How machine learning changes Project Risk Management: a structured literature review and insights for organizational innovation

Received 24 November 2022
Revised 23 January 2023
Accepted 14 February 2023

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Abstract

Purpose – In the current economic scenario characterized by turbulence, innovation is a requisite for company's growth. The innovation activities are implemented through the realization of innovative project. This paper aims to prospect the promising opportunities coming from the application of Machine Learning (ML) algorithms to project risk management for organizational innovation, where a large amount of data supports the decision-making process within the companies and the organizations.

Design/methodology/approach – Moving from a structured literature review (SLR), a final sample of 42 papers has been analyzed through a descriptive, content and bibliographic analysis. Moreover, metrics for measuring the impact of the citation index approach and the CPY (Citations per year) have been defined. The descriptive and cluster analysis has been realized with VOSviewer, a tool for constructing and visualizing bibliometric networks and clusters.

Findings – Prospective future developments and forthcoming challenges of ML applications for managing risks in projects have been identified in the following research context: software development projects; construction industry projects; climate and environmental issues and Health and Safety projects. Insights about the impact of ML for improving organizational innovation through the project risks management are defined.

Research limitations/implications – The study have some limitations regarding the choice of keywords and as well the database chosen for selecting the final sample. Another limitation regards the number of the analyzed papers.

Originality/value – The analysis demonstrated how much the use of ML techniques for project risk management is still new and has many unexplored areas, given the increasing trend in annual scientific publications. This evidence represents an opportunities for supporting the organizational innovation in companies engaged into complex projects whose risk management become strategic.

Keywords Machine learning, Project risk management, Structured literature review SLR, VosViewer, Scopus database

Paper type Literature review

1. Introduction

In the recent years, literature focused the attention to innovation and innovation management by underlying direct relationship with the growth of the companies (Kerzner, 2022). But the identification of innovative ideas and its translation into business, as output of innovation

European Journal of Innovation Management
Vol. 27 No. 8, 2024
pp. 2597-2622

1460-1060
DOI 10.1108/EJIM-11-2022-0656

activity, requires the development of innovative projects and the relative project management activities (Kerzner, 2022). Thus, the role of innovation projects are fundamental for the survival of organizations in the actual turbulent scenario (Wang *et al.*, 2010; Bowers and Khorakian, 2014) characterized by complexity and uncertainty (Troise *et al.*, 2022) which requires the development dynamic capabilities to respond to the external challenges (Teece *et al.*, 2016). In this scenario companies developed a new flexible organizational structure (Pettigrew, 2003) characterized by a high number of projects considered more strategically important. Current literature on the field of innovation and project management fails in providing a complete information useful for companies to improve their innovation activities within a continuously changing context (Kerzner, 2022). Radical changes in digital technology, customer expectations and global competition increase the complexity of innovation management activities within organizations (Keizer *et al.*, 2005) and the relative innovations' risks (Berglund, 2007; Bowers and Khorakian, 2014). Innovation processes require the integration of project risk management (PRM) techniques to mitigate risks coming from the crisis characterizing the competitive context (Williams, 1995; Emblemsvåg and Kjølstad, 2006). Moving from the above premises, the aim of this paper is to investigate on the role of digital technologies, specifically of Machine Learning (ML) techniques, in supporting organizations in the PRM for innovation activities. Risks exist since the initiating of the projects; valorizing the emergence of the novel digital technologies could provide project manager an increased capacity to identify, assess and manage risks.

Machine Learning (ML), as the core technology of Artificial Intelligence (AI), is defined as the computer's ability to learn and recognize patterns from data with the aim of providing data-driven insights, decisions and predictions (Ge *et al.*, 2017; Aaldering and Song, 2021; Mahdi *et al.*, 2021) for making decisions without explicit human instructions (Kaplan and Haenlein, 2019). Nowadays, ML has become one of the most important areas of research in almost all fields in academia and industry (Holzmann *et al.*, 2022). Among many other sectors where mature applications of ML are flourishing, we are aware about the fact that ML is still in its infancy stage in the Project Management with a specific focus of PRM where a large amounts of data supports the decision-making process within the companies and the organizations (BDVA, 2019; Nambisan *et al.*, 2017; Nambisan *et al.*, 2019; Oztemel and Gursev, 2020; Aaldering and Song, 2021).

PRM includes the processes of conducting risk management planning, identification, analysis, response planning and controlling risk on a project (Kim *et al.*, 2020; Dandage *et al.*, 2018; Liu *et al.*, 2017). The objectives of PRM are to increase the probability and impact of positive events, and decrease the probability and impact of negative events (Afzal *et al.*, 2019). Risk exists at the moment a project is conceived, specially in innovation project. Risk is an uncertain event or condition that, if it occurs, has an effect on at least one project objective (scope, schedule, cost and quality) (PMI, 2008). In the era of the Fourth Industrial Revolution, companies are required to adopt new IT (Information technology) tools for risk management. In this context, ML could be one of the most promising solutions (Mc Kinsey Company, 2017).

According to the definition provided by Stanford University "Machine Learning is the science of getting computers to act without being explicitly programmed" and a subset of AI (Mahdi *et al.*, 2021). It involves computers learning from data provided so that they carry out certain tasks: some programs teach computers to change when exposed to new data and to grow (Mitchell, 1997). With the internet development, digital information became more easily available and widespread and today ML is widely used in many fields and organizations, especially in the process of managing projects through the effectively carry out data mining and analytics (Ge *et al.*, 2017; Wijayasekera *et al.*, 2022). The management of risks can support managers in the decision-making process and in the selection of innovative project to implement or to abandon, since risks are central to innovation and require a management practices (Bowers and Khorakian, 2014).

Although in literature there are several studies on ML and Risk Management in other field such as the transportation industry (Tang *et al.*, 2022), no structured literature review (SLR) exists (Hegde and Rokseth, 2020) with reference to this promising research field at the intersection between the novel applications of ML for PRM.

Findings of the SLR offer different contributions: first, an understanding on the utilization of ML algorithms to innovate an organization practices as PRM in innovative projects. Second, a SLR on the utilization of ML Approaches for project risk management strategies. Third, the identification of the main industries in which the applications of ML for PRM are more adopted.

The remaining part is structured as follow: section 1 describes the research streams and the novelty of the study, section 2 present the methodology followed, section 3 illustrates the main research findings of the content and cluster analysis. Conclusions, research agenda and implication are detailed in the final sections.

2. Literature background: machine learning for project risk management

Nowadays, innovation is one of the main drivers for the survival and the growth of organizations (Urbinati *et al.*, 2020; Cho and Pucik, 2005). The fourth industrial revolution identifies a new era in which industries, driven by the need to compete in global market, find in technological innovation the answer to remain efficient, to improve organization and quality of work, to reduce production costs (Nambisan *et al.*, 2017). The use of intelligent, interconnected and Internet-connected machines is growing and industries need to be ready to grasp and exploit new opportunities to remain competitive in a global market. The categories of digital technologies adopted by big corporations and Small and Medium Enterprises (SMEs), listed in the Industry 4.0 plan (also renamed Enterprise 4.0 to include the service industry) are also changing the way organizations manage project complex projects and requires constant and increasingly complex changes (PMI, 2018). Companies developed a new flexible organizational structure (Pettigrew, 2003) characterized by a high number of projects considered. According to the PMI (Project Management Institute) "a project is a temporary effort for creating a product, service, or result and a risk is defined as an uncertain event or condition whose occurrence impacts at least one of the project objectives, in terms of scope, schedule, cost and quality" (PMI, 2018). The concept of project management increased rapidly and nowadays operational processes are managed as projects (Dalcher, 2016; Hodgson and Cicmil, 2016; Walker and Lloyd-Walker, 2019). Specifically, the management of risk is considered one of the key process in the project management (Raz and Michael, 2001; Hartono *et al.*, 2014; Badi and Pryke, 2016; Dandage *et al.*, 2018).

The global context and project complexity increased the importance of PRM that became a greater issue also for evaluate the project performance (Liu *et al.*, 2017; Muriana and Vizzini, 2017; Lefley, 2018; Afzal *et al.*, 2019; Natarajan, 2022). In this context, digital technologies help the project management function to plan, execute and control complex project (Wijayasekera *et al.*, 2022; Holzmann *et al.*, 2022) during the execution of innovation activities within the digitalization era.

The PRM includes a set of activities for risk identification of risk, risk analysis, risk response planning, risk monitoring and control, and lessons learned (Fang *et al.*, 2013; Williams, 2017; Mahdi *et al.*, 2021). The final aim of PRM is to identify actions for reducing threats to the realization of the project at minimum cost and risks and threats are identified by using different approaches and methods combining experiences, expertise and information search, heuristics or analysis (Kim *et al.*, 2020; Afzal *et al.*, 2019). All projects have risks (Lefley, 2018) and their identification is "the most important step in PRM (Ozcan *et al.*, 2011; Hynek *et al.*, 2014; Baryannis *et al.*, 2019).

Digital advanced technologies represent an important tools that companies and organizations can adopt for risk management and to forecast project costs and performance (Kim *et al.*, 2020; Williams, 2017; Afzal *et al.*, 2019; Natarajan, 2022). In this context, ML is one of the most promising solutions to identify risks promptly, and to ensure its success (Arnuphaptrairong, 2011; Mahdi *et al.*, 2021). ML is considered as at the intersection of computer science, engineering and statistics that could be applied in different context and problems, especially those based on interpretation of data and offers the opportunity to reduce cost, improve productivity and the management of risk. ML technologies allow to define a more accurate risk models within a large datasets with a powerful predictive tools that can grow with the increasing of available information, thus enhancing predictive power over time (Awad and Khanna, 2015; Leo *et al.*, 2019).

Although the definition of project success and failure has been defined in literature, there are long disagreements about how to assess project progress and a review of ML applications for engineering risk assessment does not exist (Hegde and Rokseth, 2020).

Specifically, to the best of the authors' knowledge, no SLR exists with reference to the intersection between ML for PRM. In order to cover the previous research gap, this paper aims to investigate on existing literature about ML and PRM.

3. Methodology section

The paper performs a SLR on the application of ML for PRM in different context. A SLR is the most appropriate methodology for categorization, summarize and appraisal the current research of a given topic (Christofi *et al.*, 2017; Tranfield *et al.*, 2003). As described by Massaro *et al.* (2016) the analysis includes the following steps (Christoffersen, 2013; Thorpe *et al.*, 2005):

(1) Define the research questions;

(2) Write a research protocol for the review;

(3) Determine the articles to include and carry out a comprehensive literature search;

(4) Develop a coding framework and

(5) Critically analyze and discuss the results.

The research questions defined in this paper are as follows:

RQ1. How is the ML field for PRM developing?

RQ2. What is the focus of the literature within ML for PRM?

RQ3. In which industry the applications of ML for PRM could be more adopted?

Afterwards, the research protocol was established to determine source of data, methods, papers to analyze, means and tools for synthesizing (Petticrew and Roberts, 2008). ML and project risk assessment are two fields of study with different context application.

In order to extract the sample, Scopus database was used. Scopus is a more complete database than Web-of-Science (WoS) (Thelwall, 2018) and includes most of the papers (97%) indexed in Web of Science (WoS) (Dumay and Cai, 2014).

In the first instance, the search string used for searching articles useful for inclusion in this analysis was identified by querying a set of relevant keywords. It has been selected the results coming from the search string "Machine Learning" AND "Project" AND "Risk Management" that include 85 documents (44 conference papers, 40 articles, 1 book).

The steps followed in order to select paper of the sample are described in Figure 1.

Specifically, after reading the abstracts of the 85 papers, 43 papers were excluded in which ML are not directly applied to Project and Risk Management. Thus the sample analyzed was

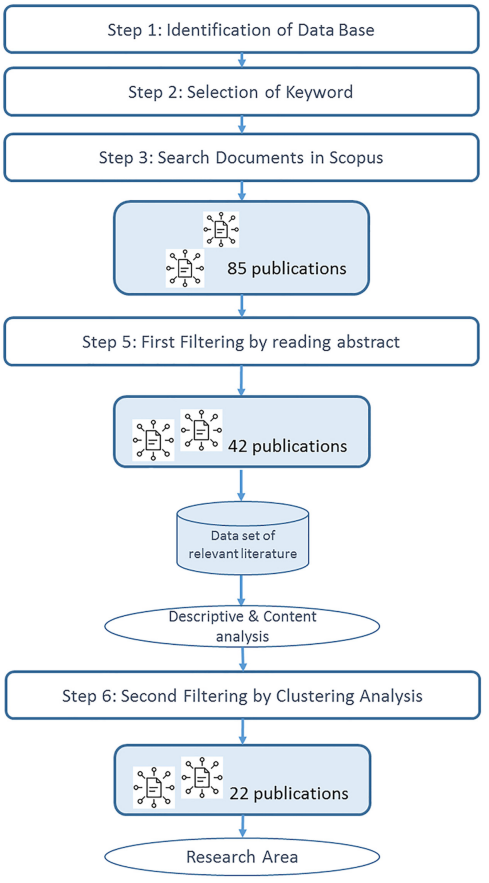

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Figure 1.
Steps for data collection and analysis

composed by articles that consider simultaneously ML and PRM. Therefore, 43 articles have been excluded, 42 documents have been maintained in the study for further analysis (Figure 1).

The fourth step consisted of developing the coding framework based on similar research frameworks. The aim of this coding framework was to analyze the state of the art of the literature, its evolution in time and its impact. Five categories for coding the articles were defined:

(1) Time evolution: number of articles published over time.

(2) Geography of articles: article distribution among countries.

(3) Journals: the distribution of papers among journals and citations received.

(4) Author and citations analysis: number of citations, citations per year (CPY), citations and collaborations among authors.

(5) Common keywords and focus topics: the type and frequency of keywords used and the emergent topic areas.

Metrics for measuring the impact the citation index approach and the CPY were used (Dumay and Cai, 2014). As for the keywords analysis, we used the author keywords occurrences to identify those most relevant and used. Most frequent keyword used in the publication were extracted though a co-occurrence analysis (Van Eck and Waltman, 2014) that allowed to evaluate the relatedness of the articles on the basis of common authors' keywords. VOSviewer, a tool for constructing and visualizing bibliometric networks and clusters (Van Eck and Waltman, 2014), was used to perform two kind of analysis: a descriptive analysis, a cluster analysis and a final content analysis.

4. Research findings

4.1 Descriptive analysis

4.1.1 Articles evolution in time. The trend of the research papers over the years is depicted in Figure 2. As noted, ML applications in project risks studies are very recent and are mainly concentrated in the last 3 years. No research has been conducted on this topic from 1991 to 2006. From 2007 to 2010 the trend varies slightly between 0 and 2 and can be considered quite stable. In the years that follow (2011–2014), the research on the issue has stopped again and then resumed with a stable trend from 2015 to 2017. The peak year for relevant publications in these journals was 2020 followed by 2018. This means that the relationship between ML and risk management reached the maximum only in the last 5 years.

4.1.2 Geography of articles. The result of the analysis in terms of geographical distribution of the documents and a comparison between the numbers of citations with the number of documents for each country is shown in Figure 3. Country, in terms of number of documents and citations, is identified on the basis of authorship for each publication. In the case of authors of different countries, the article is counted once for each different nationality. Countries with the highest number of articles are United States and United Kingdom, with 6 and 5 papers, respectively. These two countries are followed by Switzerland and India, with 4 papers. India is one of the 10 Big Emerging Markets (BEM) economies and its interest shows a widespread sensitivity toward this field across the global territory. Italy, Germany, Canada, Malaysia and Pakistan have a number of articles equal to 3. It is possible to note a relevant interest for the topics also in the European area with publications realized by a scientific community of scholars. Although the numbers of papers in some countries are low, the bar

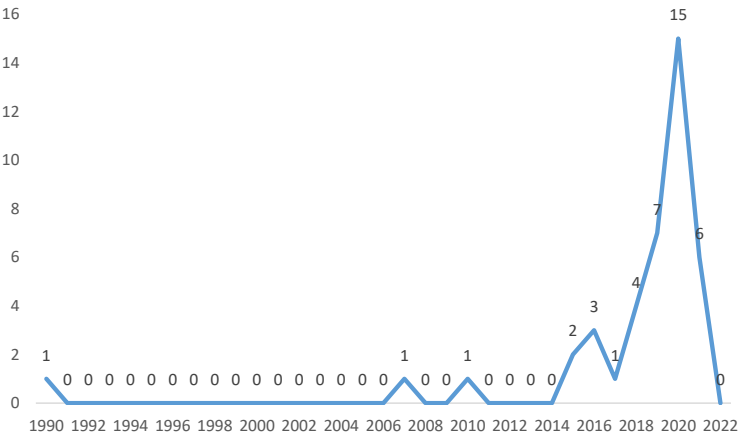

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Figure 2.
Distribution of documents over the timeframe 1990–2020

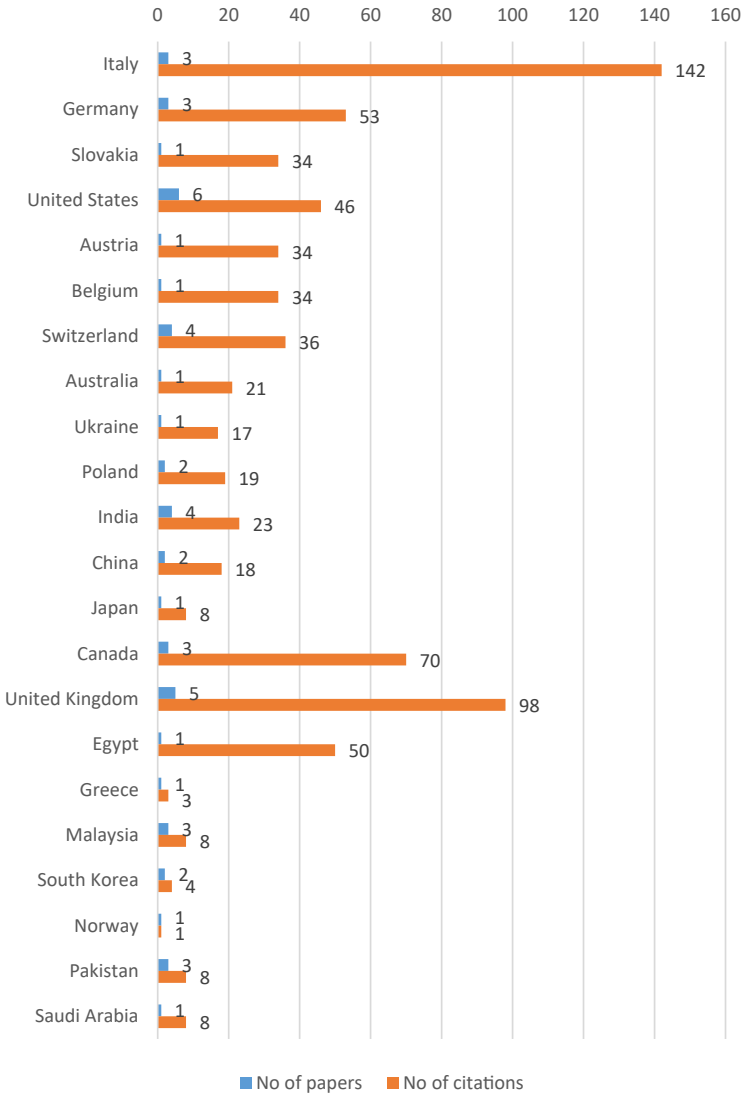

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Figure 3.
Number of papers and citations per country

chart also allows deriving nucleus of interest at global level, with the inclusion of emerging countries such as Egypt, Pakistan and Saudi Arabia. Additionally, in term of number of citations, the highest country is Italy, with 142 citations for the 3 published papers, followed by United Kingdom (98) and Canada (70), Interesting the case of Egypt that the only published paper obtained 50 citations.

4.1.3 Journals distribution. Figure 4 provides the analysis of the journals distribution and map, with the list with the relative number of records and citations. All the journals published one only article on the topic of ML and PRM.

Journal	No of papers
Sensors (switzerland)	1
Sustainability science	1
Journal of construction engineering and management	1
International journal of electrical and computer engineering	1
Soft computing	1
IEEE Access Journal	1
International journal of construction management	1
Journal of computational and theoretical nanoscience	1
Advances in Intelligent Systems and Computing	1
Developments in Marketing Science: Proceedings of the Academy of Marketing Science	1
International Journal of Economics and Business Research	1
Journal of Building Engineering	1
Jounal of Computer science	1
Risk Analysis	1
Applied Data Mining for Business and Industry	1
Scientific programming	1

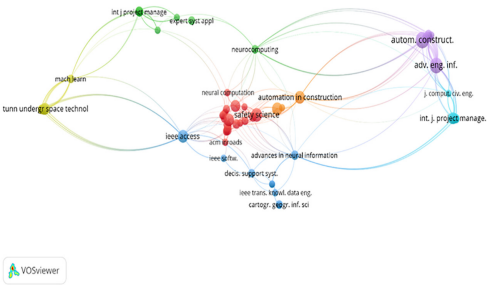


Figure 4.
Analysis of sources

Source(s): Author's own creation or elaboration

The analysis performed here demonstrates that there is the lack of structured and mature research on the field and the highly fragmentation in the journal publications. Moreover the analysis evidenced also that the most recent publications are published in conference proceedings.

Figure 4 is also represented the co-citation map on co-cited sources: the size of the spheres represent citations attribute that indicates the number of citations made to a cited source. The minimum number of citations of a source selected has been 3. Of the 1,021 sources, 70 met the threshold. The distance between two journals in the visualization approximately indicates the relatedness of the journals in terms of co-citation links.

4.1.4 Citations analysis. Figure 5 depicts the relevance of the research developed by considering the number of the citations compared to the number of papers. It is possible to note a certain parallelism with the trend in the number of papers published in the same year.

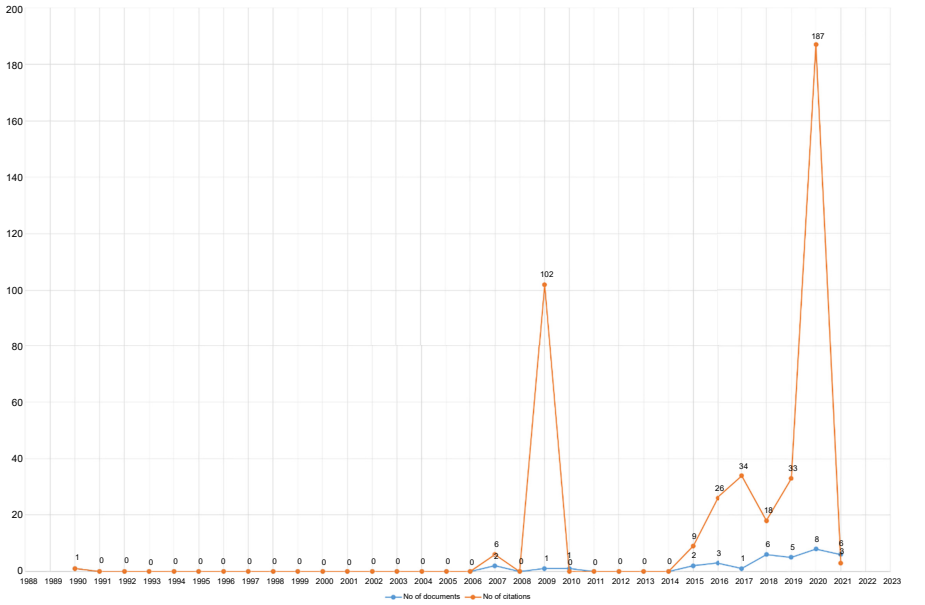


Figure 5.
Trend of documents and paper's citations for year

Source(s): Author's own creation or elaboration

In particular, the maximum value of citations is in 2020 with 187 citations for the 8 published papers, followed by 2009 with 102 citations for the only paper published, and 2017 with 34 citations for the only paper. Interesting also the number of citations for the year 2019 that are equal to 33, but for 6 papers. It is possible to understand how the scientific community has become interested in ML and PRM issues referred to seminal works of 2009, 2016 and 2017 for further studies from 2018 to 2020. The trends characterizing the number of citations received by each paper, as described in Table 1, demonstrate the relevance of the only papers published in the first period and specifically in 2009 (see Table 2).

Regarding the most cited papers, Table 3 discerns the rate of total citations and the relative CPY for the first ten most cited papers.

4.1.5 Topics and common keywords. This section analyses the main keywords covered by the 42 articles of the sample. Figure 6 presents the occurrences of different author keywords that appear simultaneously at least two five times, as well as the interrelationship and networking among them. On 490 total author keywords, 14 met the threshold.

This analysis reveals that risk management is the most recurrent keyword (31 times) followed by ML (27 times). Learning systems (16 times) and risk assessment (15 times) are also interesting. The other keywords present a number of occurrences from 5 to 10.

4.2 Clustering and content analysis

4.2.1 Clustering analysis. A content analysis was conducted starting from the 42 papers included within the sample. As explained in the methodological section, bibliometric coupling analysis was performed, with documents as the units of analysis, and the pertinence is evaluated by considering the articles that mainly share at minimum two references (Boyack and Klavans, 2010). The result of the analysis did not produce the expected results because the papers do not share common references.

The next step was to proceed with a content analysis to identify clusters and research areas. This analysis leads to identify clusters of documents with common characteristics and research areas; specifically the results produced 4 clusters and 24 papers out of the 42 analyzed.

The clusters considered bring together those articles that mark the specific topic of ML for risk management in specific fields of application. The four research areas identified are listed in Table 3.

4.2.2 Research Area 1: machine learning applications for project risk management in software development projects. This research area concerns studies conducted for the application of ML to improve risk management in software development projects and it represents the most prolific areas. According to Suresh and Dillibabu (2020), risk management is a vital factor for ensuring better quality software development processes; risks are events that could adversely affect the organization activities or the development of projects. This is confirmed by Batar *et al.* (2021) that state the necessity to develop and efficient software risk assessment and management on time before causing problems and troubles into software projects. Authors made an experimentation with ANFIS (Adaptive Neuro-Fuzzy Inference System)—for generating new original software risk rules. Chaudhary *et al.* (2016) defined project risks in software projects as future harms that happening on the software due to some non-noticeable mistakes. Scholars share the idea that one of the techniques to ensure an effective software development practices is to ensure higher degree of risk control measures that calls for an effective risk management. For this type of application, most scholars and researchers focused their efforts in the last twenty years. Contributions have been identified in terms of definition of "new Machine Learning mechanisms for performing risk assessment in software projects" (Suresh and Dillibabu, 2020) and "rule based machine learning approach for mining of associations between risks and mitigations"

Table 1.
Citations trend

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
No. of documents	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
No. of citations	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	TOT
No. of documents	2	0	1	1	0	0	0	0	2	3	1	6	5	8	6	0	36
No. of citations	6	0	102	0	0	0	0	0	9	26	34	18	33	187	3	0	419

Note(s): Timeframe 1990–2020
Source(s): Author's own creation or elaboration

Ranking cit	Authors	Title	Year	Source title	No. of citations	CPY	Ranking CPY
1	Giudici P., Figini S.	Applied Data Mining for Business and Industry	2009	Applied Data Mining for Business and Industry	102	4.25	5
2	Akinosho T.D., Oyedele L.O., Bilal M., Ajayi A.O., Delgado M.D., Akinade O.O., Ahmed A.A.	Deep learning in the construction industry: A review of present status and future innovations	2020	Journal of Building Engineering	55	18.33	1
3	Gondia A., Siam A., El-Dakhakhni W., Nassar A.H.	Machine Learning Algorithms for Construction Projects Delay Risk Prediction	2020	Journal of Construction Engineering and Management	50	16.67	2
4	Havas C., Resch B., Francalanci C., Pernici B., Scalia G., Fernandez-Marquez J.L., Van Achte T., Zeug G., Mondardini M.R.R., Grandoni D., Kirsch B., Kalas M., Lorini V., Rüping S.	E2mC: Improving emergency management service practice through social media and crowdsourcing analysis in near real time	2017	Sensors	34	5.67	4
5	Saravi S., Kalawsky R., Joannou D., Casado M.R., Fu G., Meng F.	Use of artificial intelligence to improve resilience and preparedness against adverse flood events	2019	Water (Switzerland)	26	6.50	3
6	Choetkiertikul M., Dam H.K., Tran T., Ghose A	Predicting delays in software projects using networked classification	2015	Proceedings – 2015 30th IEEE/ACM International Conference on Automated Software Engineering, ASE 2015	21	3.00	8
7	Liang W., Sari A., Zhao G., McKinnon S.D., Wu H.	Short-term rockburst risk prediction using ensemble learning methods	2020	Natural Hazards	17	5.67	4

(*continued*)

Table 2.
Top ten documents per citation and citation per year (CPY)

Ranking cit	Authors	Title	Year	Source title	No. of citations	CPY	Ranking CPY
8	Lytvyn V., Kowalska-Styczen A., Peleshko D., Rak T., Voloshyn V., Noennig J.R., Vysotska V., Nykolyshyn L., Pryshchepa H.	Aviation aircraft planning system project development	2019	Advances in Intelligent Systems and Computing	17	5.67	4
9	Ajayi A., Oyedele L., Owolabi H., Akinade O., Bilal M., Davila Delgado J.M., Akanbi L.	Deep Learning Models for Health and Safety Risk Prediction in Power Infrastructure Projects	2020	Risk Analysis	12	4.00	6
10	Suresh K., Dillibabu R.	A novel fuzzy mechanism for risk assessment in software projects	2020	Soft Computing	10	3.33	7

Table 2. **Source(s):** Author's own creation or elaboration

(Asif and Ahmed, 2020). Some of the most relevant contributions included into the first perspective are: Gouthaman and Sankaranarayanan (2018) that propose an agile fog-cloud software model which include ML techniques to provide a solution for integrating the hardware devices, operating system and risk parameters with the cloud through possible medium such as wireless fidelity, wired and mobile Internet. The major components of this tool are ML risk assessment engine, rule configuration tool, factor analysis of risk parameters and process maturity. The identified risks are analyzed and made available for ML techniques to reduce the human intervention. In addition, Firdose and Rao (2018) introduced a model called as PROM, i.e. Predictive Optimization of Risk Management designed and equipped with better risk factor assessment with an aid of ML approach. This architecture is an extension of the previous design approach, developed by the authors themselves, called 3LRM. It takes four different forms of input: development expenditures per software projects, total number of allocated software projects per employee, allocated development duration for each project on an employees and uncertainty factor. Another important contribution is given by Joseph (2015) who proposed a ML algorithm to generate risk prompts, for scanning the lists for risks and pinning down relevant risks. This ML algorithm is based risk prompting system that outputs the most relevant risk prompts based on specification, scenario and taxonomy tags for the software development project. To build the algorithm, the authors starts from a list of risk prompts obtained by compiling unique risk prompts from several lists: 433 risk prompts were compiled to make a highly granular list under 16 taxonomies. The algorithm is implemented using multi-label artificial neural networks (ANNs) that solve several multi-label classification problems.

A second perspective characterizes the research area in terms of "Rule based Machine Learning approach for mining of associations between risks and mitigations" (Asif and Ahmed, 2020). In such an area, the authors present a novel model, which identifies the

Table 3. Machine learning and project risk management: focus, details and variables analyzed

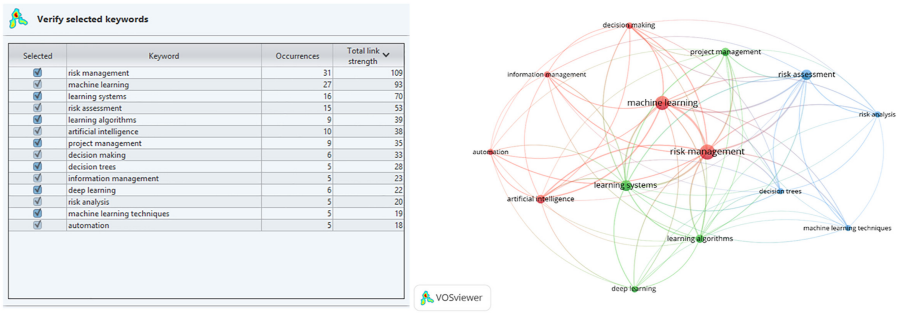
Research area	Authors	Title
Machine Learning applications for software development projects	Suresh K., Dillibabu R. (2020)	*A novel fuzzy mechanism for risk assessment in software projects*
	Asif M., Ahmed J. (2020)	*A Novel Case Base Reasoning and Frequent Pattern Based Decision Support System for Mitigating Software Risk Factors*
	Gouthaman P., Sankaranarayanan S. (2018)	*Agile software risk management architecture for IoT-fog based systems*
	Sousa A., Faria J.P., Mendes-Moreira J. (2021)	An analysis of the state of the art of machine learning for risk assessment in software projects
	Batar M., Birant K.U., Işik A.H. (2021)	Development of Rule-Based Software Risk Assessment and Management Method with Fuzzy Inference System
	Iftikhar A., Musa S., Alam M., Su'ud M.M. (2020)	*Artificial intelligence based risk management in global software development: A proposed architecture to reduce risk by using time, budget and resources constraints*
	Choetkiertikul M., Dam H.K., Tran T., Ghose A. (2016)	*Predicting delays in software projects using networked classification*
	Firdose S., Rao L.M. (2018)	*PORM: Predictive optimization of risk management to control uncertainty problems in software engineering*
	Chaudhary P., Singh D., Sharma A. (2016)	*Classification of software project risk factors using machine learning approach*
	Joseph H.R. (2015)	*Poster: Software Development Risk Management: Using Machine Learning for Generating Risk Prompts*
	Barta G., Görcsi G. (2021)	Risk management considerations for artificial intelligence business applications
	Qu Y., Yang T.-Z. (2016)	Research on occurrence frequency of IT projects risk based on fuzzy influence diagram
Machine Learning applications in construction industry	Gondia A., Siam A., El-Dakhakhni W., Nassar A.H. (2020)	*Machine Learning Algorithms for Construction Projects Delay Risk Prediction*
	Sanni-Anibire M.O., Zin R.M., Olatunji S.O. (2020)	*Machine learning model for delay risk assessment in tall building projects*
	Kifokeris D., Xenidis Y. (2019)	*The Riscona system: Constructability appraisal through the identification and assessment of technical project risks sources*
	Stone J.R., Blockley D.I., Pilsworth B.W. (1990)	*Managing risk in civil engineering by machine learning from failures*
	Akinosho T.D., Oyedele L.O., Bilal M., Ajayi A.O., Delgado M.D., Akinade O.O., Ahmed A.A. (2020)	*Deep learning in the construction industry: A review of present status and future innovations*

(*continued*)

Table 3.

Research area	Authors	Title
Machine Learning applications for project risk management in climate and environmental issues	Ghahari A., Newlands N.K., Lyubchich V., Gel Y.R. (2019)	*Deep Learning at the Interface of Agricultural Insurance Risk and Spatio-Temporal Uncertainty in Weather Extremes*
	Mori S., Washida T., Kurosawa A., Masui T. (2018)	*Assessment of mitigation strategies as tools for risk management under future uncertainties: A multi-model approach*
	Havas C., Resch B., Francalanci C. *et al.* (2017)	*E2mC: Improving emergency management service practice through social media and crowdsourcing analysis in near real time*
	Saravi S., Kalawsky R., Joannou D., Casado M.R., Fu G., Meng F. (2019)	Use of artificial intelligence to improve resilience and preparedness against adverse flood events
	Garg R., Brockett P., Golden L.L., Zhang Y. (2019)	Rapid Assessment of Customer Marketplace in Disaster Settings through Machine Learning, Geospatial Information, and Social Media Text Mining: An Abstract
	Phoon K.-K. (2020)	*The story of statistics in geotechnical engineering*
Machine Learning application for Health and Safety	Ajayi A., Oyedele L., Owolabi H., Akinade O., Bilal M., Davila Delgado J.M., Akanbi L. (2020)	Deep Learning Models for Health and Safety Risk Prediction in Power Infrastructure Projects
	Björk K.-M., Miche Y., Eirola E., Lendasse A. (2016)	A new application of machine learning in health care

Source(s): Author's own creation or elaboration



Source(s): Author's own creation or elaboration

Figure 6.
Keywords occurrences and map

relationship between risk factors and mitigations automatically by using intelligent Decision Support System (DSS). Rule-based ML approach has been used for mining of associations between risks and mitigations, after the design of the input of the system where risk factors and mitigations have been inputted. Iftikhar *et al.* (2020) investigate the application of AI techniques to manage risk in the global software development project to assessing unstructured information. Authors propose an AI-based architecture useful to reduce risk of Time, Budget and Resource constraints that will help decision maker. The paper of Sousa *et al.* (2021) provides a literature review on the various concepts related to risk and risk management in software projects, in order to systematize the techniques useful to provide better estimates and classification of the risk levels and risk factors with the final aim to develop strategies to prevent or limit the impact of the identified risks. Finally Qu *et al.* (2016) in their work describes the relationship of different factors in risk management process of IT project trough fuzzy influence diagram. In the model they analyses all factors that affect the project use.

4.2.3 Research Area 2: machine learning applications for project risk management in construction industry. ML applications for risk management in construction industry is one of the "oldest" industry along with medicine, where the tool was studied. The first paper included in this area was published in 1990. Stone *et al.* (1990) developed one of the first ML logics using discrimination and connectivity algorithms to determine patterns of failure events. The authors emphasized the new opportunities that ML could bring for the development of management tools and defined discrimination and connectivity algorithms. The other documents of this area are very recent. Sanni-Anibire *et al.* (2020) developed a ML model for assessing the risk of delay in tall building projects. They are aware that the prediction of project delays based on internal and external sources can help project managers to provide an accurate forecast of the project schedule, and this can assist a proactive management approach in the construction project. Starting from 36 delay risk factors derived from previous literature and 48 useable responses obtained from subject matter experts, the scholars develop a dataset suitable for ML application. Gondia *et al.* (2020) deal with ML for construction projects delay risk prediction. They identify and train two suitable ML models, utilizing decision tree and naïve Bayesian classification algorithms, using the data set for predicting project delay extents. They provide also an evaluation of both models through cross validation tests, comparing them with the use of machine-learning-relevant performance indices. Akinosho *et al.* (2020) made a literature review literature to identify cases that applied deep learning to prevalent construction challenges like structural health monitoring, construction site safety, building occupancy

modeling and energy demand prediction. After that authors defined some applications of deep learning for innovating construction sectors, such as for better building designs using generative design, cash flow prediction, integration of chatbots and BIM, retrofitting adviser for energy saving, on-site safety and health monitoring, project risk mitigation and analysis.

4.2.4 Research Area 3: machine learning applications for project risk management in climate and environmental issues. The third research area regards the application of ML for risk management in climate and environmental issues. Regarding climate changes, an evaluation of climate risk management options is provided by Mori *et al.* (2018) that employ the multi-model approach: it represents the basis of more sophisticated methods such as data mining or ML that could be applicable to the simulation database to extract the implicit information behind the models. Nowadays, risk management in geotechnical engineering aims to exploit data after a project is completed, the so-called dark data. Phoon (2020) throws down a challenge for the new generation of researchers: to uncover new value by hearing data by using probabilistic, ML or other data-driven methods including those informed by physics and human experience. As regards emergency management, the research project Evolution of Emergency Copernicus services (E2mC) (Havas *et al.*, 2017) aims to integrate user-generated data like social media posts or crowdsourced data into a new EMS (Emergency Management Service) component called Witness. The aim is to exploit information about the area of interest in the first hours of a disaster in order to perform a more effective disaster management. Finally, in this area a deep learning methodology is presented for the assessment of climate-induced risks in agriculture field. Ghahari *et al.* (2019) evaluate the potential of this methodology to deliver a higher predictive accuracy, speed and scalability. Saravi *et al.* (2019) focus on the use of AI in flooding. Using different method of ML approaches on big data, authors demonstrate the application of these techniques to improve resilience, prevent damage and save lives. The paper analyzed historical data (23 years) collected from flood events in order to make a classification of the type of the flood that is likely to happen in future. Furthermore, Garg *et al.* (2019) utilized a predictive modeling and geospatial interpolation along with ML to demonstrate its utility in the risk management during disaster. Predictive and probabilistic modeling starts with historical data and with GIS located text mining messages could support the reduction of risks and improve damage estimates.

4.2.5 Research Area 4: machine learning application for project risk management in health and safety. This area is the most recent ones and it is just two papers. The paper of Ajayi *et al.* (2020) through a text-mining approach in order to retrieve meaningful terms from data and develop six deep learning (DL) models health and safety in power infrastructure useful to better understand the challenges associate to health and safety risks and to minimize project costs by defining a strategy to minimize risks. Authors underline the importance of developing a tool for risks identification that could support the Health and Safety management. Finally, Björk *et al.* (2016) focus on the missing data problems in the field of medicine in order to define new solutions and to improve performance, accuracy and efficiency in healthcare, with a case on Huntington's disease (HD) diagnosis. Authors developed statistical and ML techniques for the analysis, visualization and prediction of disease proposed research trajectories.

5. Discussions, implications and future research agenda

In the conclusions of this analysis, it is important to remark the initial objective: conduct a research study on the state of the art of ML applied to PRM of innovative project and to identify the evolution of this novel and promising research area. Specifically, the analysis addressed the following research questions:

RQ1. How is the ML field for PRM developing?

RQ2. What is the focus of the literature within ML for PRM?

RQ3. In which industry the applications of ML for PRM could be more adopted?

Content analysis developed has allowed identifying four main thematic clusters as main research areas of the scientific debate on the application of ML for decrease the potential negative risks that may occur when companies activate innovation processes through complex projects where the identification, mitigation and management of risks is strategic for the project's success. The implications of the above research questions could be summarized into the following sub-sections.

5.1 Implication 1: timing and authorship' specialization on the topics

The SLR performed highlighted the novelty of the debate related to the application of ML for PRM. The timing of publication is concentrated in the last 3 years, with scant research in the previous years. A first paper was published in 1990, by Stone, Blockley and Pilsworth B.W (Stone *et al.*, 1990), but only from 2014 the themes started to be considered by researchers. This demonstrated moreover the opportunity to study more in depth the role of ML techniques for PRM to take the most of the promising digital technologies in terms of automation of some project processes. Different authors contribute to this debate, in different scientific domains, but the main fields identified regarding engineering and environmental science. In terms of citations, the analysis identified three main publications, such as Giudici and Figini (2009), Akinosho *et al.* (2020) and Gondia *et al.* (2020) and one of the papers with highest CPY corresponds to earlier years. All these evidences underlined the need to a more focused research, especially in different context of applications toward integrated and cross-disciplinary frameworks that support organizations in the PRM process when innovating.

5.2 Implication 2: journals' specializations

The descriptive analysis on the journals' specialization evidenced that the field is fragmented for what concern the choice of the venue of publication: all journals published almost one paper in the field of ML for PRM, this demonstrates the lack of structured research in this field. The analysis of citations reveals that papers published on *Applied Data Mining for Business and Industry* obtain a number of citations equal to 102, followed by *Journal of Building Engineering* with 55 citations and *Journal of Construction Engineering and Management* with 50 citations.

5.3 Implication 3: machine learning for project risk management: a critical analysis of the thematic areas

Despite the novelty of the study, the state of the art in literature allowed to identify four research area according to the adoption of ML approaches for PRM supporting organizational innovation, that are: (1) *Machine Learning applications for project risk management in software development projects*; (2) *Machine Learning applications for project risk management in construction industry*; (3) *Machine Learning applications for project risk management in climate and environmental issues;* (4) *Machine learning application for project risk management in Health and Safety*.

The analysis revealed the novelty of the research stream related to the application of ML techniques for the strategic area of project management that has received a growing attention from researcher in the last three. The two areas of ML and PRM have a great attention in the communities of engineering and environmental but their intersection

discloses several areas of deepening. This is also confirmed by the bibliographic coupling analysis performed by VOSviewer that evidenced the non-existence of common references.

The papers included in first research area – *Machine Learning applications for project risk management in software development projects* – cover a brief period that starts in 2015, with the work of Joseph, until 2021. This first thematic area can be assumed as one of the most interesting for the community of scholars in the field of ML and PRM. The papers of the second research area – *Machine Learning applications for project risk management in construction industry* – are very recent, with the exception of the oldest of Stone *et al.* (1990) and are focused on the opportunities generated from the ML techniques for the management of particular risks in constructions industry. Regarding the time distribution of the papers included in the third area – *Machine Learning applications for project risk management in climate and environmental issues* – it is possible to note that also this area belongs to the last three years, from 2017 to 2020. This reveals that the topic is still new and has many unexplored areas. The papers included in the fourth research area – *Machine learning application for Health and Safety* are published in 2016 and 2020 and the exiguous number of paper (just two) demonstrates that this is the most promising field where a lot of applications could be explored also due in consideration of the COVID-19 pandemic management.

Since the debate on ML and PRM has received growing attention during the last three years, it is a "front burner" on which research and companies must necessarily invest to remain competitive in a highly globalized world.

In coherence with the evidences it is possible to conclude that the intersection of ML with the PRM for innovative projects has been till now observed mainly from an engineering and environmental science and it requires a future and deeper investigations also in other applications contexts such as health care, government, in order to evaluate how ML could support the process of decision making to reduce risks, or life science, education and so on. A future research agenda is described in Table 4 according to the four thematic areas with the aim to identify areas unexplored areas and to derive roots for the future agenda of research, practitioners and policy makers.

6. Concluding remarks and limitations

The analysis demonstrated how much the use of ML techniques for PRM is still new and has many unexplored areas, given the increasing trend in annual publication. The debate on ML and risk management for projects supporting the innovation process within companies and organizations has received growing attention during the last three years corresponding to the explosion of the digital technologies adoption for improving in general the business process and project management areas. Therefore, it is a "front burner" on which research and companies must necessarily invest to remain competitive in a highly globalized world (Wijayasekera *et al.*, 2022; Holzmann *et al.*, 2022).

The contribution of the study refers to the deep analysis about the state of the art in the field of PRM using the methodology and algorithm of ML, with the identification of the main industrial sectors of application. This is a novel aspect in the light of the digital transformation phenomenon and innovation management. Actually the ML approaches are used in the tree phases of risk management, specifically for risk identification, risk analysis and risk evaluation (Hegde and Rokseth, 2020). ML approaches and tools give the opportunities to perform better predictive analysis than traditional statistical techniques (Leo *et al.*, 2019) when managing complex projects to accomplish the innovation process at organizational level.

The results of the study offer also some implication for theory and practice.

Implication for theory refers to the identification of a novel and promising research field characterized by the adoption of the exponential use of machine learning for PRM in order to address the research questions posed. The study underlines the adoption of ML techniques for project management to reduce risks and evidences the main sectors involved in this practice.

	Main research questions
Machine Learning applications for project risk management in software development projects	○ What are the Machine Learning approaches that can be applied in the risk factor assessment in software projects? ○ How Machine Learning mechanisms are useful to performing risk assessment in software project? ○ What are the methods that could help the management of software project risk with Machine Learning algorithms? ○ Is it possible to build better machine learning-based algorithm to increase accuracy prediction and ensure a better quality software development processes? ○ How Machine Learning can reduce software mistakes and ensure an effective software development practices? ○ In which way Machine Learning techniques could support the human decision making in software development projects? ○ How Machine Learning algorithms can be used to predict the software duration? ○ Which is the relationship between risk factors and mitigations in Machine Learning approaches?
Machine Learning applications for project risk management in construction industry	○ How ML approaches can support the management of risk in construction industry projects? ○ How ML algorithms are used to solve risk assessment-based problems in construction? ○ What is the most appropriate ML approaches to manage risk for cost overrun? ○ What are the ML algorithm useful for assessing the risk of delay in tall building projects? ○ Which ML techniques are more adapt to predict safety outcomes in construction sector? ○ How ML can support the management of risk for predicting construction project delay extents? ○ How ML techniques are able to assess risks assessment in the sustainable ground improvement? ○ Can ML approaches support risk prioritization in mega construction projects? ○ Can ML contribute in the construction sectors risk reduction? ○ What are the most suitable ML approaches to be adopted to predict environmental risk in construction industry? ○ How ML support risk analysis of urban infrastructure systems? ○ How ML techniques can automatically assess the energy consumption of buildings in cities?

(*continued*)

Table 4.
Future research agenda in the areas of machine learning and project risk management

	Main research questions
Machine Learning applications for project risk management in climate and environmental issues	○ Can ML approaches support the reduction of environmental impact of construction industry? ○ How ML approaches are useful as risk management of possible climate changes of the future? ○ What are the main environmental risks that could be manage through a ML approach? ○ What is the main ML contribute in the assessment of climate-induced risks? ○ How ML approaches support the management of climate and environmental risks? ○ How machine learning can be used to reduce gas emissions and helping society adapt to changing climate? ○ What ML techniques represent a suitable tools for improving projects related to disaster management?
Machine Learning application for project risk management Health and Safety	○ Can ML approaches support the reduction of health risks? ○ How ML approaches are useful in predicting and managing risks of projects involving health and safety of workers? ○ What are the main health and safety risks that could be managed through a ML approach? ○ What is the main ML contribute in the management of health and safety risks?

Table 4. **Source(s):** Author's own creation or elaboration

Implications for practice refer to the importance of development of digital PRM techniques. ML, as digital technologies, is nowadays a key asset for organizations and companies that want to embark on innovation activities through projects. The importance of the application of ML for managing project risks, requires novel professional profiles and human capital with the capabilities to apply this approaches and tools to reduce the failure of the project and to increase its performance (Natarajan, 2022). On the other side, Universities as generators of novel digital capabilities need to integrate their educational offers by developing programs to give knowledge, skills, attitudes and experience to increase the performance of any project's tasks as described by Project Management Institute (PMI, 2018) in its "2018 lobs report" (Rockwood, 2018). In the era of digital transformation this could be done through the adoption of novel ML techniques.

Implication for practice also refers to benefit from using ML for PRM by the companies in the era of fourth industrial revolution. These techniques affect the three main variables of a project: time, cost and quality. A better risk management allows avoiding delays, reducing costs and improving the quality of the project output: digital technologies are a source in this sense sustaining organizational innovation. On the other hand, universities and researchers can benefit from exploring this new topic and discovering new fields of application.

Further evolution of this analysis could be a deep study of documents included in the four research areas identified for deriving a more robust awareness on the state of art for the debate on ML and risk management in terms of future developments and application scenarios, benefits and limitations of this technology to support PRM. Further research context to be analyzed are required in non-financial risk management, compliance risk management and country risk management.

6.1 Limitations of the study

The study has some limitations regarded keywords defined and as well the database chosen for selecting the paper of the sample. The choice to use Scopus database could be a limit since it is possible that relevant researches on the topic of ML for PRM have been published in different venue not included in the database. Another limitation regards the number of the papers analyzed that confirm the novelty of the intersection between ML and PRM. A further investigation of the study is related to the cluster analysis that is conducted by the authors, since the bibliographic cluster analysis performed by Vosviewer software doesn't produced the cluster because papers do not share common references.

References

Aaldering, L.J. and Song, C.H. (2021), "Of leaders and laggards-towards digitalization of the process industries", *Technovation*, Vol. 105, 102211.

Afzal, F., Yunfei, S., Nazir, M. and Bhatti, S.M. (2019), "A review of artificial intelligence based risk assessment methods for capturing complexity-risk interdependencies: cost overrun in construction projects", *International Journal of Managing Projects in Business*, Vol. 14 No. 2, pp. 300-328, doi: 10.1108/IJMPB-02-2019-0047.

Ajayi, A., Oyedele, L., Owolabi, H., Akinade, O., Bilal, M., Davila Delgado, J.M. and Akanbi, L. (2020), "Deep learning models for health and safety risk prediction in power infrastructure projects", *Risk Analysis*, Vol. 40 No. 10, pp. 2019-2039.

Akinosho, T.D., Oyedele, L.O., Bilal, M., Ajayi, A.O., Delgado, M.D., Akinade, O.O. and Ahmed, A.A. (2020), "Deep learning in the construction industry: a review of present status and future innovations", *Journal of Building Engineering*, Vol. 32, 101827.

Arnuphaptrairong, T. (2011), "Top ten lists of software project risks: evidence from the literature survey", *Proceedings of the International MultiConference of Engineers and Computer Scientists*, Vol. 1, pp. 1-6.

Asif, M. and Ahmed, J. (2020), "A novel case base reasoning and frequent pattern based decision support system for mitigating software risk factors", *IEEE Access*, Vol. 8, pp. 102278-102291.

Awad, M. and Khanna, R. (2015), "Machine learning in action: examples", in *Efficient Learning Machines*, Apress, Berkeley, CA, pp. 209-240.

Badi, S.M. and Pryke, S. (2016), "Assessing the impact of risk allocation on sustainable energy innovation (SEI): the case of private finance initiative (PFI) school projects", *International Journal of Managing Projects in Business*, Vol. 9 No. 2, pp. 259-281.

Barta, G. and Görcsi, G. (2021), "Risk management considerations for artificial intelligence business applications", *International Journal of Economics and Business Research*, Vol. 21 No. 1, pp. 87-106.

Batar, M., Birant, K.U. and Işık, A.H. (2021), "Development of rule-based software risk assessment and management method with fuzzy inference system", *Scientific Programming*, Vol. 2021, pp. 1-14.

Baryannis, G., Validi, S., Dani, S. and Antoniou, G. (2019), "Supply chain risk management and artificial intelligence: state of the art and future research directions", *International Journal of Production Research*, Vol. 57 No. 7, pp. 2179-2202.

BDVA (2019), "European big data value strategic research and innovation agenda", (2017), available at: http://www.bdva.eu/sites/default/files/BDVA_SRIA_v4_Ed1.1.pdf

Berglund, H. (2007), "Risk conception and risk management in corporate innovation: lessons from two Swedish cases", *International Journal of Innovation Management*, Vol. 11 No. 4, pp. 497-513.

Björk, K.M., Eirola, E., Miche, Y. and Lendasse, A. (2016), "A new application of machine learning in health care", *Proceedings of the 9th ACM International Conference on PErvasive Technologies Related to Assistive Environments*, pp. 1-4.

Bowers, J. and Khorakian, A. (2014), "Integrating risk management in the innovation project", *European Journal of Innovation Management*, Vol. 17 No. 1, pp. 25-40.

Boyack, K.W. and Klavans, R. (2010), "Co-citation analysis, bibliographic coupling, and direct citation: which citation approach represents the research front most accurately?", *Journal of the American Society for Information Science and Technology*, Vol. 61 No. 12, pp. 2389-2404.

Chaudhary, P., Singh, D. and Sharma, A. (2016), "Classification of software project risk factors using machine learning approach", in *Intelligent Systems Technologies and Applications*, Springer, Cham, pp. 297-309.

Cho, H.J. and Pucik, V. (2005), "Relationship between innovativeness, quality, growth, profitability, and market value", *Strategic Management Journal*, Vol. 26 No. 6, pp. 555-575.

Choetkiertikul, M., Dam, H.K., Tran, T. and Ghose, A. (2015), "Predicting delays in software projects using networked classification", *2015 30th IEEE/ACM International Conference on Automated Software Engineering (ASE)*, IEEE, pp. 353-364.

Christoffersen, J. (2013), "A review of antecedents of international strategic alliance performance: synthesized evidence and new directions for core constructs", *International Journal of Management Reviews*, Vol. 15 No. 1, pp. 66-85.

Christofi, M., Leonidou, E. and Vrontis, D. (2017), "Marketing research on mergers and acquisitions: a systematic review and future directions", *International Marketing Review*, Vol. 34 No. 5, doi: 10.1108/IMR-03-2015-0100.

Dalcher, D. (2016), "Rethinking project practice: emerging insights from a series of books for practitioners", *International Journal of Managing Projects in Business*, Vol. 9 No. 4, pp. 798-821.

Dandage, R., Mantha, S.S. and Rane, S.B. (2018), "Ranking the risk categories in international projects using the TOPSIS method", *International Journal of Managing Projects in Business*, Vol. 1 No. 2, pp. 371-331.

Dumay, J. and Cai, L. (2014), "A review and critique of content analysis as a methodology for inquiring into IC disclosure", *Journal of Intellectual Capital*, Vol. 15 No. 2, pp. 264-290.

Emblemsvåg, J. and Kjølstad, L.E. (2006), "Qualitative risk analysis: some problems and remedies", *Management Decision*, Vol. 44 No. 3, pp. 395-408.

Fang, J., Zhao, L., Fransoo, J.C. and Van Woensel, T. (2013), "Sourcing strategies in supply risk management: an approximate dynamic programming approach", *Computers and Operations Research*, Vol. 40 No. 5, pp. 1371-1382.

Firdose, S. and Rao, L.M. (2018), "PORM: predictive optimization of risk management to control uncertainty problems in software engineering", *International Journal of Electrical and Computer Engineering*, Vol. 8 No. 6, pp. 2088-8708.

Garg, R., Brockett, P., Golden, L.L. and Zhang, Y. (2019), "Rapid assessment of customer marketplace in disaster settings through machine learning, geospatial information, and social media text mining: an abstract".

Ge, Z., Song, Z., Ding, S.X. and Huang, B. (2017), "Data mining and analytics in the process industry: the role of machine learning", *IEEE Access*, Vol. 5, pp. 20590-20616.

Ghahari, A., Newlands, N.K., Lyubchich, V. and Gel, Y.R. (2019), "Deep learning at the interface of agricultural insurance risk and spatio-temporal uncertainty in weather extremes", *North American Actuarial Journal*, Vol. 23 No. 4, pp. 535-550.

Giudici, P. and Figini, S. (2009), "Applied data mining for business and industry", *Applied Data Mining for Business and Industry*.

Gondia, A., Siam, A., El-Dakhakhni, W. and Nassar, A.H. (2020), "Machine learning algorithms for construction projects delay risk prediction", *Journal of Construction Engineering and Management*, Vol. 146 No. 1, 04019085.

Gouthaman, P. and Sankaranarayanan, S. (2018), "Agile software risk management architecture for IoT-fog based systems", *2018 International Conference on Smart Systems and Inventive Technology (ICSSIT)*, IEEE, pp. 48-51.

Hartono, B., Sulistyo, S.R., Praftiwi, P.P. and Hasmoro, D. (2014), "Project risk: theoretical concepts and stakeholders' perspectives", *International Journal of Project Management*, Vol. 32 No. 3, pp. 400-411.

Havas, C., Resch, B., Francalanci, C., Pernici, B., Scalia, G., Fernandez-Marquez, J.L. and Rüping, S. (2017), "E2mc: improving emergency management service practice through social media and crowdsourcing analysis in near real time", *Sensors*, Vol. 17 No. 12, p. 2766.

Hegde, J. and Rokseth, B. (2020), "Applications of machine learning methods for engineering risk assessment–A review", *Safety Science*, Vol. 122, 104492.

Hodgson, D. and Cicmil, S. (2016), "Making projects critical 15 years on: a retrospective reflection (2001-2016)", *International Journal of Managing Projects in Business*, Vol. 9 No. 4, pp. 744-751.

Holzmann, V., Zitter, D. and Peshkess, S. (2022), "The expectations of project managers from artificial intelligence: a Delphi study", *Project Management Journal*, 87569728211061779.

Hynek, J., Janeček, V., Lefley, F. and Půžová, K. (2014), "Evaluating project risk: an exploratory study of UK and Czech Republic practices", *International Journal of Systems, Control and Communications*, Vol. 6 No. 2, pp. 167-179.

Iftikhar, A., Musa, S., Alam, M. and Su'ud, M.M. (2020), "Artificial intelligence based risk management in global software development: a proposed architecture to reduce risk by using time, budget and resources constraints", *Journal of Computational and Theoretical Nanoscience*, Vol. 17 Nos 2-3, pp. 878-885.

Joseph, H.R. (2015), "Poster: software development risk management: using machine learning for generating risk prompts", *2015 IEEE/ACM 37th IEEE International Conference on Software Engineering*, Vol. 2, IEEE, pp. 833-834.

Kaplan, A. and Haenlein, M. (2019), "Siri, siri, in my hand: who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence", *Business Horizon*, Vol. 62 No. 1, pp. 15-25, doi: 10.1016/j.bushor.2018.08.004.

Keizer, J.A., Vos, J.P. and Halman, J.I. (2005), "Risks in new product development: devising a reference tool", *R&D Management*, Vol. 35 No. 3, pp. 297-309.

Kerzner, H. (2022), *Innovation Project Management: Methods, Case Studies, and Tools for Managing Innovation Projects*, John Wiley & Sons, Hoboken, NJ.

Kifokeris, D. and Xenidis, Y. (2019), "The Riscona system: constructability appraisal through the identification and assessment of technical project risks sources".

Kim, Y., Lee, J., Lee, E.B. and Lee, J.H. (2020), "Application of natural language processing (NLP) and text-mining of big-data to engineering-procurement-construction (EPC) bid and contract documents", *2020 6th Conference on Data Science and Machine Learning Applications (CDMA)*, IEEE, pp. 123-128.

Lefley, F. (2018), "An exploratory study of team conflict in the capital investment decision-making process", *International Journal of Managing Projects in Business*, Vol. 11 No. 4, pp. 960-985.

Leo, M., Sharma, S. and Maddulety, K. (2019), "Machine learning in banking risk management: a literature review", *Risks*, Vol. 7 No. 1, p. 29.

Liang, W., Sari, A., Zhao, G., McKinnon, S.D. and Wu, H. (2020), "Short-term rockburst risk prediction using ensemble learning methods", *Natural Hazards*.

Liu, S., Wang, X., Liu, M. and Zhu, J. (2017), "Towards better analysis of machine learning models: a visual analytics perspective", *Visual Informatics*, Vol. 1 No. 1, pp. 48-56.

Lytvyn, V., Kowalska-Styczen, A., Peleshko, D., Rak, T., Voloshyn, V., Noennig, J.R. and Pryshchepa, H. (2019), *Aviation aircraft planning system project development", Conference on Computer Science and Information Technologies*, Springer, Cham, pp. 315-348.

Mahdi, M.N., Mohamed Zabil, M.H., Ahmad, A.R., Ismail, R., Yusoff, Y., Cheng, L.K. and Happala Naidu, H. (2021), "Software project management using machine learning technique—a review", *Applied Sciences*, Vol. 11 No. 11, p. 5183.

Massaro, M., Dumay, J. and Guthrie, J. (2016), "On the shoulders of giants: undertaking a structured literature review in accounting", *Accounting, Auditing and Accountability Journal*, Vol. 25 No. 5, pp. 767-801.

Mc Kinsey Company (2017), "Unlocking success in digital transformations", available at: https://www.mckinsey.com/business-functions/organization/our-insights/unlocking-success-in-digital-transformations#

Mitchell, T. (1997), *Machine Learning*, McGraw Hill, New York.

Mori, S., Washida, T., Kurosawa, A. and Masui, T. (2018), "Assessment of mitigation strategies as tools for risk management under future uncertainties: a multi-model approach", *Sustainability Science*, Vol. 13 No. 2, pp. 329-349.

Muriana, C. and Vizzini, G. (2017), "Project risk management: a deterministic quantitative technique for assessment and mitigation", *International Journal of Project Management*, Vol. 35 No. 3, pp. 320-340.

Nambisan, S., Lyytinen, K., Majchrzak, A. and Song, M. (2017), "Digital Innovation Management: reinventing innovation management research in a digital world", *Mis Quarterly*, Vol. 41 No. 1, pp. 223-228.

Nambisan, S., Wright, M. and Feldman, M. (2019), "The Digital Transformation of innovation and entrepreneurship: progress, challenges and key themes", *Research Policy*, Vol. 48 No. 8, 103773.

Natarajan, A. (2022), "Reference class forecasting and machine learning for improved offshore oil and gas megaproject planning: methods and application", *Project Management Journal*, Vol. 53 No. 5, pp. 456-484, 87569728211045889.

Ozcan, G., Dikmen, I. and Birgonul, M.T. (2011), "Assessment of risk paths in construction projects", *International Journal of Project Organisation and Management*, Vol. 3 Nos 3-4, pp. 316-334.

Oztemel, E. and Gursev, S. (2020), "Literature review of Industry 4.0 and related technologies", *Journal of Intelligent Manufacturing*, Vol. 31 No. 1, pp. 127-182.

Petticrew, M. and Roberts, H. (2008), *Systematic Reviews in the Social Sciences: A Practical Guide*, Blackwell Publishing.

Pettigrew, A. (2003), *Innovative Forms of Organizing: Progress, Performance and Process*, SAGE Publications, doi: 10.4135/9781446219386.

Phoon, K.K. (2020), "The story of statistics in geotechnical engineering", *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, Vol. 14 No. 1, pp. 3-25.

PMI Standards Committee (2008), *A Guide To the Project Management Body of Knowledge (PMBOK Guide)*, Project Management Institute, Newtown Square, PA.

Project Management Institute (PMI) (2018), The project manager of the future: developing digital-age project management skills to thrive in Disruptive times.

Qu, Y. and Yang, T.Z. (2016), "Research on occurrence frequency of IT projects risk based on fuzzy influence diagram", *2016 International Conference on Machine Learning and Cybernetics (ICMLC)*, IEEE, Vol. 1, pp. 166-171.

Raz, T. and Michael, E. (2001), "Use and benefits of tools for project risk management", *International Journal of Project Management*, Vol. 19 No. 1, pp. 9-17.

Rockwood, K. (2018), "2018 jobs report: in a time of change, demand for project talent will keep rising", *PM Network*, Vol. 32 No. 1, pp. 28-47.

Sanni-Anibire, M.O., Zin, R.M. and Olatunji, S.O. (2020), "Machine learning model for delay risk assessment in tall building projects", *International Journal of Construction Management*, Vol. 22 No. 11, pp. 2134-2143.

Saravi, S., Kalawsky, R., Joannou, D., Rivas Casado, M., Fu, G. and Meng, F. (2019), "Use of artificial intelligence to improve resilience and preparedness against adverse flood events", *Water*, Vol. 11 No. 5, p. 973.

Sousa, A., Faria, J.P. and Mendes-Moreira, J. (2021), "An analysis of the state of the art of machine learning for risk assessment in software projects", *The 33rd International Conference on Software Engineering and Knowledge Engineering, SEKE*, pp. 1-10.

Stone, J.R., Blockley, D.I. and Pilsworth, B.W. (1990), "Managing risk in civil engineering by machine learning from failures", *Proceedings. First International Symposium on Uncertainty Modeling and Analysis*, IEEE, pp. 255-259.

Suresh, K. and Dillibabu, R. (2020), "A novel fuzzy mechanism for risk assessment in software projects", *Soft Computing*, Vol. 24 No. 3, pp. 1683-1705.

Tang, R., De Donato, L., Besinović, N., Flammini, F., Goverde, R.M., Lin, Z., Ronghui, L., Tianli, T., Vittorini, V. and Wang, Z. (2022), "A literature review of Artificial Intelligence applications in railway systems", *Transportation Research Part C: Emerging Technologies*, Vol. 140, p. 103679.

Teece, D., Peteraf, M. and Leih, S. (2016), "Dynamic capabilities and organizational agility: risk, uncertainty, and strategy in the innovation economy", *California Management Review*, Vol. 58 No. 4, pp. 13-35.

Thelwall, M. (2018), "Dimensions: a competitor to Scopus and the Web of science?", *Journal of Informetrics*, Vol. 12 No. 2, pp. 430-435.

Thorpe, R., Holt, R., Macpherson, A. and Pittaway, L. (2005), "Using knowledge within small and medium-sized firms: a systematic review of the evidence", *International Journal of Management Reviews*, Vol. 7 No. 4, pp. 257-281.

Tranfield, D., Denyer, D. and Smart, P. (2003), "Towards a methodology for developing evidence-informed management knowledge by means of systematic review", *British Journal of Management*, Vol. 14 No. 3, pp. 207-222.

Troise, C., Corvello, V., Ghobadian, A. and O'Regan, N. (2022), "How can SMEs successfully navigate VUCA environment: the role of agility in the digital transformation era", *Technological Forecasting and Social Change*, Vol. 174, 121227.

Urbinati, A., Landoni, P., Cococcioni, F. and De Giudici, L. (2020), "Stakeholder management in open innovation projects: a multiple case study analysis", *European Journal of Innovation Management*, Vol. 24 No. 5, pp. 1595-1624.

Van Eck, N.J. and Waltman, L. (2014), "Visualizing bibliometric networks", in *Measuring Scholarly Impact*, Springer, Cham, pp. 285-320.

Walker, D. and Lloyd-Walker, B. (2019), "The future of the management of projects in the 2030s", *International Journal of Managing Projects in Business*, Vol. 12 No. 2, pp. 242-266.

Wang, J.T., Lin, W. and Huang, Y.H. (2010), "A performance-oriented risk management framework for innovative R&D projects", *Technovation*, Vol. 30 Nos 11-12, pp. 601-611.

Wijayasekera, S.C., Hussain, S.A., Paudel, A., Paudel, B., Steen, J., Sadiq, R. and Hewage, K. (2022), "Data analytics and artificial intelligence in the complex environment of megaprojects: implications for practitioners and project organizing theory", *Project Management Journal*, Vol. 53 No. 5, pp. 485-500, 87569728221114002.

Williams, T. (1995), "A classified bibliography of recent research relating to project risk management", *European Journal of Operational Research*, Vol. 85 No. 1, pp. 18-38.

Williams, T. (2017), "The nature of risk in complex projects", *Project Management Journal*, Vol. 48 No. 4, pp. 55-66.

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