cold chain)

and retail demand, both for cold and dry products, which generates more purchase orders, and thus the process can continue. Another detail that can be appreciated in this interpretation is the relationship between each of the variables considered, as well as the definition of the four feedback loops (R1, R2, B1 and B2).

As previously mentioned, we then proceeded with the development and formulation of the dynamic hypotheses to simulate the model with the behavior of the different variables to be considering, which will help to determine the policies to be used to achieve the established objective. Having mentioned the above, the dynamic hypotheses proposed are the following:

1. All of the organization's products in the January-April period were considered, both wholesale and retail cold and dry products.
2. All suppliers of the organization are considered.
3. If the cold store (refrigerator) exceeds its capacity of 436.8 kg, it will be sent to a cold store with a larger capacity (15,750 kg).
4. The claims used were taken from the organization's historical records for the January-April period.
5. Delivery times (loading, transfer, and unloading) are considered in real-time in hours per kilogram.

6. Demand requirements will be taken from the sum of cold and dry demand for wholesale and retail in kilograms per hour grouped by product family.
7. The model will have a *dt* of 16 and the total demand will have a pulse every 24 h.
8. Storage costs are calculated based on the sum of the three different warehouses by multiplying the warehouse inventory by the cost of storing one kilogram.
9. In the case of going for products with the supplier, the difference of the cost of supplying minus the total cost of going for the product obtained from the sum of the price for going for the product plus the result obtained from the division of the average kilometers traveled of the suppliers between the km/lt yield of the Transit Truck to subsequently multiply what is obtained by the cost of gasoline per liter of the day (The cost of references is from February 05, 2019).
10. Warehouse utilization is calculated by dividing the inventory of the different warehouses by the capacity of each warehouse.
11. Cycle time is the sum of all average times.

4.2 Flow and Level Diagram

Based on the causal diagram, the next stage consists of the development of the Forrester Diagram and formulation of the mathematical equations of the model; Fig. 2 shows an example of the resulting flow and level diagram.

On the other hand, by way of example, a part of the mathematical equations resulting from the Flow and Level Diagram is presented. There are only 6 equations (Eqs. (1)–(6)) as an example of this paper.

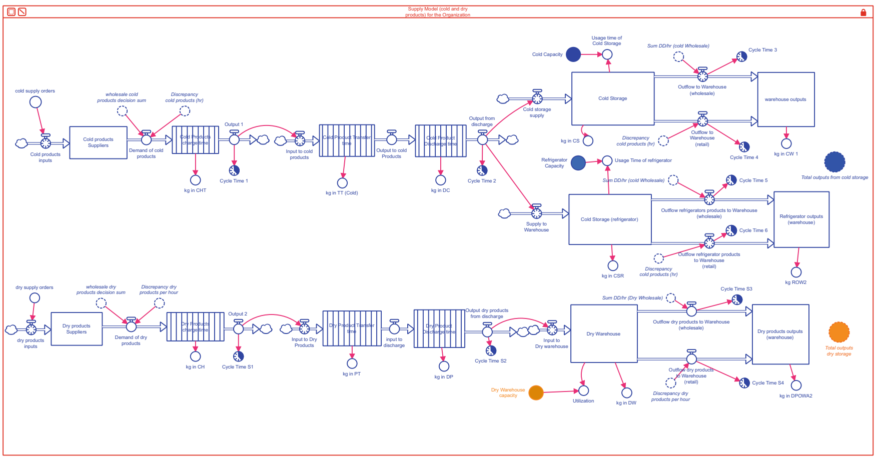


Fig. 2 Forrester diagram of the sourcing process

Stocks

$$CPS(t+dt) = CPS(0) = \int_0^t [CPI(t) - DCP(t)]dt \quad (1)$$

where
CPS: Cold products supply.
CPI: Cold products inputs.
DC: Demand for cold products.

$$CSt(t+dt) = CS(0) = \int_0^t [ICSS(t) - OWW(t) - OWR(t)]dt \quad (2)$$

where
CSt = Cold Storage.
ICSS = Inputs–Cold Storage Supply.
OWW = Output to warehouse (wholesale).
OWR = Output to warehouse (Retail).

Flows

$$CSS(t) = IFOFD > 436.8Then, OFD, Else0 \quad (3)$$

where
CSS = Cold Storage Supply.
OFD = Output from discharge

$$OW(t) = \sum DDColdWholesale \quad (4)$$

where
OW = Outflow to Warehouse (wholesale).
DD = Discrepancy of demand.

Auxiliary

$$DD(t) = \sum_{Di}^{n} (D1 + D2 + D3 + Dn) \quad (5)$$

where
DD = Discrepancy of demand.
Di = Demand per product i.
i = 1, 2….n

$$TOS = KginCW1 + KgROW2 \quad (6)$$

where

TOS = Total output from cold storage.

Kg in CW1 = total Kg of products in Cold Warehouse.

Kg ROW2 = total Kg ROW2.

The mathematical equations of different variables are classified according to their function, i.e., stocks, flows and auxiliaries.

4.3 Validation Through Consistency and Extreme Value Testing of the Model

The purpose of the model validation was to check if the behavior emitted was adequate. To ensure this behavior, the unit consistency test and the extremes test were used. The validation using the unit consistency test was carried out with the help of Stella Architect software, where it was necessary to verify each of the variables and parameters represented in the model. The figure above shows the dialog box derived from the analysis performed. To perform the analysis, it was necessary to enter each of the variables and then enter the units and apply the revision, a message appears indicating that the units of measurement are consistent throughout the model.

4.4 Simulation of Scenarios

In the dynamic simulation for the construction of quantitative scenarios of cold and dry products for wholesale and retail deliveries, the following critical variables have been modified: (1) the demand for wholesale and retail; (2) the lot size (Q); (3) the reorder point; (4) the cost of keeping a kilogram in stock; (5) the cost of going for products with suppliers in kilogram; (6) the cost of supplying products in kilogram.

Concerning the implementation of the EOQ Model for wholesale, an Excel spreadsheet was developed, where first the weekly wholesale demand for each of the products was established. A summary of this information is presented in Table 1.

This section shows a summary of the weekly demand for four months, which are January, February, March, and April. It can also be seen that there is variation in these data, i.e., on some occasions, two kilograms of a certain product are requested and the following week 56.1 kg. After establishing these demands, we proceeded to calculate the average and standard deviation, which was useful for evaluating the confidence intervals shown in Table 2.

With the above information, confidence intervals were calculated to determine a range between the values of the demands, i.e., the maximum and minimum demands were obtained, which are useful for the construction and simulation of pessimistic, normal, and optimistic scenarios.

Table 1 Weekly wholesale demand

Products Date	Chuck Roll meat in pieces	Stick in meat sliced	Oil drum 20 lt	Butter
05/11 Jan	393	10	716.4	37.4
12/18 Feb	–	40	–	–
26/01 Feb	–	–	–	–
2/08 Feb	–	–	19.9	2
9/15 Feb	100	–	457.7	38.4
16/22 Feb	355	7	597	18.7
23/1 Mar	280	16.7	318.4	56.1
2/8 Mar	80	7.06	417.9	18.7
9/15 Mar	–	79.2	–	–
16/22 Mar	–	–	19.6	–
23/29 Mar	–	–	39.8	–
30/5 Apr	–	–	–	–
Average	241.6	26.66	330.837	28.55
Standard Deviation	144.413	28.586	263.989	19.1483

Source Own elaboration

Table 2 Confidence intervals for wholesale products

Products	Maximum demand	Minimum demand	Confidence level (%)
Chuck roll meat in pieces	420.91	62.28	95
Stingray meat	50.17	3.19	90
Soft Sausage 2.4	337.85	16.81	85
Chorizo	224.99	3.11	80

Source Own elaboration

Equation (7) was used:

$$[\overline{x} \pm \text{tn} - 1, \alpha/2(\text{s/n})] \tag{7}$$

Since the data are less than 30, also, different confidence levels were used, i.e., for 26 products 95% was used, three-plus 90%, for another three products 85% and two 80%, another 10 products require a confidence level of less than 80%, since the minimum demand resulted in negative data, for this reason, it was decided to consider 80%. Finally, for the remaining 25 products, it was not possible to calculate the confidence intervals since there is insufficient data for their evaluation, so it was decided to place the average in the ranges.

After the previous point, the costs necessary to quantify the cost of ordering, which is necessary to calculate the lot size, were estimated (see Table 3).

Table 3 Summarized report-costs

Products	Unit cost ($)	Orders	Payroll cost ($)	Freight cost ($)	Administrative ($)	Cost of ordering ($)
Chuck roll in pieces	85	27	96,000	285.75	7089	82.04
Stickin meat sliced	110	30	96,000	285.75	7089	82.04
Shoulder steak	100	18	96,000	285.75	7089	82.04
Top Sirloin meat	116	3	96,000	285.75	7089	82.04

Source Own elaboration, with Mexican pesos, at an exchange rate of 20.6 Mexican pesos per 1 US dollar

Table 4 Cost to maintain

Product	Unit cost ($)	The aggregate rate of interest (%)	Cost of maintenance ($)
Chuck roll meat slides 1/2”, 1”, 4”	85.00	8.2	6.97
Stickin meat sliced	110.00	8.2	9.02
Shoulder steak	100.00	8.2	8.20
Top Sirloin meat	116.00	8.2	9.51

Source Own elaboration

The information presented refers to the costs that were needed to calculate the cost of ordering. Among those costs are identified the unit cost of each product, the payroll cost, administrative costs, and the freight cost. Finally, the cost of ordering was calculated by adding the costs mentioned above and dividing the result by the number of total orders. It should be noted that this procedure was followed for each of the products. Continuing with the cost evaluation, Table 4 shows the maintenance cost.

The information represents the costs required for the calculation of the cost of holding, these refer to the unit cost of each product and the aggregate interest rate, which was consulted on May 3, 2019, and was 8.2% according to the Bank of Mexico. Once this information was available, the unit cost of the product was multiplied by the interest rate, resulting in the cost of holding.

Once all the results presented above were executed, we continued with the calculation of the Economic Order Quantity (EOQ) and the reorder point. A summary is shown in Table 5.

For the development of the calculation of the order size (Q), Eq. (8) was used:

$$Q = \frac{\sqrt{2DS}}{IC} \tag{8}$$

Table 5 Economic order quantity and reorder point

Products	Annual demand	EOQ	Time of delivery in days	Point of reorder
Chuck roll meat slides	21,887.33	717.82	1	60.79
Stickin meat sliced	2609.12	217.86	1	7.24
Shoulder steak	1584.09	178.04	1	4.40
Top Sirloin meat	312.00	73.36	1	0.86

Source Own elaboration

The number two was multiplied by the annual demand times the cost of ordering, this result was divided by the cost of maintaining and finally, the square root was taken, obtaining, as a result, the lot size of the product. Likewise, in this section the reorder point was calculated, that is, the minimum quantity that must exist in the inventory to be able to launch a new order, due to the current conditions of the organization, this point was evaluated by multiplying the daily demand by the delivery time. It is necessary to mention that this procedure was carried out for each of the products.

On the other hand, the inventory policy used for the demand of retail products was Just in Time, so the product is requested in the quantity required and at the time it is needed. To capture this demand in the scenarios, an average of the demand of the packages was calculated and then increased by 20% for the optimistic scenario. After performing all the above calculations, the results obtained in the simulation of the three scenarios are shown.

4.4.1 Pessimistic Scenario

To develop this scenario, it was necessary to modify the Forrester Model, i.e., a sector was added for each product, where the behavior of the EOQ model can be seen. Figure 3 shows the sectors corresponding to cold and dry wholesale products.

The structure showed the economic order quantity, that is, the lot size and the reorder point of the cold graded diced neck and dry graded spaghetti products. The lot size (Q) was calculated with the minimum demand previously evaluated in Table 4. Similarly, the reorder point is automatically calculated at the time of entering the daily demand resulting from the minimum demand.

The retail demand considered in this scenario was zero, due to the current conditions of this type of sale. After entering the required data in the model, the simulation of the pessimistic scenario was carried out, and the results obtained are shown in Table 6.

The results obtained from the simulation should be noted that this is a summary table, due to the number of products used, the results that make up the pessimistic scenario can be observed. The variables considered are demand, lot size, and reorder point. To corroborate that the demand requested by the next process leaves the warehouse, a stock was established to measure the outflows.

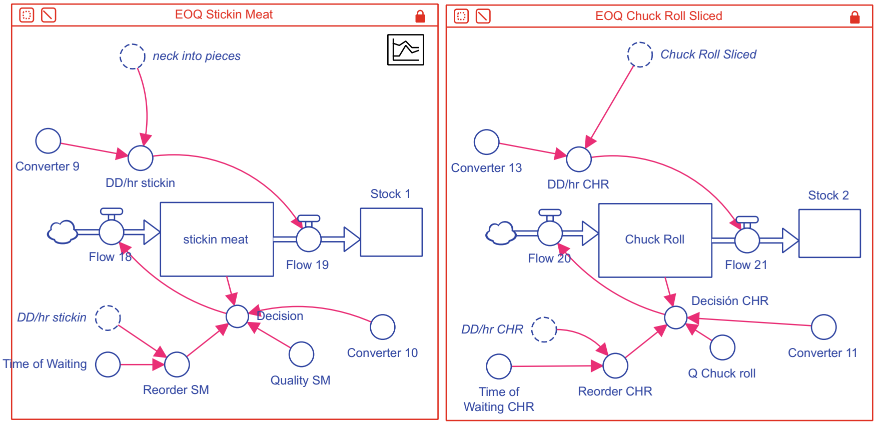


Fig. 3 Sectors of the EOQ model for wholesale cold and dry goods

Table 6 Pessimistic scenario: conditions of the simulated dynamic model

Variable	Cold products		Dry products	
	Wholesale	Retail	Wholesale	Retail
Demand	289.31	0	128.41	0
Lot Size (Q)		0		0
Reorder Point		0		0
Cost of storing 1 kg in warehouse	5.83	5.83	14.36	14.36
Cost of going per product in kg	7.20	7.20	4.80	4.80
Cost of supplying products in kg	9.60	9.60	7.20	7.20

Source Own elaboration

The data obtained in the warehouse outputs for cold products is 384.26 kg and for dry products, it is 125.73 kg, therefore, the total output was 509.99 kg (see Table 7).

Another variable that was simulated was the cost of storage, where the cost obtained for each warehouse was considered; the results generated by the simulation are in the cold store has a total of 150.59 kg inside, which generates a storage

Table 7 Pessimistic scenario: demand from the production process for each product

Type of product	Departures (kg)	Storage cost ($)	Total (kg)
Cold	384.26	878.27	150.59
Refrigerator	–	8.20	1.40
Dry	125.73	645.92	84.48
Total otput (Kg)	509.99		
Total storage cost ($)		1532.39	

Source Own elaboration

Table 8 Monetary difference of supplying and distribution for products in pessimistic scenario

Products	Kg per Day	Cost of Gas ($)	Distribution cost ($)	Supply Cost ($)	Diference
Cold	289.31	$69.84	$2152.90	$2777.40	$624.50
Dry	128.41	$65.48	$681.85	$924.55	$242.70

Source Own elaboration

cost of $878.27, for the refrigerator, the total kilograms were 1.40 and the storage cost was $8.2, finally, for the dry store the total kilograms were 84.48, generating a storage cost of $645.92, the total storage cost was equal to $1532.39, the cost per kilogram for each store is $645.92, the total storage cost was equal to $1532.39.48 generating a storage cost of $645.92, the total storage cost was equal to $1532.39, the cost per kilogram for each warehouse is $5.83 for the cold storage and $14.36 for the dry storage.

The last information obtained from this scenario required the cost of distribution and supplying per kilogram, with this information it was determined the difference that exists in monetary terms of the suppliers supplying in the company or the organization deciding to go for the products to the suppliers' location.

For cold products, the daily kilograms are 289.31 kg, which is multiplied by the cost per kilogram shown in Table 6, which is $7.2, and then the cost of fuel is added to the resulting product, resulting in a cost per product of $2152.9. On the other hand, the cost of supply proposed by the suppliers is calculated using the kilograms per day times the cost of supply, which is $9.6. Finally, the difference is calculated with the cost of supply minus the cost of going per product, therefore, the difference was $624.5. This same procedure was performed with dry products, the difference being $242.70 (see Table 8).

4.4.2 Current Scenario

The development of this scenario was based on the same model used for the pessimistic scenario. However, in this section, the product demands and the different costs used in this scenario were modified.

The retail demand determined for this scenario was 108 packages per week of package 1, which was obtained from the average of the data obtained by the organization.

On the other hand, in the case of wholesale, the average demand calculated previously was used. The normal state of the organization for the critical variables and parameters is shown in Table 9.

It should be noted that, although they are cold or dry products, their values are different due to their storage condition.

The first result consisted of checking that the demand was reflected in the outgoing stock of the different warehouses. The results of the simulation are for cold products

Table 9 Conditions of the current scenario of the dynamic model performed

Variables	Cold products		Cold products	
	Wholesale	Retail	Wholesale	Retail
Demand	647.32	26.22	267.70	43.81
Lot Size (Q)		0		0
Reorder Point		0		0
Cost of storing 1 kg in warehouse	4.86	4.86	11.97	11.97
Cost of going per product in kg	6	6	4	4
Cost of Supplying products in kg	8	8	6	6

Source Own elaboration

Table 10 Demand per product and their costs

Type of product	Departures (kg)	Storage Cost ($)	Total (kg)
Cold	783.9217	0.00	0.00
Refrigerator	–	0.00	0.00
Dry	332.7839	1011.4	84.48
Total otput (Kg)	1116.70		
Total storage cost ($)		$1011.4	

Source Own elaboration

is 783.92 kg and for dry products, it is 332.78 kg, therefore, the total demand for outputs was 1116.70 kg (dee Table 10).

The result obtained with the cost of storing was to identify the cost obtained for each warehouse, whether cold storage, refrigerated storage, and dry storage, the results generated with the simulation are in the dry warehouse was the only one with a storage cost because it remained with 84.48 kg of product inside, obtaining a storage cost of $1011.40, the total storage cost was equal to $1011.40.

The last result obtained from this scenario with the cost of distribution and sourcing per kilogram was to determine the difference that exists in monetary terms of suppliers sourcing in-house or the organization deciding to go for the products at the suppliers' location for cold products, the daily kilograms are 691.97 kg, which is multiplied by the cost of going per kilogram, which is $4, then the cost of fuel is added to the resulting product, which yields a cost of going per product of $4221.Finally, the difference is calculated with the cost of supply minus the cost of going per product, therefore, the difference was $1314.1. It is important to mention that the same procedure was carried out with the dry products, which generated a difference of $557.6 (see Table 11).

Finally, it is important to mention that it was decided to do it in a general way for each type of product classification, whether cold or dry, and not for each product

Table 11 Monetary difference of supplying and distribution for products

Products	Kg per day	Cost of gas ($)	Distribution cost ($)	Supply cost ($)	Diference
Cold	691.97	$69.84	$4221.70	$5535.80	$1314.10
Dry	311.52	$65.48	$1311.60	$1869.20	$557.60

Source Own elaboration

Table 12 Summary report of the results of the critical variables in the different scenarios

Type of product	Product	Variables	Pessimistic scenario	Normal scenario	Optimistic scenario
Wholesale	Steak	Daily demand (kg)	0.27	2.33	4.40
		Lot size (Q)	44.11	129.70	178.04
		Reorder point	0.27	2.33	44.11
		Cost of storage	1.57	11.34	17.10
Retail	Bean	Daily demand (kg)	0	108.00	192.00
		Cost of storage	0	1292.94	1838.47

Source Own elaboration

because there is total of 83 products between cold and dry. To conclude this section, Table 12 shows a summary of the results obtained from the simulation.

The behavior of two products in the pessimistic, normal, and optimistic scenarios are based on the critical variables that shape wholesale demand or retail demand.

4.5 Graphical Interface Development

In this phase of the method, the graphical interface with the user was developed, through which the client can interact, observe and analyze the behavior of its products for the inventory policies that were used and that can be modified according to the dynamics of the business over time. Figures 4 and 5 shows a summary of the graphical interface.

The first part of the interface that was developed consists of the presentation of the business image, which establishes that the process studied was the supplied link. On this screen, there is also a start button, which when activated sends you directly to page two, where there is a graphic that represents the supply chain.

Also, several buttons are activated, some of them are Cold Wholesale Demand, Dry Wholesale Demand, Retail Demand, Inventory Policy for Cold Product, Inventory Policy for Dry Product, Warehouse Entries, Warehouse Exits, Storage Cost, Supply Cost, and Summary. The summary button, as its name suggests, presents a

Fig. 4 The graphical interface of the main menu

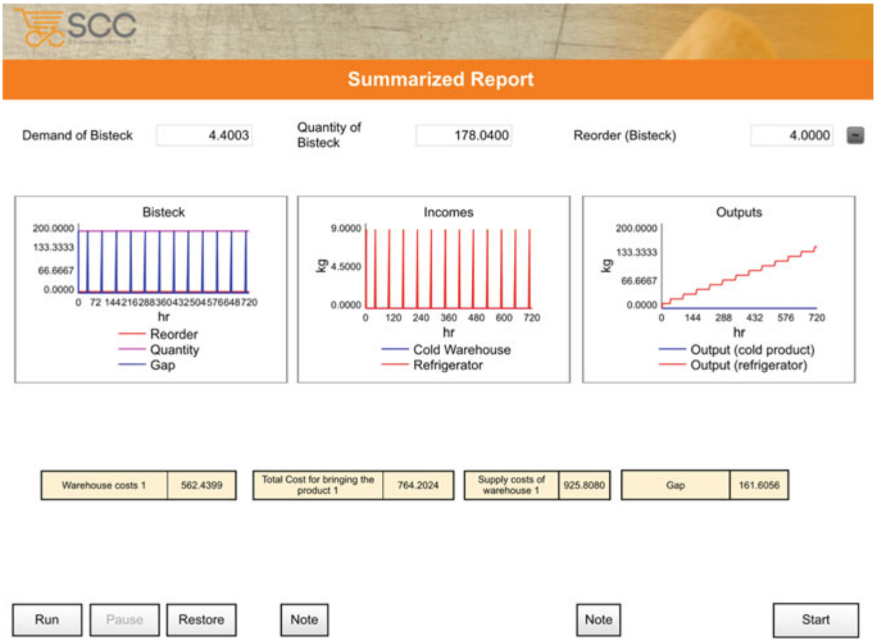


Fig. 5 Graphical interface summarized report

film in which you can see the demand for a single product along with the other critical variables. Figure 5 is presented for further visualization of this summarized report.

This section represents a synthesis of the entire interface. It displays the product's lot size, demand, and reorder point. Besides, different graphs are presented, in which the behavior of the product in terms of inputs and outputs of the warehouse, storage cost, and the cost of supplying are displayed. It should be noted that the established data can be modified so that the user can analyze the behavior of his inventory in different scenarios.

5 Conclusions and Recommendations

It can be concluded that system dynamics is a very useful and important tool for developing simulation models to evaluate behaviors over time. This boils down to a graphical interface with the user that provides the opportunity to modify parameters and variables of the model and thus facilitate decision-making.

At the beginning of this project, we had the notion that it was focused on the supplied link of the supply chain of dry and cold products in a food marketing company in southern Sonora, to develop quantitative scenarios with different variables and parameters, through a simulation model in the software called Stella Architect. Also, it was planned to perform *ABC* classification, but due to the current conditions of the organization, it was impossible to do it.

Once the analysis of the organization was carried out, the problem was detected that the supply process required raw material inventory policies to meet the requirements of the production area according to the demand, due to the lack of inventory policies, absence of performance indicators, variability in demand, as well as in suppliers, among others.

Having said the above, the objective of the project was determined, which was to carry out quantitative scenarios through a graphic interface in a simulation model that would allow modifying some of the variables and critical parameters and thus be able to evaluate the performance of the supplied link in the products under study.

After conducting research on inventory management articles and applying the EOQ model in conjunction with system dynamics, developing the causal diagram and its dynamic hypotheses, making the Forrester Diagram with its mathematical equations of variables and critical parameters detected in the causal diagram, validating the model, building the quantitative scenarios and finally constructing the graphic interface, it can be confirmed that the objective of the project was met, providing a solution to the research question posed in the problem. It is important to mention that studies related to the EOQ (Economic Order Quantity) model were investigated, since it was the contribution that was made to the model, meeting the requirements of the master consultant, who suggested it.

Finally, the following recommendations are made: (1) It is recommended the use of inventory policies equal to those determined in this project such as lot size to request, reorder point and just in time; (2) work with marketing, advertising to attract more customers because it has very few customers and the profit is insufficient, otherwise by having more customers the income would be higher obtaining a better profit; and (3) invest in the Stella Architect software license so that the model made during this project is implemented in the organization, since it would facilitate the user to make decisions in the future, through the analysis of its possible quantitative scenarios through the graphical interface designed.

6 Future Work

Future work is to develop a model that aggregates the packaging and distribution links to the final customers in the delivery process using a more robust model and to model the organization's ability to extend service to a larger number of customers beyond the region where it is located. The model can be the basis for adapting to small businesses that represent more than 80% of the establishments in Mexico. This application could be placed on a web page and run the model from any work center making it flexible to the user.

Acknowledgements The author is greatful to CONACYT (Consejo Nacional de Ciencia y Tecnología) through Insituto Tecnológico de Sonora (ITSON, Laboratorio Nacional de Sistemas de Transporte y Logística) for the development of this project. Thanks to the companies Sistema Comercial Cerrado for opening their facilities and provide primary data; to ITSON for their financing support through the project PROFAPI 2021.

Conflicts of Interest There is no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; and in the decision to publish the results.

References

Agudelo Serna, D.A., López Rivera, Y.M.: Dinámica de sistemas en la gestión de inventarios. Ingenierías USBMed **9**(1), 75–85 (2018). https://doi.org/10.21500/20275846.3305

Albornz, M., Beron, M., Montejano, G.: Interfaz gráfica de usuario: el usuario como protagonista del diseño. XIX Workshop de Investigadores en Ciencias de la Computación (WICC 2017, ITBA, Buenos Aires), pp. 570–574 (2017). http://sedici.unlp.edu.ar/handle/10915/62078

Angerhofer, B., Angelides, M.: A model and a performance measurement system for collaborative supply chains. Decis. Support Syst. **42**, 283–301 (2006). https://doi.org/10.1016/j.dss.2004.12.005

Aracil, J., Gordillo, F.: Dinámica de sistemas. Alianza, Madrid (1997)

Aracil, J.: Dinámica de Sistemas. Isdefe, España (1995)

Balaji, V., Venkumar, P., Sabitha, M.S., et al.: DVSMS: dynamic value stream mapping solution by applying IIoT. Sādhanā **45**, 38 (2020). https://doi.org/10.1007/s12046-019-1251-5

Batero, D.F., Orjuela, J.A.: Inventory routing problem in perishable supply chains: a literature review. Ingeniería 23(2), 117–143 (2018). https://doi.org/10.14483/23448393.12691

Causado, E.: Modelo de inventarios para control económico de pedidos en empresa comercializadora de alimentos. Revista Ingenierías Universidad Medellín (2015)

Echeverri, S.R., Ochoa, D.E., Toro, M.P., Peña, G.E.: Impacto en las decisiones de la cadena de suministros de una empresa de confección de prendas deportiva acuaticas con la utilización de dinámica de sistemas. Revista Ingeniería Ind. **9**(1) (2010)

Escobar, J., Linfati, R., Adarme, W.: (2017). Inventory management for distributors of perishable products. Ingeniería Desarrollo, **35**(1), 219–239 (2017). https://doi.org/10.14482/inde.35.1.8950

Forrester, J.: Dinámica industrial (Segunda edición). El ateneo, Buenos Aires (1981)

Forrester, J.W.: System Dynamics as a Foundation for Pre-College Education (D-4133), p. 14. Cambridge, MA 02139. System Dynamics Group, Massachusetts Institute of Technology, April 10 (1990)

Galitz, W.: The Essential Guide to User Interface Design: An Introduction to GUI Design Principles and Techniques (2007)

INEGI: Retrieved Febrero 26, 2019, from Encuesta Intercensal 2015: http://www.beta.inegi.org.mx/programas/intercensal/2015/default.html#Tabulados (2015)

INEGI: Clasificación Mexicana de Actividades y Productos (CMAP). Retrieved from Clasificación Mexicana de Actividades y Productos (CMAP) (2018)

INEGI: Retrieved Febrero 26, 2019, from Directorio Estadístico Nacional de Unidades Económicas (DENUE): https://www.inegi.org.mx/app/mapa/denue/ (2019)

Jing, S., Hou, K., Yan, J., et al.: Investigating the effect of value stream mapping on procurement effectiveness: a case study. J. Intell. Manuf. **32**, 935–946 (2021). https://doi.org/10.1007/s10845-020-01594-x

Lagarda, E.: Recolección y distribución de trigo, dinámica del proceso de envío los mercados internacionales; Caso de estudio. Int. J. Supply Chain Manage. 43–57 (2019)

Lagarda-Leyva, E.A., Ruiz, A.: A systems thinking model to support long-term bearability of the healthcare system: the case of the Province of Quebec. Sustainability **11**, 7028 (2019). https://doi.org/10.3390/su11247028

Lagarda-Leyva, E.: Collection and distribution of wheat, dynamic of the process of shipping to international markets: case study. Int. J. Supply Chain Manage. **8**, 43–57 (2019)

Lagarda-Leyva, E.A., Castañeda-Rodriguez, G, Soto-Fierro, I.: Strategic plan for a processed foods company using megaplanning and balanced scorecard. Perf. Improv. Qrtly. **28**, 27–54 (2016). https://doi.org/10.1002/piq.21208

Lara, J.: Tribuna. Retrieved from sitio web Tribuna: https://www.tribuna.com.mx/economia/Sector-terciario-el-mas-dinamico-de-la-economia-en-Sonora-20181102-0016.html (2018)

Liévano Martínez, F., Villada Oquendo, J.G.: Un modelo de dinámica de sistemas para la administración de inventarios (A System Dinamics Model For Inventory Management). Revista Soluciones Postgrado **6**(11), 121–135 (2014). Recuperado a partir de https://revistas.eia.edu.co/index18.php/SDP/article/view/565

Schwartz, P.: The Art of The Long View: "Planning for the Future in an Uncertain World". Currency Doubleday, New York, USA (1996)

Senge, P., Roberts, C., Ross, R.: La quinta disciplina en la práctica: estrategias y herramientas para construir la organización abierta al aprendizaje. Granica, Buenos Aires (2006)

Sterman, J.: Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw Hill, United States (2000)

Vergara, J., Fontalvo, T., Maza, F.: La planeación por escenarios: revisión de conceptos y propuestas metodológicas. Prospect 21–29 (2010)

Womack, J., Jones, D.: Lean Thinking: Banish Waste and Create Wealth in Your Corporation (1996). https://doi.org/10.1038/sj.jors.2600967

Analyzing Supply Quality Improvements in ETO Companies That Switch to Mass Customization via AI Techniques

Francisco Javier Bermejo Ramírez de Esparza, Jorge Luis García Alcaraz, Juan Carlos Sáenz Diez-Muro, Eduardo Martínez Cámara, Emilio Jiménez Macías, and Julio Blanco Fernández

Abstract This article presents the case of an Engineering to Order (ETO) company that switches to Mass Customisation (MC), applying the CRISP-DM method. A statistical model is drawn up by analyzing data gathered over four years, enabling the entry variables that characterize supply defectiveness to be identified and quantified. The impact of "advanced purchasing" is identified and measured by Multidisciplinary Design Assessment Teams (MDATs) and other factors. The research concludes by showing that advanced purchasing through MDATs reduces defectiveness in supplies to levels below one-tenth of the initial values and improves the supply quality.

Keywords Multivariate analysis · Engineering to order · Mass customisation · Supply management · Early purchasing involvement · Multidisciplinary teams of design assessment

F. J. B. Ramírez de Esparza · J. C. Sáenz Diez-Muro · E. Jiménez Macías
Department of Electrical Engineering, University of La Rioja, Edificio Departamental—C/Luis de Ulloa, 20, 26004 Logroño, La Rioja, Spain
e-mail: juan-carlos.saenz-diez@unirioja.es

E. Jiménez Macías
e-mail: emilio.jimenez@unirioja.es

E. Martínez Cámara · J. Blanco Fernández
Department of Mechanical Engineering, University of La Rioja, Edificio Departamental—C/Luis de Ulloa, 20, 26004 Logroño, La Rioja, Spain
e-mail: eduardo.martinez@unirioja.es

J. Blanco Fernández
e-mail: julio.blanco@unirioja.es

J. L. García Alcaraz (✉)
Department of Industrial and Manufacturing Engineering, Autonomous University of Ciudad Juarez, Av. Del Charro 450 Norte, Col. Partido Romero, 32310 Ciudad Juárez, Chihuahua, México
e-mail: jorge.garcia@uacj.mx

J. L. García Alcaraz and A. Realyvásquez Vargas (eds.), *Algorithms and Computational Techniques Applied to Industry*, Studies in Systems, Decision and Control 435, https://doi.org/10.1007/978-3-031-00856-6_19

1 Introduction

The world is currently immersed in a severe economic crisis, and global competition. For companies to be competitive over time, they must focus on creating value for customers. Sabri and Shaikh (2010) and Badurdeen and Jawahir (2017) describe three different strategies for creating value: a. *product leadership*: focus on invention, innovation, and rapid development of the product, b. *operational Excellence*: focus on optimizing operations, production costs, and delivery and c. closeness to the customer: focus on customer relations (customer-centric).

These strategies are closely related to those proposed by Porter (2009): competition is either in terms of costs or differentiation. The current competitive environment is characterized by its harshness, with uncertainty in demand, with customers looking for a variety of personalized products, in small batches, at reasonable costs, and with fast delivery. It leads manufacturers and companies to compete in the three strategies mentioned, generating new business opportunities and management models applications.

This research is set in the context of purchasing and supplies at ETO companies in Mass Customisation (MC) environments, considering that they work systemically as a single whole, and no local conclusions or optimal local results are obtained. The object of this paper is the pursuit of Operational Excellence using improving the quality of supplies. It reports a statistical model that identifies and quantifies the impact of various factors of the purchasing and supply's function (supply management) on supply management for ETO companies that work in MC environments.

Alternative tools for operation management are used (Brusco et al. 2012): specifically, the CRISP-DM method (Sheather 2009) and WEKA software (Witten and Eibe 2011) are selected. CRISP-DM is a comprehensive data mining method and process model that provides anyone—from novices to data mining experts—with a complete blueprint for conducting a data mining project (Huber et al. 2019).

For the study presented here, artificial intelligence (AI) is used to create a descriptive model that determines the influence of management indicators at the Purchase and Supply Unit of the company.

1.1 Mass Customisation and Engineering-To-Order

Over the past four decades, Lean Management or Toyota Production System (TPS) philosophy has become a paradigm for management systems at manufacturing and service companies. Currently, it is necessary to go beyond that philosophy and supplement it with systems that allow competitiveness in the updated environments, i.e., MC strategies.

The term MC was coined by Davis (1989) and later popularised by Pine (1992). It represents a paradox that combines the concepts of mass production and craft-based production, which correspond to opposing business models. Wan et al. (2012) affirm that companies aimed at competitive strategies such as costs and differentiation could not reach strategic success, i.e., they should compete in terms of cost or differentiation, but not both.

Brabazon and MacCarthy (2006) classify order fulfillment strategies as Make-to-Stock (MTS), Make-to-Order (MTO), Assembly-to-Order (ATO), Engineering-to-Order (ETO), and others. This article focuses on the ETO strategy for machinery or high added value (usually unique) products. In such production systems, the customer interacts closely with suppliers from the engineering phase onwards and usually work with low budgets and in multi-project environments, rather than with product lines or assembly lines, which gives them features unlike those of companies that work with production runs (automotive, white line, and others).

In MC, the ETO strategy is vital for the supply chain, given the high customer involvement in the product design and development phases. However, little scientific literature has been published on this topic (Cannas et al. 2018; Adrodegari et al. 2015). However, there are recent contributions, for example, Gosling and Naim (2009) cover this develop a more robust definition of the ETO supply chain and its links with lean strategy approaches, Powell et al. (2014) report a set of principles for pursuing the ideal lean in ETO, while Strandhagen et al. (2018) reports the lean principles for lead time reduction in ETO. However, readers interested in main concepts, enablers, and assessment techniques regarding MC, consult Medini et al. (2012).

1.2 Early Purchasing Involvement (EPI)

According to Huang et al. (2010), companies that work with a high level of MC, e.g., those that apply ETO, are affected positively if they have flat organic structures, are decentralized, and have multifunctional employees. For efficient supplies, it is thus necessary for the purchasing and ordering of materials to be separated (Liu and Yao 2018). Purchasing is related to the framework set up with suppliers and involves analyzing quotes, negotiating prices, exploring suppliers, and other issues, i.e., it has a supporting function (Song et al. 2014; Janipha et al. 2015). On the other hand, suppliers of materials see that orders issued to suppliers are fulfilled to the extent, in the amount, and in the timeframe agreed upon (Ventura et al. 2013). This aspect is of paramount importance for ETO supplying in an efficient MC.

In the same way, Sabri and Shaikh (2010) take into account the difference in the super-process of Supplier Relationship Management (SRM) within which there is an operational activity or sub-process called Purchase Order Management (POM) whose objective is to manage the order from its issuing up to its reception at the point of delivery. Rozemeijer (2008) and Wong and Ngai (2019) highlight the need to distinguish between administrative and strategic supply activities and classes them as strategic, tactical, and operational, the latter being related to the issuing of purchase orders and the follow-up and monitoring of the fulfillment of the order. This distinction between activities enables firms to be more competitive than their rivals (Weele 2018).

In ETO environments, the Purchasing function is closely related to purchasing per project. Each project is new and requires new suppliers to be found for each order. The products to be bought must be thoroughly analyzed with suppliers, and intense interaction with the engineering department is needed (Zhang et al. 2011). Delivery on time and the quality of the product are more important than the price. The purchasing department should respond quickly to design and planning changes within the project (Weele 2018).

Under such conditions, the purchasing function must not work reactively: work must be done in advance. It must be fully involved in the process before orders are issued to suppliers and even before the phase of looking for offers starts (Yoon and Moon 2019). Close attention should be paid to the phases of preparation of offers for end customers, giving support to the sales department in assessing the technical (in terms of supplies) and financial (in terms of purchasing costs) feasibility of the project. The purchasing department must collaborate and be present in the conceptual design and product development phases and review and validate blueprints and specifications before making purchases. It is known as Advanced Purchasing, Purchasing Engineering, or Early Purchasing Involvement (EPI).

Given the high-value nature of ETO products, such as large customized machinery and ships, they tend to comprise a vast number of items of material and components with small quantities of each item, including one-unit batches, wide ranges of items and great uncertainty concerning demand. Therefore, suppliers tend to be quite numerous and varied, making supply management difficult. The more suppliers have to be managed, the higher the transaction costs are (Sunil Kumar et al. 2018). Most suppliers have low purchasing values, which poses an added difficulty.

MC calls for more (and more varied) suppliers, which poses challenges in supplier selection and coordination in the supply chain (Deradjat and Minshall 2018). It is magnified in high-level environments such as ETO companies.

The concept of Operational Excellence is essential to this research, i.e., every employee can see the flow of value to the customer and take the necessary measures before that flow is broken (Makkonen and Sundqvist-Andberg 2017). Operational Excellence in business operations supports and contributes to the growth of the business in a sustainable way over time and thinking in the medium-long term. A strategic area where Operational Excellence needs to be achieved is Purchasing (Legenvre et al. 2020), or more generically, supply management (Bag et al. 2020).

2 Material and Methods

The model for measuring supplies quality in ETO companies that work in MC environments belongs to the production and operation management environment. Therefore, the Cross-Industry Standard Process Model for Data Mining (CRISP-DM) is used (Sheather 2009; Huber et al. 2019).

This method provides an overall framework for obtaining a statistical model and is composed of the following phases:

- Step 1: Business Understanding. This section shows the company's status to be taken as a case study and the field of work of the improvement.
- Step 2: Data Understanding. Firstly, an analysis of the problem to be solved is made, and it is indispensable to know and understand the environment under which development occurs, and the data is extracted. Then the data should be analyzed in an "exploratory analysis" so that proper data preparation can occur.
- Step 3: Data Preparation. The data must be prepared to facilitate the creation of accurate and reliable models, and this is the phase that usually requires the most time and effort.
- Step 4: Modelling. This phase seeks solutions to the problem of creating models, be it predictive or descriptive. In the case of this article, the models obtained are descriptive.
- Step 5: Evaluation. Once the models have been created, a selection must be made to evaluate further and validate them before they are used to solve the problem initially stated.
- Step 6: Deployment and results. Finally, the model is used after its validation (development phase). In this case, the model will be used first to learn which entry variables affect the response variable that measures supply chain quality performance in ETO companies with MC environments, and second, to quantify their impact.

Statistical tools are used to apply the CRISP-DM methodology: specifically, the statistical analysis software R has been selected through the Comprehensive R Archive Network-CRAN (Dalgaard 2008; Everitt and Hothorn 2011; Jank 2011; Kabacoff 2011; Sheather 2009; Sfumato et al. 2019). The Waikato Environment for Knowledge Analysis (WEKA) package has also been used for data mining (Corne et al. 2012) to obtain M5P and J48 model trees and to gain knowledge through the Apriori association rules algorithm (Bouckaert et al. 2010). Finally, for editing scripts in R, the RStudio™ package has been used because it offers an integrated development environment (IDE) for R, which is freely available.

2.1 Business Understanding

The case study is a medium-sized company in the equipment sector that focuses on engineering, development, project management, purchasing/supplying of components and materials, assembly, installation, and implementation of highly customized engineering projects. The production system used is ETO, i.e., it is only after receiving the request from the customer that work begins. No machinery is produced for stock: the company only works on an MTO basis. According to Amaro et al. (1999) and Barbosa and Azevedo (2018), the activities of the company can be classified into ETO and MTO in the context of Versatile Manufacturing Companies (VMC).

The company's philosophy is to pioneer innovation, production, and marketing of automated systems directed at growth in the global market. Accordingly, supply chain management must be aligned to the company's mission and strategy so that the pursuit of operational Excellence supports and contributes to business strategic competitive excellence. Excellence refers to how each part of the business operations supports and contributes to the growth of the business (Calefariu 2017).

As these concepts show, this research is directed towards Operational Excellence in supply chain management by creating an ETO supply quality model in MC. That model is based on the "defectiveness of supplies" indicator, which is highly relevant to this study and is measured as the number of defective parts as a proportion of the total number of parts received.

Several tools are used to introduce Early Purchasing Involvement. It is worth mentioning Multifunctional Design Assessment Teams (MDATs). In this case, the Purchasing Department works with other departments (engineering, quality, assembly) to review the conceptual, detailed, and final designs. In this way, each blueprint issued is reviewed by multidisciplinary groups before it is sent to the suppliers, and the Purchasing department function plays a significant role in this.

The qualitative and quantitative data used in this research were gathered for more than four years. Two kinds of projects were selected for the study, each belonging to a different business unit. This selection was based on the importance of the sales volume of the two project types for each business unit. After an analysis lasting approximately four months by multidisciplinary teams (engineering, production, purchasing, and project management department), product structures that could be modulated and standardized were created, which served as a basis to "freeze" the design of multiple purchases references. In this way, groups of standardized items for purchasing were located.

This made it possible to enter medium-term item purchasing agreements with a low risk of obsolescence in future products. It also enabled plans to be drawn up to improve quality at suppliers by manufacturing small batches and improving the planning of delivery and supplier workload management.

2.2 Data Understanding

Statistical analysis techniques are used to check the data used because data analysis is just as good as the data used (Montgomery et al. 2012; Kim and Shin 2019). There are three basic ways of gathering data: a retrospective study based on historical data, observation, and experiment design, and this research uses the observational method.

The variables to be used are defined, gathered, and processed to obtain the relevant, accurate, and reliable data to reduce outliers related to mistakes in data. However, it is possible that multicollinearity issues may arise and must be eliminated. The goal of the problem to be solved is to find and show what factors or variables significantly affect the performance of the supply chain in terms of the quality of supplies and to learn the extent of their impact. It is done utilizing statistical models created to help validate the practical and qualitative results obtained in the research from the case study.

The introduction of EPI or Advanced Purchasing through MDATs is an objective of the company's strategic plan. Some results can be seen to have improved after its implementation. However, it is not known whether this factor is statistically significant or relevant or to what extent the results in terms of defectiveness of supplies influence suppliers.

2.3 Data Preparation

For obtaining the data, several indicators regarding the management of the Purchasing and Supplies Unit of the company were drawn up and measured periodically throughout this research. These indicators have proved helpful in making decisions about the state of the business and especially the performance of supply chain management. Therefore, the data are of good quality, and there should be no outliers and no significant amounts of missing data (lower than 10% for each variable) (Yue et al. 2019). In this case, every variable was standardized for outlier detection, considering an outlier if that value is bigger than four in absolute value (Hoffman 2019), and the variance inflation factor (VIF) method was used to detect multicollinearity, looking to have VIF values lower than ten and the condition number η (Vu et al. 2015).

The data gathering period for this research was four years and four months. The multi-variant observations were made monthly, giving a total of 52 observations. The present article focuses on modeling the defectiveness of supplies (PDP—the percentage of defective parts) because quality is a factor that significantly affects the supply chain performance in ETO environments. If the quality of supplies is appropriate, delivery issues concerning materials for projects in the assembly phase are minimized. The delivery of good-quality supplies can also lead to lower total acquisition costs. It minimizes indirect quality management activities, returns, and the replacement of materials for appropriate quality conditions. If suppliers make products without defects, their total costs will be lower, enabling them to be more competitive with their customers. In ETO environments working on a project, if defective materials or products are received, the project lead time may be affected if it is in the critical phase. If it is not in the critical phase, the productivity or efficiency of the project may still be affected as certain activities would have to be re-planned.

Table 1 shows 26 independent and dependent variables presented in the statistical and data mining analysis. There are several categories of variables: financial situation, the structure of the purchasing department, level of activity, inefficiencies, financial and others. The objective is to have a broad spectrum of explanatory variables so that the responses can be better explained and more accurate models can be obtained.

For confidentiality reasons, the values of the continuous variables are set between 0 and 1. Given that the distribution of the variables is not normal, the histograms are drawn up, leading to the correlations being calculated via the non-parametric method of Kendall (Dalgaard 2008; Wang and Li 2019), based on the number of concordant and discordant pairs. A pair of points is concordant if the difference on the x-axis is equal to the difference on the y axis. All pairs must be concordant or all discordant for a perfect monotonous relationship. In this case, the relationship is measured through "tau".

Table 2 shows ten pairs with high correlations with "tau" > 0.75, obtained with the Kendall method.

The information obtained can be used to locate multicollinearity problems between independent variables at the time of modeling and find which independent variables best explain the responses.

Pre-processing shows some data are missing because the data gathering interval was not followed 100%. In the relevant cases, specific quarterly data or data from longer periods have been made extensive, e.g., in the case of the variable *Repe*. It is not expected to distort the analysis, given that the study is observational and not based on historical data gathering. It means that there was better control of data gathering. The histograms drawn up for the PDP response in the ScatterPlot matrices indicate that this variable is biased towards low values: it is thus advisable to make logarithmic transformations for a better linear adjustment of the models (Andrilli and Hecker 2016).

If an algorithm needs to turn numeric variables into categorical ones in the second modeling phase, the transformations will occur. To reduce the dimensions, the categorical variable month is eliminated because no pattern offering relevant information was created. Some other variables are not eliminated because although there are correlated variables, there is no way to know which may be more relevant. More variables are eliminated in the modeling phase.

No observations are eliminated to reduce size in this phase: they are maintained until the modeling phase. It must be pointed out that although data gathering started in April, in the first year of research, the data was some months later. The project was in its initial phase, and data is considered inconsistent until September that year, mainly due to the organizational inertia effect, i.e., from the introduction of the actions to the time when the effects of the results start to be noticed.

Table 1 Independent variables and answers for the statistical and data mining analysis

	Denomination	Description	Frequency	Type	Category
Independent variables	Year	Year of the data mining	N/A	Categorical	N/A
	Month	The month of the data mining	N/A	Categorical	N/A
	n_Planos	Number of blueprints issued for the purchase	Monthly	Numeric	Activity
	IPRI	Index of industrial prices. Presented in percentages. Source INE	Monthly	Numeric	Economic situation
	IPI	Index of industrial production. Index values over 100	Monthly	Numeric	Economic situation
	PMI	Purchasing Managers Index. Index = 50, no change > 50, decrease. < 50, decrease	Monthly	Numeric	Economic situation
	MDAT	Multidisciplinary Design Assessment Teams. MDAT = Yes; MDAT = No	N/A	Categorical	Organizational
	n_D_Stock	Number of days of the stock of raw materials and materials in use	Monthly	Numeric	Logistics
	Stock	Economic volume in € of stock	Monthly	Numeric	Logistics
	n_Buyer	Number of buyers	Annual	Numeric	Structure UCA
	n_Buyer_Ap	Number of buyers plus suppliers	Annual	Numeric	Structure UCA
	n_Mod_ext	Number of modifications of a blueprint that affect issued orders	Monthly	Numeric	Inefficiencies

(continued)

Table 1 (continued)

	Denomination	Description	Frequency	Type	Category
	n_Lineas_Compo	Number of purchase lines of components	Monthly	Numeric	Activity
	Vol_Compo	Economic volume in € of components purchase	Monthly	Numeric	Activity
	Fact_Compo	Invoiced volume in € of components by the suppliers	Monthly	Numeric	Activity
	n_Lineas_Sub	Number of subcontract purchase lines	Monthly	Numeric	Activity
	Vol_Sub	Economic volume in € of subcontract purchase	Monthly	Numeric	Activity
	Fact_Sub	Invoiced volume in € of components by the suppliers	Monthly	Numeric	Activity
	n_Lineas_URG	Number of purchase lines treated as Urgent	Monthly	Numeric	Inefficiencies
	Vol_URG	Purchase volume in € purchased as Urgent	Monthly	Numeric	Inefficiencies
	n_Facturas_NOK	Number of invoices received from the suppliers	Monthly	Numeric	Activity
	Repe	% of the economic volume of parts that were also purchased in the previous year (repeated) over the total purchase volume of the period taken as reference	Annual-quarterly	Numeric	Sales mix and standardization of references
	n_Prov	Number of suppliers	Annual	Numeric	Purchase management

(continued)

Table 1 (continued)

	Denomination	Description	Frequency	Type	Category
	n_Sub	Number of subcontractors	Annual	Numeric	Purchase management
	HE	Number of extra hours for the buyers	Monthly	Numeric	Activity
	HF	Number of training hours	Monthly	Numeric	RRHH
Answers	PPD	Percentage of defective parts in the supplies over the total	Monthly	Numeric	Supply chain management

Table 2 Correlation data (Kendall)

Item	Variable_1	Variable_2	TAU		P-value
[1,]	MDAT	n_Buyer_Ap	0.83		$p \ll 0.05$
[2,]	MDAT	n_Lineas_Sub	0.75		$p \ll 0.05$
[3,]	MDAT	Vol_Sub	0.75		$p \ll 0.05$
[4,]	MDAT	Fact_Sub	0.77		$p \ll 0.05$
[5,]	MDAT	n_Sub	0.79		$p \ll 0.05$
[6,]	n_Buyer	n_Prov	0.77		$p \ll 0.05$
[7,]	n_Buyer_Ap	n_Sub	0.88		$p \ll 0.05$
[8,]	n_Lineas_Sub	Vol_Sub	0.80		$p \ll 0.05$
[9,]	n_Prov	HF	0.91		$p \ll 0.05$
[10,]	n_Prov	Evo_P_Repe	0.78		$p \ll 0.05$

2.4 Modelling

In this section, the work is tackled in three ways: by creating regression models through continuous dependent variables, creating classifying models with categorical response variables, and using association rules as a compliment.

Several methods and tools are thus available for obtaining knowledge. The more available methods, the more possibilities there are of appropriately describing the response to be modelled. Once all the models obtained have been evaluated the model that most accurately describes the response for "defectiveness in quality of supplies" is selected. At the same time, the model results are supplemented by the knowledge gained using association rules.

Table 3 M5P tree statistic data

Correlation coefficient	0.5613
Mean absolute error	0.7943
Root mean squared error	0.9788
Relative absolute error	84.1998%
Root relative squared error	80.5358%
Total number of instances	52

2.4.1 Regression Models with Continuous Response Variables for PDP

Several models are proposed, one of which is later selected. To that end, M5P model trees are used in WEKA along with multiple linear regression models with R™. To obtain a model for PDP, the variable is transformed using the Napierian logarithm (ln) as it is biased towards the source. It must be considered when interpreting the results.

M5P Model Tree

The M5P algorithm provides regression trees by dividing the observation space and considering a linear regression model for each leaf, usually called model trees. The M5P tree obtained comprises three nodes and four leaves. The nodes are the variables Year, IPRI (Index of Industrial Prices), and n_Mod_ext (Number of blueprint modifications that affect orders issued to suppliers). Four linear regression models are obtained (LM1, LM2, LM3, and LM4) corresponding to the four leaves of the tree.

The M5P model proposed it distinguishes different types of linear regression models based on the year when the data was gathered. On a second level, different types of linear regression are distinguished based on the value of IPRI (0.35). Below, other linear regression models can be distinguished, considering whether n_Mod_ext is equal to, lower than, or higher than 96. Table 3 shows the statistical data for the model described.

Multiple Linear Regression Model Nº 1

Multiple linear regression models enable regression problems involving more than one regressive variable to be analysed. When this kind of technique is used to create models, problems tend to appear in the selection of variables, autocorrelation of errors, multicollinearity, and linear dependence between regressors. These aspects should be considered when the final model is created.

As shown in Table 4, the model obtained provides a good fit compared to the other models generated and meets the assumptions of the OLS (Ordinary Least Squares) for regression. It has a severe multicollinearity problem as it obtains the values VIF

Table 4 Statistic data from the multiple linear regression Model N1

	Estimate Std	Error	t value	Pr(>|t|)	VIF
(Intercept)	−2.09E + 01	2.43E + 00	−8.574	2.05e−10***	NA
IPRI	2.94E-01	1.14E−01	2.587	0.013641*	1.252323
MDAT	−2.63E + 00	4.96E−01	−5.309	5.04e−06***	9.170828
n_D_Stock	3.72E-02	1.10E−02	3.372	0.001728**	3.00695
Stock	−4.90E-07	1.86E−07	−2.639	0.011992*	2.451226
n_Buyer	−1.95E + 00	2.60E−01	−7.5	5.23e−09***	11.863164
Fact_Compo	6.17E-07	2.53E−07	2.444	0.019292*	7.117596
Vol_Sub	−2.72E-07	2.09E−07	−1.3	0.201336	1.863666
Fact_Sub	−8.69E-07	3.83E−07	−2.271	0.028872*	1.91446
n_Facturas	3.28E-03	1.12E−03	2.937	0.005597**	8.583593
Repe	−3.38E-02	1.55E−02	−2.183	0.035285*	1.41499
n_Prov	5.74E−02	7.26E−03	7.905	1.52e−09***	15.26407
n_Sub	3.39E−01	4.70E−02	7.21	1.28e−08***	6.758726
n_Facturas_NOK	−1.87E−02	5.09E−03	−3.665	0.000752***	7.603694
Residual standard error	0.5895 on 38 degrees of freedom				
Multiple R-squared	0.8156				
Adjusted R-squared	0.7525				
F-statistic	12.93 on 13 and 38 DF				
p-value	3.43E−10				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

= 15,26 > 10 and values of $\eta = 45{,}284 > 1000$ (Condition Number) (Yue et al. 2019). Therefore, necessary to generate a model with lower multicollinearity and a good fit.

Multiple Linear Regression Model Nº 2

As shown in Table 5, there is a significant improvement in multicollinearity, and a proper fit has been lost ($R^2 = 0.6076$); however, although VIF < 10, the $\eta = 10{,}641 > 1000$ and that represents severe multicollinearity.

To solve this problem, the Principal Components regression method is used in Model 2 (Kalogridis and Van Aelst 2019; Solanki et al. 2018).

Table 5 Statistic data from the multiple linear regression Model N2

	Estimate Std.	Error	t value	Pr(>|t|)	VIF
(Intercept)	−16.578783	2.274382	−7.289	2.98e−09***	NA
MDAT	−2.252515	0.428547	−5.256	3.52e−06***	4.326923
n_Buyer	−1.646033	0.276058	−5.963	3.07e−07***	8.426829
n_Prov	0.045733	0.006822	6.704	2.30e−08***	8.493699
n_Sub	0.281829	0.043432	6.489	4.88e−08***	3.647061
Residual standard error	0.7423 on 47 degrees of freedom				
Multiple R-squared	0.6384				
Adjusted R-squared	0.6076				
F-statistic	20.75 on 4 and 47 DF				
p-value	6.64E−10				

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.'0.1 ' ' 1

Multiple Linear Regression Model 3

The Principal Components (PC) and eigenvectors corresponding to the 13 multiple linear regression variables in model Number 1 and the response PDP are found (Solanki et al. 2018). If the eigenvectors are approximated to one, the original regressors are orthogonal. However, if the eigenvectors are zero, there is a perfect linear relationship between the original regressors—one or more regressors with values near zero mean multicollinearity (Solanki et al. 2018). Accordingly, several main components whose eigenvectors are close to zero are eliminated, thus solving the multicollinearity problem. The regression is made over the remaining main components to obtain the biased estimators of the coefficients of regression model Number 1.

Principal components regression is selected because regressors are orthogonal, and therefore, the elimination arrangement can be determined by a "t-test". The "t values" are put in order, and the components to be considered for elimination starting with the lowest "t value". Eight proposals are obtained from the model studied, which eliminates the vectors with the lowest significance level. As shown in Table 6, Number 5 is considered the best solution overall three metrics: predicted residual error sum of squares (PRESS) as a substitute of R2, standard deviation (s), and the sum of squared residuals (SSres), where low values are better for everyone.

The proposal chosen is the one that eliminates the four main components whose alphas are set to zero, i.e., PC7, PC9, PC10, and PC12. Once the multicollinearity problem has been solved, and the four main components (PC7, PC9, PC10, and PC12) have been eliminated, the next step is to run the regression on the rest of the main components (Table 7).

Table 6 Statistic data of the proposals for the elimination of main components

#Proposal	SSres	s	Press
1	13.20520	0.5894958	23.31449
2	13.22188	0.5822565	22.01525
3	13.24722	0.5754827	21.52210
4	13.27441	0.5690044	20.42255
5	13.33168	0.5634013	19.91008
6	13.78318	0.5661618	19.74657
7	14.24366	0.5689635	19.27263
8	15.26377	0.5824043	20.1049

Table 7 Statistic data from the multiple linear regression Model N3

Item	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	−0.74972	0.07813	−9.596	3.79e−12***
Z2[, c(1:6, 8, 11, 13)]PC1	−0.18781	0.03668	−5.12	7.20e−06***
Z2[, c(1:6, 8, 11, 13)]PC2	0.09319	0.05198	1.793	0.08023
Z2[, c(1:6, 8, 11, 13)]PC3	0.40967	0.06415	6.386	1.11e−07***
Z2[, c(1:6, 8, 11, 13)]PC4	0.08351	0.07002	1.193	0.2397
Z2[, c(1:6, 8, 11, 13)]PC5	0.20738	0.08272	2.507	0.01613*
Z2[, c(1:6, 8, 11, 13)]PC6	0.41685	0.09009	4.627	3.54e−05***
Z2[, c(1:6, 8, 11, 13)]PC8	−0.4125	0.12952	−3.185	0.00273**
Z2[, c(1:6, 8, 11, 13)]PC11	0.2934	0.2436	1.204	0.23516
Z2[, c(1:6, 8, 11, 13)]PC13	−4.06464	0.47674	−8.526	1.05e−10***
Residual standard error	0.5634 on 42 degrees of freedom			
Multiple R-squared	0.8138			
Adjusted R-squared	0.774			
F-statistic	20.4 on 9 and 42 DF			
p-value	1.22E−12			

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Each principal component is a linear model of the variables of the initial model on which the main components are obtained; the coefficients of this model appear in Table 8:

To show the relative importance of the coefficients obtained the data are standardised as shown in Table 9.

The most relevant variables are MDAT, n_Buyer, n_Prov, and n_Sub. It is mainly from these variables that conclusions are drawn.

Table 8 Coefficient of model N3

Item	Coefficient
Intercept	−20.89307
IPRI	3.085081e−01
MDAT	−2.584367e + 00
n_D_Stock	3.525140e−02
Stock	−4.647646e−07
n_Buyer	−1.931197e + 00
Fact_Compo	5.796862e−07
Vol_Sub	−2.669004e−07
Fact_Sub	−9.318181e−07
n_Facturas	3.681652e−03
Repe	−3.289433e−02
n_Prov	5.720828e−02
n_Sub	3.348870e−01
n_Facturas_NOK	−2.062572e−02

Table 9 Standardized statistic data of multiple linear regression Model N3

Item	Estimate Std.	Error	t value	Pr(>|t|)
(Intercept)	−0.74972	0.08175	−9.171	3.57e−11***
IPRI	0.23896	0.09237	2.587	0.013641*
MDAT	−1.32709	0.24998	−5.309	5.04e−06***
n_D_Stock	0.48261	0.14314	3.372	0.001728**
Stock	−0.34105	0.12924	−2.639	0.011992*
n_Buyer	−2.13243	0.28431	−7.5	5.23e−09***
Fact_Compo	0.53816	0.22022	2.444	0.019292*
Vol_Sub	−0.14653	0.11269	−1.3	0.201336
Fact_Sub	−0.25942	0.11421	−2.271	0.028872*
n_Facturas	0.71037	0.24184	2.937	0.005597**
Repe	−0.21435	0.09819	−2.183	0.035285*
n_Prov	2.54928	0.3225	7.905	1.52e−09***
n_Sub	1.54725	0.2146	7.21	1.28e−08***
n_Facturas_NOK	−0.83426	0.22762	−3.665	0.000752***
Residual standard error	0.5895 on 38 degrees of freedom			
Multiple R-squared	0.8156			
Adjusted R-squared	0.7525			
F-statistic	12.93 on 13 and 38 DF			
p-value	3.427E−10			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

2.4.2 Classifying Models with Categorical Response Variables

This section proposes a classifying model with categorical response variables whose purposes are descriptive rather than predictive. To that end, algorithm J48 trees are used. Tree models are comprehensive models, i.e., they can be expressed symbolically and as groups of conditions that make them easier to understand for other people. Among the WEKA algorithms in terms of decision trees (classifiers), algorithm J48 (based on partition algorithm C4.5, with J48 being a variant form for Java) enables partitions to be made in numeric and nominal values (Kumar et al. 2017).

MDAT and Year variables are transformed into nominal variables by the "Numeric to Nominal" function. The variables are first transformed by discretizing responses using the WEKA function "Discretize". Values are classed in three groups: Low ($-\infty$ to 0.995), Medium (0.995 to 1.974), and High (1.974 to ∞); however, it is necessary to "balance the costs" in the response variable using the "Resample" function of WEKA (Kumar et al. 2017).

The J48 tree makes partitions considering whether the number of buyers plus suppliers (n_Buyer_Ap) is lower than, equal to, or higher than 11. In the first case, the classification is based on the IPRI value (1.1) and the number of stock days (63). In the second case, the classification is based on the invoicing of Subcontracting (€127.7 k). The results are classified into Low, Medium, and High levels of defectiveness of supplies.

The model has an acceptable fit, as can be seen in the metrics of Kappa (Table 10) and the confusion matrix (Table 11). The confusion matrix indicates how many observations predicted for a, b, and c correspond to the real data. It is observed that

Table 10 Kappa of a classification model

Correctly classified instances	45 (86.5385%)
Incorrectly classified instances	7 (13.4615%)
Kappa statistic	0.7973
Mean absolute error	0.1
Root mean squared error	0.2787
Relative absolute error	22.5694%
Root relative squared error	59.1426%
Coverage of cases (0.95 level)	98.0769%
Mean rel. region size (0.95 level)	46.7949%
Total number of instances	52

Table 11 Confusion matrix

a	b	c	Classified as
17	3	0	a = '(−inf−0.995]'
2	12	2	b = '(0.995−1.974]'
0	0	16	c = '(1.974−inf)'

7 (2 + 3 + 2) of the 52 are not in the diagonal of the matrix, i.e., the model does not classify them appropriately. By contrast, the model appropriately classifies 45 (17 + 12 + 16) observations (corresponding to the matrix's diagonal). The Kappa statistic measures the model's goodness: its maximum value is one. In this case the Kappa value is 0.7973, which is considered acceptable (Trabelsi et al. 2019).

2.4.3 Association Rules

The "Apriori" algorithm for association rules is used in this section to gain knowledge about the data via the relationships between variables using WEKA. Association rules express behavior patterns between data based on the apparition of values with two or more attributes, i.e., links between variables can be obtained to get knowledge from the data. "Apriori" is quite a simple association rules algorithm, and it is based on looking for groups of elements with a specific cover.

The cover of a rule (also called its support) is the number of instances that a rule predicts correctly. First, two groups are built composed of only one item that exceeds the minimum cover. This group of groups is used to build the group of groups of two elements until a size is reached where the group of elements fails to meet the cover requirement (Kumar et al. 2017). In this case, all the variables are previously transformed using discretization, except for the categorical variables MDAT and Year. Values must be classified into three groups: High, Medium, and Low. Rules are selected by eliminating variables and modifying the properties of the "Apriori" algorithm.

There are many ways of measuring the quality of rules, though "support" and "trust" are the basic ones. These rules do not explain causality but co-occurrence. The association rules obtained with the "Apriori" algorithm whose "trust" level is higher than 0.75 are selected; the maximum "trust" is 1. Sometimes a high value of "trust" leads to errors, and other metrics such as "support", "lift" or "interest" need to be used (Bouckaert et al. 2010; Orallo et al. 2010).

2.5 Evaluation

The models obtained are descriptive in their purpose, which helps quantify the effects of independent variables on the PDP response. Given that the aim is not predictive, it is not necessary to validate the models; those with the best fit that the assumptions of the OLS for the regression are simply selected.

WEKA validates models directly when making them using cross-validation of 10 leaves, classifying models using the confusion matrix and association rules by cover and trust (Orallo et al. 2010; Witten and Eibe 2011). Several models are first selected to select the regression models so that conclusions can be drawn (Table 12). Regression models are selected based on the criterion of better metrics (R^2adj, R^2,

Table 12 Summary and comparison for the selection of the model PPD

	η	SSres	s	Press	R^2adj	R^2
M5P Model	NA	X	X	X	X	0.5613
Regression Mod. Nº1	45.284	13.205	0.5895	X	0.7525	0.8156
Regression Mod. Nº2	10.641	25.895	0.7423	X	0.6076	0.6384
Regression Mod. Nº3	Reduce	13.332	0.5634	19.91	0.774	0.8138

s, SSres, and multicollinearity—"η"). For further interpretation, classifying models (J48 trees) and association rules are also considered to help complete the analysis.

Once all the models have been analyzed, it is necessary to select model Number 3 for Y = ln (PDP). This model does not present multicollinearity problems; it is also the best compromise solution for its fit (R^2adj, R^2), SSres, and s. Likewise, given that there may be doubts about the fulfillment of the OLS assumptions for the regression, a specific test is run for that purpose, and the assumptions are found to be fulfilled (Kabacoff 2011).

3 Results and Discussion

Once the coefficients of the regression models and those of the interpretation of the classifying trees for the PDP response have been analyzed, it is possible to show in the models selected that the coefficients are significantly different from zero and that they are measured for values of "p" according to 0 '***; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ". Relevance is measured according to the models with normalized coefficients, which measure importance among coefficients.

Linear model Number 3 is selected from the set. The most relevant variables are MDAT, n_Buyer, n_Prov, and n_Sub. As the study is conducted with responses transformed with natural logarithm (ln), the model is not an additive model but multiplicative; this must be taken into account for its interpretation (Trabelsi et al. 2019), and response is affected not by the sum of the coefficient, but by its multiplication. As shown in Table 13, if the MDAT coefficient is 0.08 after the transformation to its original units, the effect of MDAT is not the sum of 0.08 PDP, but the response is multiplied by that factor, i.e., PDP is reduced by 1/12.5. A pretty significant improvement is achieved thanks to the introduction of the MDAT.

If IPRI goes up by one percentage point, PDP goes up by 1.36. If the increase is by one day's stock of raw materials and materials in use, PDP goes up by 1.04. For each buyer hired, PDP is reduced by approximately 1/7. If the materials and components (items) bought increase by 1% on the previous year, the improvement in PDP takes the form of a reduction of 3%. If a new buyer is introduced, PDP increases by 1.06, and if a subcontractor is introduced, it increases by 1.4.

Finally, it can be seen that the ratio of the reduction in PDP to the increase in n_Facturas_NOK is 0.98 (a 2% improvement). It does not make sense for PDP to

Table 13 Results obtained from the multiple linear regression Model N3

Denomination	Description	Type	Category	Importance	Relevance	Coefficient	Transformed coefficient
Intercept				***	Medium	−2.09E + 01	0
IPRI	Index of Industrial Prices. Presented in percentages. Source INE	Numeric	Economic situation	*	Medium	3.09E−01	1.36
MDAT	Multidisciplinary groups of design assessment. MDAT = Yes; MDAT = No	Categorical	Organizational	***	High	−2.58E + 00	0.08
n_D_Stock	Number of days of the stock of raw materials and materials in use	Numeric	Logistic	**	Medium	3.53E−02	1.04
Stock	Economic volume in € of stock	Numeric	Logistic	*	Medium	−4.65E−07	1
n_Buyer	Number of buyers	Numeric	Structure UCA	***	High	−1.93E + 00	0.14
Fact_Compo	Invoiced volume in € of components by the suppliers	Numeric	Activity	*	Medium	5.80E−07	1
Vol_Sub	Economic volume in € of subcontract purchase	Numeric	Activity	N/A	Medium	−2.67E−07	1
Fact_Sub	Invoiced volume in € of components by the suppliers	Numeric	Activity	*	Medium	−9.32E−07	1
n_Facturas	Number of invoices received from the suppliers	Numeric	Activity	**	Medium	3.68E−03	1

(continued)

Table 13 (continued)

Denomination	Description	Type	Category	Importance	Relevance	Coefficient	Transformed coefficient
Repe	% of the economic volume of parts that were also purchased in the previous year (repeated) over the total purchase volume of the period taken as reference	Numeric	Sales mix and standardization of references	*	Medium	−3.29E−02	0.97
n_Prov	Number of suppliers	Numeric	Purchase management	***	High	5.72E−02	1.06
n_Sub	Number of subcontractors	Numeric	Purchase management	***	High	3.35E−01	1.4
n_Facturas_NOK	Percentage of incorrect invoices issued by the suppliers	Numeric	Inefficiencies	***	Medium	−2.06E−02	0.98

improve when wrong invoices are received from suppliers, but it happens in this study. The reason probably lies elsewhere. From the classifying model for PDP, the interpretation is that if the number of suppliers is 11 or lower if the number of stock days is 63 or lower, and if the IPRI for the month is lower than 1.1, then PDP is low. PDP is high if the number of suppliers exceeds 11 and if the number of purchase lines issued for purchasing components is lower than 5061 units and invoicing by subcontractors exceeds €127,664.

From the association rules, it can be deduced that if the number of purchase orders issued as Urgent is low, PDP is low, and the same occurs if buyers' number of additional hours is low. The same happens when there is a slight increase in the price of repeat parts and when there are high delivery indicators, i.e., if the situation is good, then it is good for all the indicators. It is essential to highlight that if the number of modifications of items issued for an order is low, the PDP is also low. If the amount of stock is Low, so is the PDP.

Considering the coefficients with the greatest statistical significance, these results can be summed up as follows:

- Advanced purchases through *MDATs* decrease defectiveness by 0.08.
- For each additional buyer, defectiveness is reduced by 0.14
- For each new supplier, defectiveness increases by 1.06.
- For each new subcontractor, defectiveness increases by 1.4.
- For each percentage point increase in the purchase of repeat parts, supply quality improves by 3%.
- For each additional day's stock of raw materials and materials in use, *PDP* rises by 1.04.

This research shows how 0.08-fold reduces the defectiveness of the supplies with advanced purchasing along with other practices. At the beginning of the research, the level of defectiveness of the supplies found was 1.39%, and at the end, it was 0.68%, i.e., an improvement of more than 50% is observed.

Moreover, best practices are identified for implementing improvements. The results obtained and the best practices detected are summarised below.

3.1 Reduction of Stocks

From a logistical point of view, if stocks of raw materials and materials in use are increased by one day, supplier defectiveness levels increase by 1.04, i.e., the efficiency of "lean" principles is demonstrated: with a smaller inventory supplier have fewer quality problems.

In terms of inefficiencies, it is essential to point out that if the number of modifications of references of an issued order is low, so is the PDP. If the amount of stock is low, so is the PDP. The rules of association show a marked link between good results in pricing trends for repeat purchases and deliveries on the one hand and PDP on the other. Good quality, price, and delivery timeframe go in the same direction and do not contradict each other.

For every ten additional modifications that affect orders issued, the standard of deliveries falls by 0.16%. The association rules show that the Deliveries indicator is high if the number of lines issued as urgent orders is low. A high level in Deliveries and a low level in PDP are also linked if the number of lines issued as urgent orders is low.

3.2 Organisation of the Purchasing Department

The organization of ETO Purchasing directly impacts improvements in supply quality in the case studied here. The importance of freeing buyers from administrative tasks such as issuing orders and giving them more time to manage relations with suppliers and negotiations or properly dimensioning the department is evident. For each additional buyer, defectiveness is reduced by 0.14.

If the level of additional work at the Purchasing Department is low and the level of Deliveries is high, this is closely related to a low PDP.

3.3 Early Purchasing Involvement (EPI): Advanced Purchasing

The existence of MDATs has a significant impact on the quality of supplies as they reduce defectiveness by 1/12.5. Work in multidisciplinary teams, communication, and the role of advanced purchasing are all quite significant in ETO Supplies in MC and help eliminate functional silos. This is the most significant result of this research work.

In terms of practical implications, these results help ETO companies working in or migrating to MC become more competitive through the pursuit of Operational Excellence by improving the quality of supplies. Using the model results, companies can focus on the practices described in this section and focus on less developed ones. This enables them to learn a priori how effective introducing such practices is.

The more suppliers and subcontractors are used, the worse the quality of supplies is. For each additional supplier, defectiveness of supplies increases by 1.06; and for each additional subcontractor, it rises by 1.4. Supplier management is of great importance, keeping the number of suppliers low and rational.

The role of standardization and modularisation of components is significant, given that if the percentage of repetitive purchases increases by 1%, quality improves by 3%.

4 Conclusions and Future Research

The use of multivariable analysis statistical and data mining techniques via the CRISP-DM methodology enables knowledge to be extracted from data gathered over more than four years of research at an ETO company working in MC environments. The variables that affect the defectiveness response in supply quality in the study are identified and quantified.

The models obtained are descriptive and not predictive. This paper aims not to predict but to understand, interpret, and quantify the input variables and their effects on the defectiveness response of supplies (PDP).

Quantitative research is presented, which identifies and measures the factors related to defectiveness in supplies at ETO companies working in MC and highlights best practices for improving that response:

- Due to advanced purchasing or early purchasing involvement (*EPI*) through *MDAT*, the defectiveness of supplies is reduced by a factor of 0.08.
- For each additional supplier, defectiveness increases by 1.06, and for each additional subcontractor, by 1.4.
- If the percentage of repeat parts bought from one year to the subsequent increases by 1%, defectiveness improves by 3%.
- If there is a one-day increase in stocks of raw materials and materials in use, defectiveness of supplies increases by 4%.

Another contribution of this paper is that it identifies the best practices for achieving these results, such as:

- *Reduction of stocks.* The efficiency of lean principles is verified: with a smaller inventory, there are fewer quality issues with suppliers.
- *The organization of the Purchasing Department*. The importance of freeing buyers from administrative tasks such as issuing orders and giving them more time to manage relations with suppliers and stage negotiation, and properly dimensioning the department is evident.
- *Early Purchasing Involvement or advanced purchasing.* Via *MDATs,* this has a direct impact on the quality of supplies.

ETO companies working or migrating to MC can improve their results by introducing the best practices described here. This can help them become more competitive in their pursuit of Operational Excellence by improving the quality of supplies. Also, the management of supplier numbers is of paramount importance, as is keeping a small, rational number of suppliers.

This research fills the gap left by the few empirical and quantitative papers published concerning ETO supply chain management in MC and other statistical models for measuring the supply chain performance in such companies. It identifies and quantifies the factors that affect other responses, such as the level of deliveries, pricing trends for repeat purchasing, and the bill's impact for goods consumed as a proportion of total sales.

However, this paper focused only on a percentage of defective parts in the supplies over the total (PDP) as the dependent variable, which can be a research limitation. For solving it, future research must focus on:

- Prices evolution of repeated parts in the current period over the previous year's prices.
- Percentage of delivery fulfillment by suppliers within the agreed period.
- Percentage of incorrect invoices issued by suppliers.
- Time without working due to lack of raw materials.

References

Adrodegari, F., Bacchetti, A., Pinto, R., Pirola, F., Zanardini, M.: Engineer-to-order (ETO) production planning and control: An empirical framework for machinery-building companies. Prod. Plan. Control **26**(11), 910–932 (2015). https://doi.org/10.1080/09537287.2014.1001808

Amaro, G., Hendry, L., Kingsman, B.: Competitive advantage, customisation and a new taxonomy for non make-to-stock companies. Int. J. Oper. Prod. Manag. **19**(4), 349–371 (1999). https://doi.org/10.1108/01443579910254213

Andrilli, S., Hecker, D.: Linear transformations. In: Andrilli, S., Hecker, D. (eds.) Elementary Linear Algebra, Chapter 5, 5th edn, pp. 319–412. Academic Press, Boston (2016). https://doi.org/10.1016/B978-0-12-800853-9.00005-0

Badurdeen, F., Jawahir, I.S.: Strategies for value creation through sustainable manufacturing. Procedia Manufact. **8**, 20–27 (2017). https://doi.org/10.1016/j.promfg.2017.02.002

Bag, S., Wood, L.C., Xu, L., Dhamija, P., Kayikci, Y.: Big data analytics as an operational excellence approach to enhance sustainable supply chain performance. Resour. Conserv. Recycl. **153**, 104559 (2020). https://doi.org/10.1016/j.resconrec.2019.104559

Barbosa, C., Azevedo, A.: Towards a hybrid multi-dimensional simulation approach for performance assessment of MTO and ETO manufacturing environments. Procedia Manufact. **17**, 852–859 (2018). https://doi.org/10.1016/j.promfg.2018.10.137

Bouckaert, R.R., Frank, E., Hall, M.A., Holmes, G., Pfahringer, B., Reutemann, P., Witten, I.H.: WEKA−Experiences with a Java open-source project. J. Mach. Learn. Res. **11**, 2533–2541 (2010)

Brabazon, P., MacCarthy, B. Order fulfillment models for the catalog mode of mass customization—a review. In: Blecker, T., Friedrich, G. (eds.) Mass Customization: Challenges and Solutions, vol. 87, pp. 211–232. Springer Boston (2006). https://doi.org/10.1007/0-387-32224-8_10

Brusco, M.J., Steinley, D., Cradit, J.D., Singh, R.: Emergent clustering methods for empirical OM research. J. Oper. Manag. **30**(6), 454–466 (2012). https://doi.org/10.1016/j.jom.2012.06.001

Calefariu, E.: Vision and strategy for cultural management. Bulletin of the Transilvania University of Brasov, Series VIII: Performing Arts **10**, 25–30 (2017)

Cannas, V.G., Pero, M., Pozzi, R., Rossi, T.: An empirical application of lean management techniques to support ETO design and production planning. IFAC-PapersOnLine **51**(11), 134–139 (2018). https://doi.org/10.1016/j.ifacol.2018.08.247

Corne, D., Dhaenens, C., Jourdan, L.: Synergies between operations research and data mining: the emerging use of multi-objective approaches. Eur. J. Oper. Res. **221**(3), 469–479 (2012). https://doi.org/10.1016/j.ejor.2012.03.039

Dalgaard, P.: Introductory Statitics with R. Springer Science. Statistics and Computing. Springer, New York. https://doi.org/10.1007/978-0-387-79054-1

Davis, S.: From "Future Perfect": mass customization. Plan. Rev. **17**, 16–21 (1989). https://doi.org/10.1108/eb054249

Deradjat, D., Minshall, T.: Decision trees for implementing rapid manufacturing for mass customisation. CIRP J. Manuf. Sci. Technol. **23**, 156–171 (2018). https://doi.org/10.1016/j.cirpj.2017.12.003

Everitt, B., Hothorn, T.: An Introduction to Applied Multivariate Analysis with R, vol 1. Springer, New York (2011). https://doi.org/10.1007/978-1-4419-9650-3

Gosling, J., Naim, M.: Engineer-to-order supply chain management: A literature review and research agenda. Int. J. Prod. Econ. **122**(2), 741–754 (2009). https://doi.org/10.1016/j.ijpe.2009.07.002

Hoffman, J.I.E. Outliers and extreme values. In: Hoffman, J.I.E. (ed.) Basic Biostatistics for Medical and Biomedical Practitioners, Chapter 9, 2nd edn, pp 149–155. Academic Press, Boston (2019). https://doi.org/10.1016/B978-0-12-817084-7.00009-7

Huang, X., Kristal, M.M., Schroeder, R.G.: The impact of organizational structure on mass customization capability: a contingency view. Prod. Oper. Manag. **19**(5), 515–530 (2010). https://doi.org/10.1111/j.1937-5956.2009.01117.x

Huber, S., Wiemer, H., Schneider, D., Ihlenfeldt, S.: DMME: data mining methodology for engineering applications—a holistic extension to the CRISP-DM model. Procedia CIRP **79**, 403–408 (2019). https://doi.org/10.1016/j.procir.2019.02.106

Janipha, N.A.I., Ahmad, N., Ismail, F.: Clients' involvement in purchasing process for quality construction environment. Procedia. Soc. Behav. Sci. **168**, 30–40 (2015). https://doi.org/10.1016/j.sbspro.2014.10.207

Jank, W. Business Analytics for Managers. Springer, New York (2011). https://doi.org/10.1007/978-1-4614-0406-4

Kabacoff, R.: R in Action: Data analysis and graphics with R. Manning Publications Co., Shelter Island, NY, USA (2011)

Kalogridis, I., Van Aelst, S.: Robust functional regression based on principal components. J. Multivar. Anal. **173**, 393–415 (2019). https://doi.org/10.1016/j.jmva.2019.04.003

Kim, B., Shin, S.J.: Principal weighted logistic regression for sufficient dimension reduction in binary classification. J. of the Korean Stat. Soc. **48**(2), 194–206 (2019). https://doi.org/10.1016/j.jkss.2018.11.001

Kumar, S., Dey, S., Kumar, A., Kumar, T.: Handbook of research on advanced data mining techniques and applications for business intelligence (Advances in business information systems and analytics) Advances in business information systems and analytics. Business Science Reference, Hershey (2017)

Legenvre, H., Henke, M., Ruile, H.: Making sense of the impact of the internet of things on purchasing and supply management:a tension perspective. J. Purchasing Supply Manage. **100596** (2020). https://doi.org/10.1016/j.pursup.2019.100596

Liu, C., Yao, J.: Dynamic supply chain integration optimization in service mass customization. Comput. Ind. Eng. **120**, 42–52 (2018). https://doi.org/10.1016/j.cie.2018.04.018

Makkonen, M., Sundqvist-Andberg, H.: Customer value creation in B2B relationships: Sawn timber value chain perspective. J. for. Econ. **29**, 94–106 (2017). https://doi.org/10.1016/j.jfe.2017.08.007

Medini, K., Cunha, C.D., Bernard, A.: Sustainable mass customized enterprise: key concepts, enablers and assessment techniques. IFAC Proc. Volumes **45**(6), 522–527 (2012). https://doi.org/10.3182/20120523-3-RO-2023.00242

Montgomery, D., Peck, E., Vining, G.: Introduction to linear regression analisys, 5th edn. Wiley, Hoboken (2012)

Orallo, J., Quintana, M., Ramírez, C.: Introduction to data mining [In Spnish], 2nd edn. Prentice Hall, Madrid (2010)

Pine, J.: Mass customization: the new frontier in business competition. Harvard Business Press, Boston (1992)

Porter, M.: To be competitive [In Spanish]. Deusto S.A. Ediciones, Barcelona, Spain (2009)

Powell, D., Strandhagen, J.O., Tommelein, I., Ballard, G., Rossi, M.: A new set of principles for pursuing the lean ideal in engineer-to-order manufacturers. Procedia CIRP **17**, 571–576 (2014). https://doi.org/10.1016/j.procir.2014.01.137

Rozemeijer, F.: Purchasing myopia revisited again? J. Purch. Supply Manag. **14**(3), 205–207 (2008). https://doi.org/10.1016/j.pursup.2008.06.001

Sabri, H., Shaikh, N.: Lean and agile value chain management: a guide to the next level of improvement. J Ross Publishing, Plantation, FL, USA (2010)

Sfumato, P., Filleron, T., Giorgi, R., Cook, R.J., Boher, J.M.: Goftte: A R package for assessing goodness-of-fit in proportional (sub) distributions hazards regression models. Comput. Methods Programs Biomed. **177**, 269–275 (2019). https://doi.org/10.1016/j.cmpb.2019.05.029

Sheather, S.A.: Modern approach to regression with R. Springer Texts in Statistics. Springer, New York (2009). https://doi.org/10.1007/978-0-387-09608-7

Solanki, R.B., Kulkarni, H.D., Singh, S., Verma, A.K., Varde, P.V.: Optimization of regression model using principal component regression method in passive system reliability assessment. Prog. Nucl. Energy **103**, 126–134 (2018). https://doi.org/10.1016/j.pnucene.2017.11.012

Song, D.-P., Dong, J.-X., Xu, J.: Integrated inventory management and supplier base reduction in a supply chain with multiple uncertainties. Eur. J. Oper. Res. **232**(3), 522–536 (2014). https://doi.org/10.1016/j.ejor.2013.07.044

Strandhagen, J.W., Vallandingham, L.R., Alfnes, E., Strandhagen, J.O.: Operationalizing lean principles for lead time reduction in engineer-to-order (ETO) operations: A case study. IFAC-PapersOnLine **51**(11), 128–133 (2018). https://doi.org/10.1016/j.ifacol.2018.08.246

Sunil Kumar, C.V., Routroy, S., Mishra, R.K.: Lean supplier management for better cost structures. Mater. Today Proc. **5**(9, Part 3): 18941–18945 (2018). https://doi.org/10.1016/j.matpr.2018.06.244

Trabelsi, A., Elouedi, Z., Lefevre, E.: Decision tree classifiers for evidential attribute values and class labels. Fuzzy Sets Syst. **366**, 46–62 (2019). https://doi.org/10.1016/j.fss.2018.11.006

Ventura, J.A., Valdebenito, V.A., Golany, B.: A dynamic inventory model with supplier selection in a serial supply chain structure. Eur. J. Oper. Res. **230**(2), 258–271 (2013). https://doi.org/10.1016/j.ejor.2013.03.012

Vu, D.H., Muttaqi, K.M., Agalgaonkar, A.P.: A variance inflation factor and backward elimination based robust regression model for forecasting monthly electricity demand using climatic variables. Appl. Energy **140**, 385–394 (2015). https://doi.org/10.1016/j.apenergy.2014.12.011

Wan, X., Evers, P.T., Dresner, M.E.: Too much of a good thing: The impact of product variety on operations and sales performance. J. Oper. Manag. **30**(4), 316–324 (2012). https://doi.org/10.1016/j.jom.2011.12.002

Wang, F., Li, H.: A practical non-parametric copula algorithm for system reliability with correlations. Appl. Math. Model. **74**, 641–657 (2019). https://doi.org/10.1016/j.apm.2019.05.011

Weele, A.: Purchasing and Supply Chain Management, 7th edn. Cenage Learning EMEA, Boston (2018). 978-1408018965

Witten, I., Eibe, F.: Data Mining: Practical machine learning tools and techniques. Morgan Kaufmann, San Francisco (2011)

Wong, D.T.W., Ngai, E.W.T.: Critical review of supply chain innovation research (1999–2016). Ind. Mark. Manage. (2019). https://doi.org/10.1016/j.indmarman.2019.01.017

Yoon, J., Moon, J.: The moderating effect of buyer purchasing strategy on the relationship between supplier transaction-specific investment and supplier firm performance. J. Bus. Res. **99**, 516–523 (2019). https://doi.org/10.1016/j.jbusres.2017.08.022

Yue, L., Li, G., Lian, H., Wan, X.: Regression adjustment for treatment effect with multicollinearity in high dimensions. Comput. Stat. Data Anal. **134**, 17–35 (2019). https://doi.org/10.1016/j.csda.2018.11.002

Zhang, C., Viswanathan, S., Henke, J.W.: The boundary spanning capabilities of purchasing agents in buyer–supplier trust development. J. Oper. Manag. **29**(4), 318–328 (2011). https://doi.org/10.1016/j.jom.2010.07.001