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Review article

Project portfolio risk management. Bibliometry and collaboration Scientometric domain analysis

Camilo Andrés Micán Rincón [a], Oscar Rubiano-Ovalle [a,*], Carolina Delgado Hurtado [b], Carlos-Augusto Andrade-Eraso [c]

[a] *Universidad del Valle, Colombia*
[b] *Universidad del Cauca, Colombia*
[c] *Rice University, USA*

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ABSTRACT

Purpose: "Project Portfolio Risk Management" is approached through a bibliometry and collaboration networks study determining its dynamics and development as a formal domain that links Project, Risk Management and Portfolio concepts.
Design/methodology/approach: To facilitate replicability, a scientometric study under a PRISMA structure is carried out: i) Identification or domain structuring, as well as keywording accuracy; ii) Screening: Search string refinement and outputs review; iii) Eligibility: Several criteria applied to a content analysis, and iv) Inclusion: Consolidation of domain analytics through bibliometry and collaboration networks.
Originality and findings: Assessing the field as a formal knowledge domain is novel, contributing to a synthesis of its trends and evolution: For first time, descriptive statistics show increasing attention based on the growing citation scores, participation, H index and productivity of its main journals. Project Portfolio Selection is established as hot topic, the main authors are identified, as well as key concepts such as optimization, mathematical programming, multi-objective optimization, stochastic programming, and robust optimization. Three main research themes are obtained: Incorporation of Risk Assessment into Project Portfolio Selection problem, Risk Management as a Project Portfolio Management process, and Risk Analysis considering social and environmental issues. An accurate match is found in the contrast of the domain's behavior with some bibliometric and linguistic laws.
Practical implications: Theoretical richness is achieved in the conjunction of the three terms, presenting dynamics and tendencies and thus contributing to focus related research processes on a unified field for the use of both scholars' and practitioners' perspectives.

1. Introduction

Project Management (PM) has garnered significant attention in organizations, leading to increased resource allocation and project implementation to drive strategic benefits [1]. Consequently, Project Portfolios have emerged as a collection of projects and programs

* Corresponding author.
E-mail addresses: camilo.mican@correounivalle.edu.co (C.A. Micán Rincón), oscar.rubiano@correounivalle.edu.co (O. Rubiano-Ovalle), carolinadelgado@unicauca.edu.co (C. Delgado Hurtado), caa13@rice.edu (C.-A. Andrade-Eraso).

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aimed at achieving specific organizational objectives [2,3]. Managing these portfolios involves coordinating interfaces between projects to ensure their successful execution [4]. Effective project portfolio management can have positive implications for the strategic advancement of the parent organization.

Effective Risk Management (RM) is pivotal for project portfolio success [5], enhancing the alignment with strategic objectives [2,3]. From a project portfolio perspective, solely managing risks at the project level is inadequate as it fails to account for crucial project portfolio attributes, including project interdependency, risk interdependency, shared risks between projects, and the strategic impact of the portfolio [2,6,7]. As a result, the literature has progressively shifted from risk management applied to individual projects to encompass risk management applied to project portfolios, forming the domain of Project Portfolio Risk Management (PPRM) [2].

The concept of a "knowledge domain" encompasses the representation of underlying knowledge development in a specific topic area, field of study, discipline, or their combination [8]. Shapere [9] describes domains as repositories of information addressing specific problems. In the case of Project Portfolio Risk Management (PPRM), the literature addresses various issues and generates diverse definitions, perspectives, methodologies, and methods, establishing it as a formal knowledge domain. However, research on the current state and trends of PPRM is limited. While literature reviews exist on Project Portfolio Management and Project Risk Management, few studies focus specifically on the configuration of PPRM literature. For instance, a recent qualitative analysis identified recurring topics and proposed future research directions [10], but acknowledged limitations in terms of search criteria and exclusions of relevant results. Therefore, a comprehensive understanding of the current landscape and trends in PPRM literature remains necessary.

A comprehensive understanding of the current state and dynamics of the PPRM domain is essential for addressing field-specific challenges. It is crucial to grasp the current configuration of PPRM and identify future research opportunities. In this context, scientometric studies play a vital role in studying knowledge domains, offering insights into trends and developments and bridging the existing gap.

This research employs scientometric techniques to analyze PPRM dynamics, integrating production and collaboration indicators to reveal knowledge development. The study's conceptual analysis offers practical implications for future research, contributing to a cohesive scientific body. It aims to create a bibliometric landscape illuminating PPRM's status and dynamics, emphasizing interconnections between Project, Risk Management (RM), and Portfolio. Research questions were formulated, including the general inquiry: What insights into PPRM's status, dynamics, and trends does a scientometric study of bibliometry and collaboration networks offer? Secondary questions are detailed in section 3.1.1.

Scientometrics quantitatively evaluates scientific activity by measuring researchers, production, institutions, and countries [11]. It applies metrics to analyze quantity, quality, interrelationships, cohesion, citations, and countries [12–14]. This approach offers valuable insights into the dynamics and characteristics of scientific research.

Bibliometric domain analysis addresses the gap and research question, akin to other fields [15,16]. PPRM aims to reveal trends, collaboration patterns, and research components. This analysis clarifies the intellectual structure within existing literature, which would otherwise be scattered and unclear.

Recent scientometric and bibliometric studies have made significant contributions to the fields of Economy, Firms, and Management. Notably, Anugerah, Muttaqin, and Trinarningsih [17] and other researchers [18–21] provide valuable insights and techniques for domain analytics. These studies employ diverse bibliometric indicators and explore collaboration networks, advancing knowledge in the field. This article also addresses network dynamics, a critical aspect of Scientometrics, as it provides indicators essential for capacity building and project management [22–26]. These contributions offer valuable tools to analyze and understand the dynamics of any knowledge domain, including the one explored in this study.

The bibliometric analysis uncovered notable insights on Project Portfolio Selection. The study revealed its high relevance, with key concepts centering on optimization, mathematical programming, multi-objective optimization, stochastic programming, and robust optimization. Additionally, three major research themes emerged: the integration of Risk Assessment into Project Portfolio Selection, the role of Risk Management as part of Project Portfolio Management, and the consideration of Risk Analysis in social and environmental contexts. These findings provide valuable insights into the current trends and focal points in Project Portfolio Selection.

Some limitations are brought up for discussion, notably the potential omission of seminal and preprinted literature within the time scope of bibliometric studies. Additionally, the H-index's application is limited due to its current use in gauging scholarly interest in PPRM. Notable weaknesses of this metric are addressed and interpreted in the ensuing discussion section.

The paper proceeds as follows: First, a brief conceptualization and background of PPRM is presented. Then, in the materials and methods section, the domain is established through keywording techniques. A whole section that describes the methodology used in the frame of PRISMA. It is followed by a results section that carefully describes not only the descriptive results, but also explains what variables and for what purposes they are used in each deployed indicator. These results are discussed either by supporting or contrasting other studies, shading light for the understanding of the meaning of the findings in the field. Lastly, there is a final section that synthesizes the conclusions of the study.

2. Background - project portfolio risk management –PPRM

PPRM originates from the foundational concept of project portfolios, stemming from Markowitz's Modern Portfolio Theory (MPT) [27–29]. Initially, PPRM centered on infusing Risk Assessment into Project Portfolio selection, akin to financial portfolio structuring [28], primarily addressing the initial phase of Project Portfolio Management, known as Project Portfolio Structuring. Yet, for a comprehensive coverage of all management phases – Project Portfolio Structuring, Resource Management, and Portfolio Control – a secondary Risk Planning approach emerged. This approach adapts traditional Project Risk Management techniques employed at the project level [3,6] to account for interdependencies between projects within the portfolio, recognizing their impact on project risks., recognizing their impact on project risks.

Furthermore, specific studies focus on the characteristics of different types of project portfolios. For instance, research investigates information technology project portfolios [30], oil and gas exploration project portfolios [6], among others. Some studies adopt a more generic approach, examining project portfolios in a broader context [3]. Consequently, the literature suggests that risks at the project portfolio level can be analyzed at a moderately unified level of detail [2,31]. To achieve this, discussions in PPRM integrate risk approaches derived from both Modern Portfolio Theory and traditional Project Risk Management. These approaches consider the entire Project Portfolio Management life cycle, encompassing various PPRM elements and accommodating the distinctive characteristics of different project portfolio types.

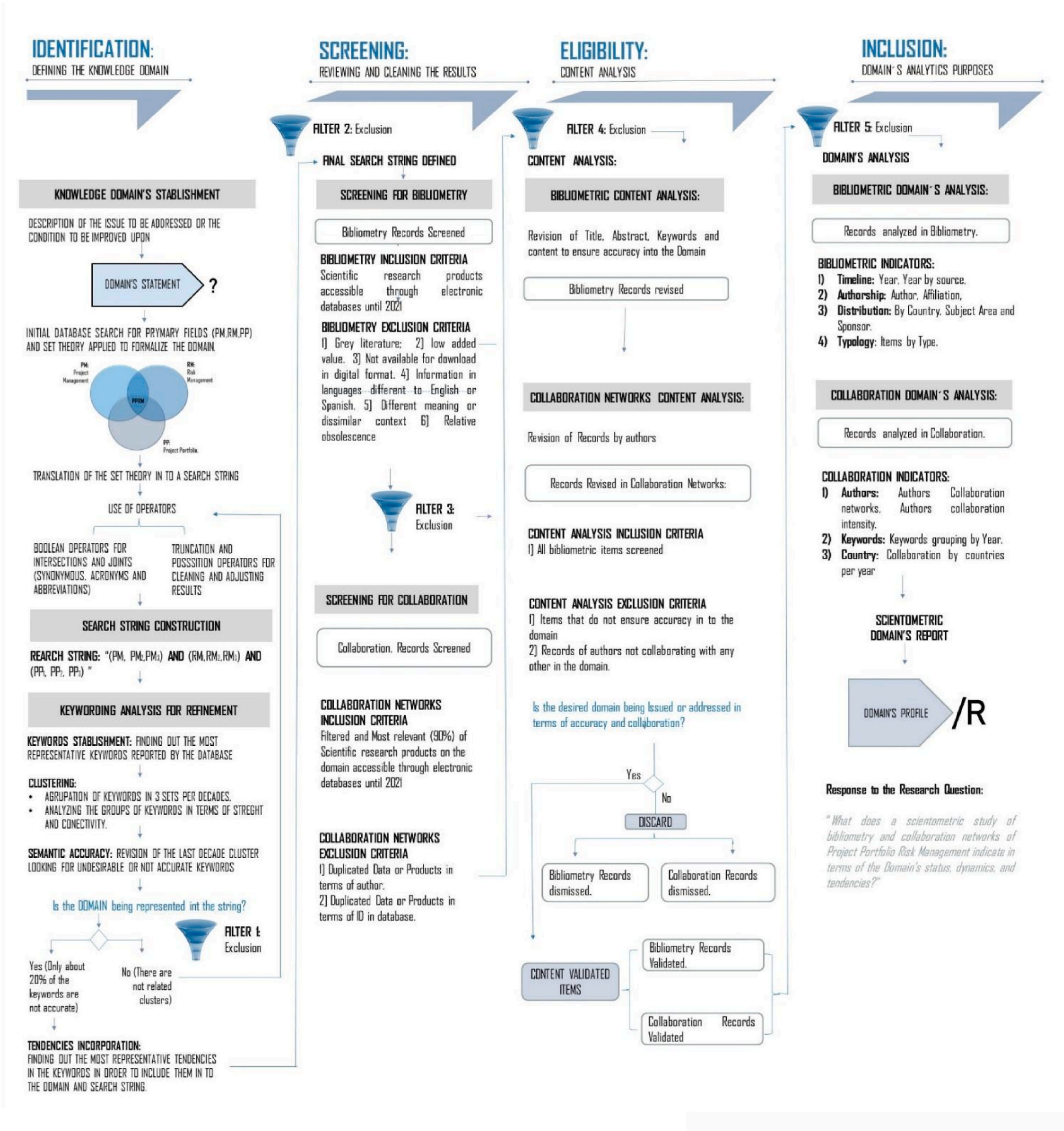

Fig. 1. Methodology for the analysis of the PPRM domain.
Source: Own 2022

Regarding the current state of PPRM, recent studies [32–35] highlight the increasing attention given to Risk Identification, process integration, technology adoption, and continuous evolution within Project Portfolio Risk Management. Organizations recognize the significance of managing risks in their project portfolios and actively seek to implement Risk Management strategies. There is a clear trend towards conducting thorough analyses of potential risks, considering both internal and external factors, and emphasizing early identification and assessment throughout the project portfolio management process. Furthermore, there is a growing emphasis on integrating risk considerations across different stages of Project Portfolio Management, including project selection, resource allocation, and project execution.

Increasing technology integration in PPRM meets the need for real-time risk analysis, aided by risk management software. This technological shift spurs the field's evolution, with companies acknowledging their risk management strengths and weaknesses, prompting adaptations to tackle emerging challenges. PPRM's dynamism arises from continuous enhancements driven by organizational awareness of risk management practices, reflecting an iterative process of improvement and adaptation.

Addressing gaps for improved effectiveness in risk management practices and project portfolio outcomes is essential in the field. S. Meskendahl [36] has established a positive correlation between project portfolio performance and business-level results. However, achieving desired outcomes faces challenges from project and portfolio risks, as well as the dynamic nature of projects, portfolios, and parent organizations [36,37]. Consequently, Risk Management plays a crucial role in successful project portfolio management [6,32,38], and ultimately, project portfolio success [39,40]. Nevertheless, unresolved issues persist, as highlighted by these authors. Concerns include the absence of standardized risk management practices, limited research in areas like Risk Appetite, the need for integration with other management processes, and a lack of comprehensive insights into the evolving landscape of Dynamic Risk Management.

PPRM is highly relevant and holds implications for organizations and society, as evident from the literature. It serves as a framework for consolidating risk management activities at the project portfolio level, avoiding duplication of effort and resources. This consolidation enhances risk management effectiveness throughout the Project Portfolio Life Cycle [2,33,31]. The main goal of PPRM is to maximize value by conducting comprehensive risk analysis and management. It involves mitigating negative impacts, capitalizing on opportunities, considering project interdependencies, and aligning with organizational capabilities [2,33,34]. By adopting an integrated PPRM approach, organizations can optimize risk management practices, resulting in improved project outcomes and operational efficiency.

3. Materials and methods

Information Sciences offer diverse approaches for literature analysis in various domains, including Domain Analysis, Analytical Domain Theory, or the Analytical Paradigm of Domain. This technique, derived from disciplines like Bibliotechnology and Software Engineering, provide valuable insights [30]. Hjørland [5] identified 11 techniques and suggested their combined use for more robust and comprehensive results. By synergistically employing these techniques, researchers can gain a deeper understanding of domain-specific literature and enhance their insights into the field.

Bibliometry is recognized as a valuable approach in research methodologies [41], often integrated with network analysis techniques [11–14]. This article adopts a synergistic approach by combining bibliometric and network analysis methods. Through the analysis of publication and collaborative networks, it aims to provide a comprehensive understanding of the research landscape in the field.

To ensure replicability, we adhered to a systematic protocol encompassing research design, questions, data source, type, software, and treatment. This approach, aligned with PRISMA's four stages in Fig. 1, offers a comprehensive and reproducible method for such studies.

3.1. Research design

This section outlines research questions, methods, tools, analysis unit, data source, software, treatment protocol, and research approach.

3.1.1. Research questions

The general research question to what this study points out is:

(RQ): What does a scientometric study of bibliometry and collaboration networks of Project Portfolio Risk Management indicate in terms of the domain's status, dynamics, and tendencies?

The secondary or specific research questions are: (RQ1) ¿What is the overall dynamics of the scientific output in PPRM? (RQ2); ¿Which topics have mainly been approached in the PPRM domain?; (RQ3) ¿What is the thematic structure supported by the most representative keywords in research related to PPRM, and how has it evolved over time?; (RQ4) ¿To what extent does scientific collaboration represent the link between the studies that contribute to construct the PPRM domain?

3.1.2. Unit of analysis

This aims to analyze Scopus database for scientific products, focusing on Project Management, Risk Management, and Project Portfolio conjunction of topics and keywords.

3.1.3. Data source

Both examined databases exhibit similar dynamics with no significant differences [15], rendering them comparable and excellent research resources, supported by previous studies [16]. Researchers can confidently utilize either database, ensuring reliable and valuable data for analysis.

The selection process considered six key requirements, including multidisciplinarity, selectiveness, bibliographical references, availability, coverage, and accuracy, as suggested by Ref. [42]. The databases were evaluated based on their ability to ensure comprehensive coverage of scientific journals, address misspellings and inconsistencies, and avoid biases towards countries, languages, or publishers [42]. Scopus, known as the world's largest abstract and citation database [43], met all the criteria and was chosen as the data source. Scopus offers multidisciplinary coverage, utilizes computerized methods for data collection, and is recognized for its statistical reliability. It provides extensive coverage of publications in the field of PPRM and employs unified indexes and selection policies for scientific journals across disciplines [15]. These factors contribute to Scopus's suitability for this study, ensuring a robust and comprehensive analysis of the research landscape in PPRM.

3.1.4. Data type

The study concentrated on six document types as per Scopus Indexed Documents [44]: scholarly articles, conference papers, reviews, book chapters, conference reviews, and short surveys.

3.1.5. Software tools

Bibliometrix version 3.0 and 4.0 packages [45] were used, which are specialized bibliometric software to deal with data exported from databases as Scopus. They use APIs (application programming interfaces) from R-Scopus version 0.6.6 [46].

Biblioshiny [46] facilitated bibliometric analysis using a web-based Shiny App, allowing data management, importing, filtering, and converting information. It provided clustering analytics and plots for sources, authors, and documents without altering the code.

3.1.6. Data treatment protocol

A thorough research process covered 1970 to 2022, applying diverse data treatment methods as per technical requirements (see section 2.5).

Data collection for this study was carefully conducted, addressing aspects such as cleaning for duplicity, refining keywords, and assessing output quality. As recommended by Ref. [47], the collection took place within a single day to minimize discrepancies and changes resulting from database updates.

To analyze thematic evolution, we employ co-word network analysis and clustering, following methodologies by Ref. [45] inspired by Ref. [48].

For document coupling data, a bi-dimensional Coupling Map was created, indicating coupling strength using a novel method involving title and abstract keywords. Clustering employed Callon's Centrality Index [49] and Normalized Local Citation Score [46],

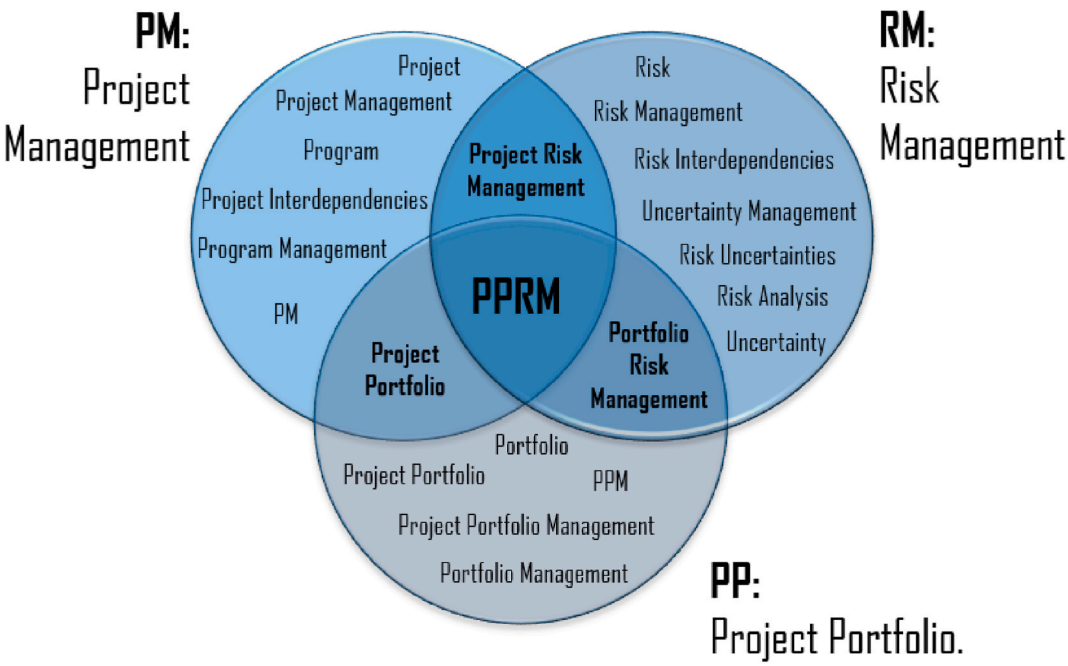

Fig. 2. Conjunction of three concepts – Project Management, Risk Management, and Project Portfolio, to conform the PPRM domain.
Source: Own 2022

comparing actual citations to expected rates within the publication year.

To generate co-occurrence data as keyword networks, we employed the "Louvain Community Detection Algorithm." This algorithm calculates community vectors and global modularity, indicating community structure quality. It was executed in the Biblioshiny App with the R Network Toolbox (version 1.4.2) [50].

Co-citation analysis grouped cited articles into two clusters: highly cited articles based on co-citation counts, and current articles assigned to clusters using reference distribution. This approach formed Co-citation clusters containing reference articles and their citing current counterparts.

3.1.7. *Research approach*

The study followed a PRISMA structure, ensuring replicability and transparency. Each phase of the process was thoroughly reported [51]. This approach aligns with the requirements of Domain Analytics, which emphasize the use of clear mechanisms and indicators to analyze emerging trends and changes in the domain [8].

The four PRISMA stages deployed in Fig. 1 were accomplished as follows.

3.1.7.1. Identification stage. Define the knowledge domain by describing the research question and creating a comprehensive search string to represent the field.

Knowledge Domain Establishment: Formally define PPRM as a knowledge domain using Venn diagrams for unit analysis and comprehensive literature review [52] (See Fig. 2).

Fig. 2 shows the conjunction of the three concepts that formally make up the PPRM domain.

Search String Construction: Venn diagrams were utilized to represent and visualize the proposed domain, and they served as the basis for constructing search strings using Boolean, Truncation, and Position operators [53,54]. Multiple versions of these strings were generated, producing initial outcomes (See Table 1). The keywording methodology employed a novel approach, incorporating general and broad criteria, along with a review of clustering and semantic accuracy. Through this analysis, a specific search string, denoted as RSn RS3, was selected, yielding 3688 results.

3.1.8. *Keywording analysis for search string refinement*

Keywordsestablishment: To faithfully represent main domain concepts' grouping and combination, a specific keywording methodology was initiated using Bibliometrix for main word extraction.

Clustering: Keywords were grouped into clusters based on time periods spanning three decades from 1970 to 2022. The analysis focused on identifying the strongest and most interconnected keywords within each decade. Additionally, a review of the most recent decade was conducted, considering the potential impact of Price's Second Bibliometric Law on the dynamics of the domain, specifically the obsolescence of scientific literature [55,56]. The distribution of keywords was carefully examined to identify any "noise" or irrelevant words that were unrelated to the domain, ensuring more accurate results.

Semantic Accuracy review: A filtering process was applied to eliminate inaccurate items. The cluster from the last decade was reviewed for semantic accuracy, and the main trends were identified based on significant keywords. Following Zipf's Law and Goffman's transition point [57], new exclusion and truncation operators were used to adjust word groups unrelated to the domain. If unrelated clusters were successfully removed and non-domain keywords constituted less than 20% of the total, the inclusion and exclusion criteria were considered met. This approach aimed to refine the results and ensure the relevance of the obtained data.

Word Tendencies Incorporation: We incorporated the most representative keyword tendencies in the domain and search string.

3.1.8.1. Screening stage. This was conceived to broadly review and clean the results obtained with the final search string, filtering results to an outcome of 461 from the initial 3688 records.

Screening for Bibliometry: The records were screened under the following criteria:

Inclusion: Scientific research products accessible through Scopus during the 1970 to 2022 timespan.

Exclusion: As filter, the records were excluded if they were duplications, gray literature or had a different meaning or belonged to a dissimilar context.

Screening for Collaboration: The records available for scientific collaboration analysis were screened under the following criteria:

Inclusion: Filtered and most relevant (90%) of scientific research products on the domain accessible through Scopus from 1970 to 2022.

Table 1
Search strings tested in terms of keyword analysis.

RSn	Research String	Outcomes
RS_1	(portfolio OR "Project portfolio" OR "Portfolio management" OR "Project portfolio management" OR PPM) AND (project OR projects OR "project management" OR pm OR "project interdependencies" OR "projects interdependencies" OR "project interdependency" OR program OR "program management") AND ("risk management" OR risk OR RM OR uncertainty OR "uncertainty management" OR "risk analysis" OR "uncertainty analysis" OR "risk interdependencies" OR "risk and uncertainties").	4461
RS_2	(portfolio OR PPM) AND (project OR projects OR pm OR program) AND (risk OR RM OR uncertainty)	4461
RS_3	(portfolio) AND (project OR projects OR program) AND (risk OR uncertainty)	3688
RS_4	(portfolio) AND (project) AND (risk OR uncertainty)	2530

Exclusion: Records were excluded if they duplicated products, authors, or ID.

3.1.8.2. Eligibility stage. Employing Conceptual Content Analysis, a widely-used technique for inferring concepts in written documents, the study refined the domain definition [57]. This analysis quantified term presence, revealing patterns and interpreting underlying meanings of identified concepts [58]. It offered valuable insights into the domain's conceptual landscape.

3.1.9. Bibliometric Conceptual Content Analysis-CA

To enhance data quality and mitigate accuracy and database coverage risks, a conceptual content analysis was conducted on the retrieved publications. This analysis aimed to identify and eliminate publications that were not relevant to the field and identify errors in variables such as authors, institutions, journals, years, and citations. Through this Bibliometric Conceptual Content Analysis, the remaining 421 items underwent a thorough review, ensuring the reliability of the data and improving the overall analysis quality. The analysis focused on evaluating the Title (T), Abstract (A), Keywords (K), and content to refine the results and enhance accuracy within the domain.

Collaboration Networks Content Analysis: A CA revision of author-constructed networks was performed based on criteria: included accurate bibliometric items and collaboration reporting; excluded records lacking accuracy or author collaboration. This led to validated content items.

3.1.9.1. Inclusion stage. Utilizing scientometric indicators, we generate and present a domain's profile through analytical techniques:

Bibliometric Domain Analysis: Utilized to depict current journal performance and emerging trends [59], our analysis contributes to delineating the evolving structure of the scientific domain. By employing bibliometric methods, we map PPRM science [46], covering Source Growth, H Index-based Source Impact, Top Authors' production over time, Thematic evolution, Scientific Productivity Frequency Distribution, and Bradford's Law Source Distribution.

3.1.10. Scientific collaboration domain analysis

Scientific Collaboration Network Analysis is a prevalent approach for studying interactions among scholars. It employs author(s), country, and institution connections to mirror academic research and collaboration dynamics.

This study employs indicators such as Clusters, Collaboration, and Network Analysis to explore cooperation within institutions, countries, and international affiliations [60].

4. Results

4.1. By analyzing 461 scientific items, we provide a PPRM profile and highlight emerging domain areas using the following indicators

4.1.1. Source Growth

Fig. 3 illustrates cumulative publication occurrences in prominent scientific journals from 1970 to 2022, providing insights into the frequency of PPRM-related publications during that period.

The European Journal of Operational Research, represented by the brown curve, demonstrates the growth of PPRM. Other journals

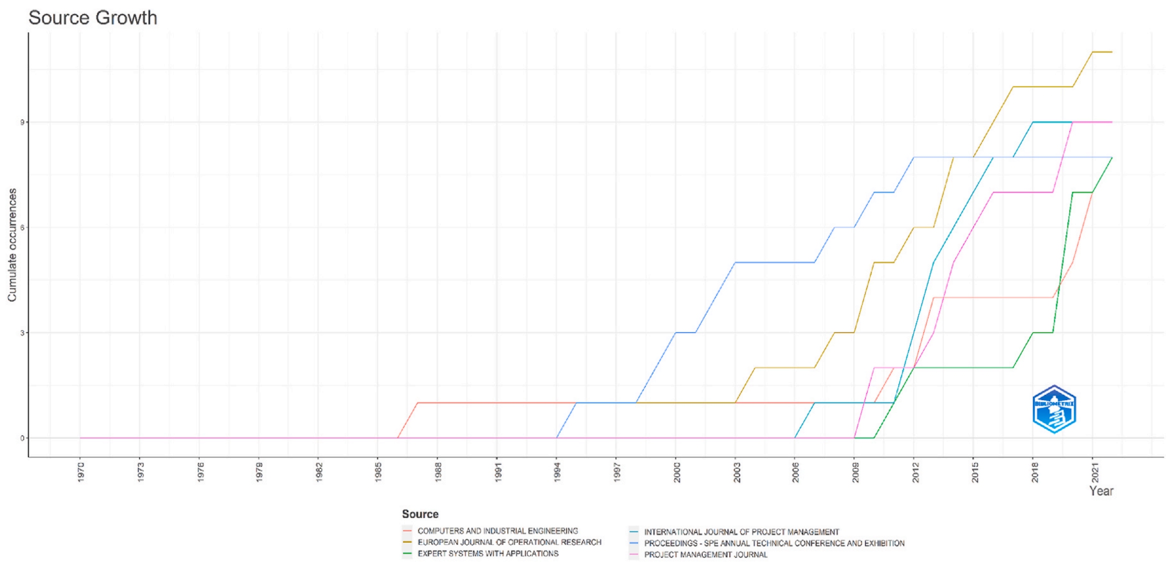

Fig. 3. Source growth bibliometric indicator.
Source: Own, based on Bibliometrics 3.0 2022 [46].

also contribute to the field's development from 1970 to 2017, with ongoing growth. Notably, the domain experienced significant progress starting in 1987.

4.2. *Source Impact by H index*

Fig. 4 presents author-level variables indicating impact and productivity of influential researchers in PPRM. The Hirsch Index, also known as the Hirsch number, is used to measure this impact. It identifies the scientist's most cited papers in the domain and the number of citations they have received from other publications [46]. The European Journal of Operational Research and the International Journal of Project Management are recognized as leaders with a score of 9, while other journals follow with scores of 6.

4.2.1. *Top-Authors' production over the time*

Fig. 5 displays the author's production over time using a red line to indicate the timeline. The number of articles is shown as dots or bubbles, with larger bubbles representing higher records (ranging from 1.0 to 3.0). The blue dots represent Times Cited (TC) per year, with the intensity shade indicating the citation count within the PPRM domain (ranging from 0 to 10). Notably, authors like Mohagheghi and Mousavi made contributions between 2015 and 2022, each with one paper in the last two years, cited between one and three times. Salo Ahti has the longest track record, writing on PPRM topics from 2005 to 2017.

4.2.2. *Thematic evolution*

In Fig. 6, a keyword map spanning over 52 years (1970–2022) illustrates the usage, emergence, and evolution of key terms in the PPRM domain. Notably, no persistent keywords were found throughout this period. "Investment" emerged from 2001 to 2010 and remains relevant, while terms like "Project Management," "Construction Industry," and "Research and Development" disappeared after 2020. "Risk assessment" prevailed for eleven years, including the present. Emerging topics indicated by keywords include "Project Assessment," "Linear Programming," "Monte Carlo Methods," "Risk Assessment," "Bayesian Networks," "Project Portfolio Selection," "Investment," "Managers," and "Decision Theory."

4.2.3. *Frequency Distribution of the scientific productivity*

Fig. 7 presents the distribution of Lotka's Law, introduced by Alfred Lotka in 1926 [61]. The plot shows the actual percentage of authors contributing to PPRM on the ordinate axis, while the abscissa axis represents the number of documents considered. A dotted line represents the application of Lotka's Law, enabling a comparison between the actual records and the model proposed by Lotka, which is discussed in Section 4. The interpretation of the graph shows that in the field of PPRM, more than 80% of the authors have published only one article, while those who have written more than one article account for less than 20% of the total. Authors with three or more papers account for fewer than 5%.

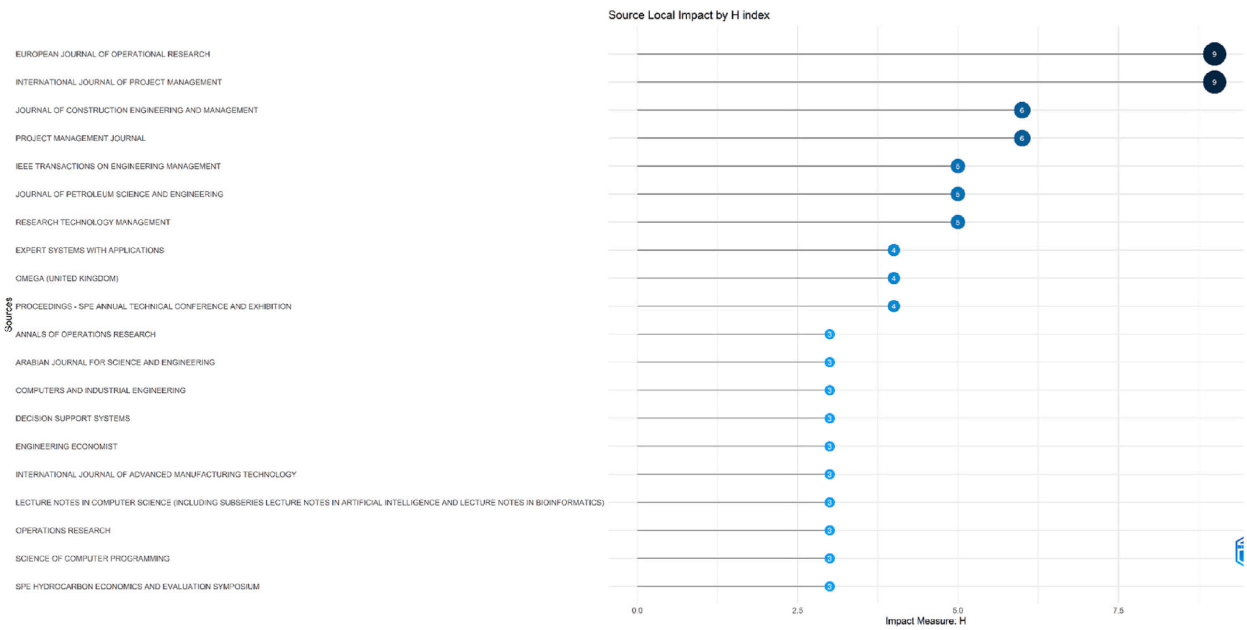

Fig. 4. Source impact by H Index bibliometric indicator.
Source: Own, based on Bibliometrics 3.0, 2022 [46].

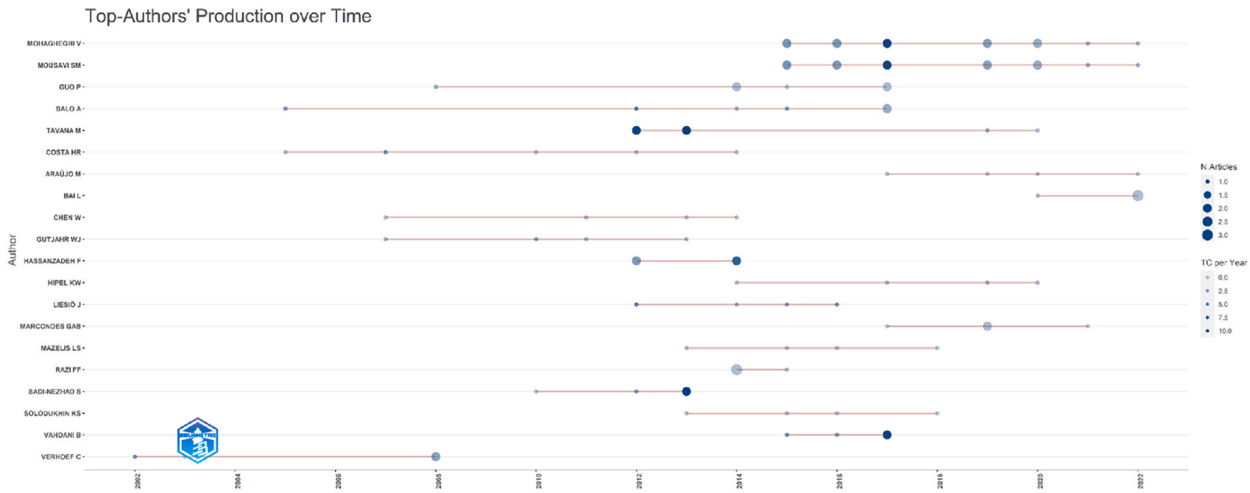

Fig. 5. Top-Authors' production over the time bibliometric indicator.
Source: Own, based on Bibliometrics 3.0, 2022 [46].

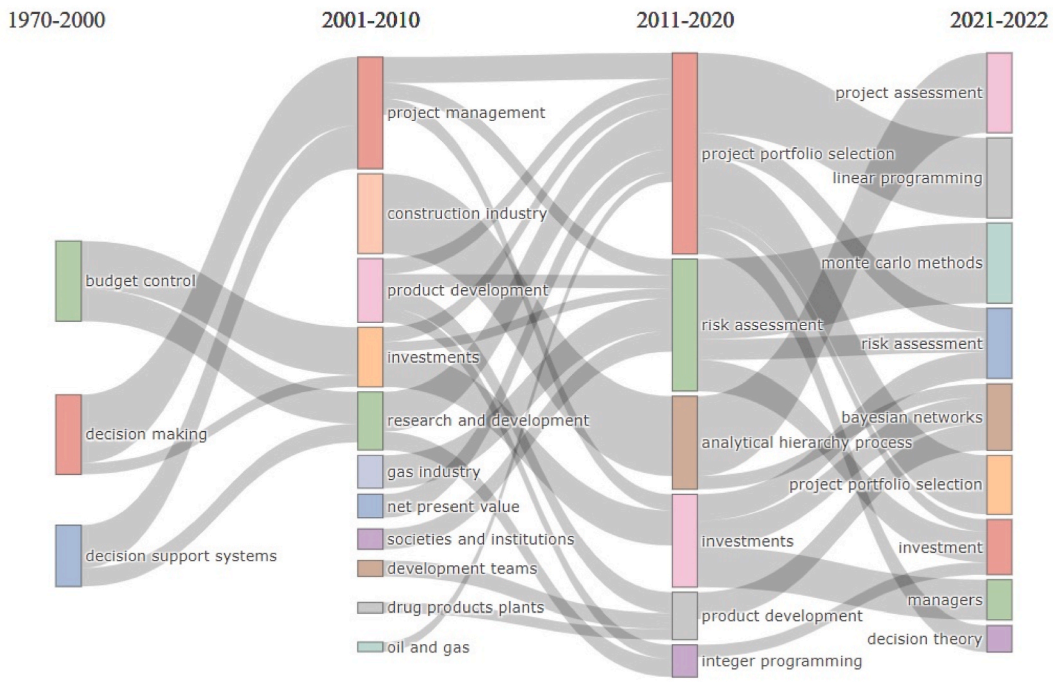

Fig. 6. Thematic evolution indicator.
Source: Own, based on Bibliometrics 3.0, 2022 [46].

4.2.4. Bradford's law Source Distribution

Bradford's Law [62] highlights a pattern commonly observed in bibliometric studies, indicating exponentially diminishing returns when searching for references in scholarly journals. In Fig. 8, we sorted the journals in the PPRM domain into three groups, each containing about one-third of all articles. Following Bradford's Law, the number of journals in each group should be proportional to 1: n:n2. The figure displays the most representative journals in blue, forming the core publications. Notably, the European Journal of Operation Research emerges as the most representative journal, alongside others like the International Journal of Project Management, Project Management Journal, and the Proceedings SPE Annual Technical Conference and Exhibition, which collectively constitute a 'nucleus' within the PPRM domain.

4.2.5. Trend Topics

Fig. 9 illustrates a plot where the size of circles corresponds to the frequency of a term or keyword used. The smallest circle represents 0–25 occurrences, with increasing sizes for 26–50, 51–75, 76–100, and 101–125 occurrences. The gray line indicates the timeframe during which each term has been studied. Among the most prevalent terms in the PPRM domain, Cost Benefit Analysis stands out, present from 2003 to 2018. Notably, Risk Assessment, Project Portfolio Selection, and Decision Making are frequently used words, with 101–125 occurrences. Recent trends include the use of words like Multiobjective Optimization, Sustainable Development, Stochastic Systems, and Project Portfolio.

4.3. Scientific collaboration domain analysis results

4.3.1. Institution collaboration network

Fig. 10 presents a network analyzing collaboration and social interactions [63]. It illustrates linkages over time among key institutions contributing to the PPRM domain. The dominant network, shown in red, consists mainly of Asian institutions, with the Islamic Azad University and the Shahed University as prominent members. Another network, denoted in green, involves nine participants, primarily from North American institutions. A smaller network, mainly comprising United States institutions, is also observed. The remaining linkages show one-to-one interactions between different countries. This visual representation provides valuable insights into collaborative relationships and the geographic distribution of contributions in the PPRM field.

4.3.2. Country/Region collaboration

Fig. 11 presents a Country Collaboration Map using a world map with shaded blue and gray areas, and link lines of varying width to display affiliations among countries. Dark blue shades indicate high productivity, while gray indicates no articles. The map highlights countries where PPRM is a significant topic, with the United States leading in article count (159), followed by China (118), Iran (99), Brazil (54), and Canada (37). The line width between countries represents linkage strength. North America emerges as the highest publisher, followed by Asia, while Africa shows minimal or no contribution. Notably, the primary collaboration occurs between the US and Iran. This visualization underscores global research trends and collaborative patterns in the domain.

4.3.3. Clusters by document coupling

Fig. 12 depicts a bi-dimensional Coupling Map, measuring cluster centrality along the x-axis and cluster impact along the y-axis using Callon's Centrality Index [49].

As suggested by Ref. [64], the results in figure show the behavior of the PPRM domain in terms of four quadrants:

The upper-right quadrant indicates strong centrality and impact; it contains two "motor themes" clusters. The prominent red cluster includes keywords like Project Portfolio Selection (76%), Project Portfolio Configuration (51.7%), and Portfolio Selection (60%). The blue cluster, comparatively lower in impact and centrality, comprises Project Portfolio Selection (14%), Portfolio Management (27.8%), and Project Portfolio Management (22.7%) keywords.

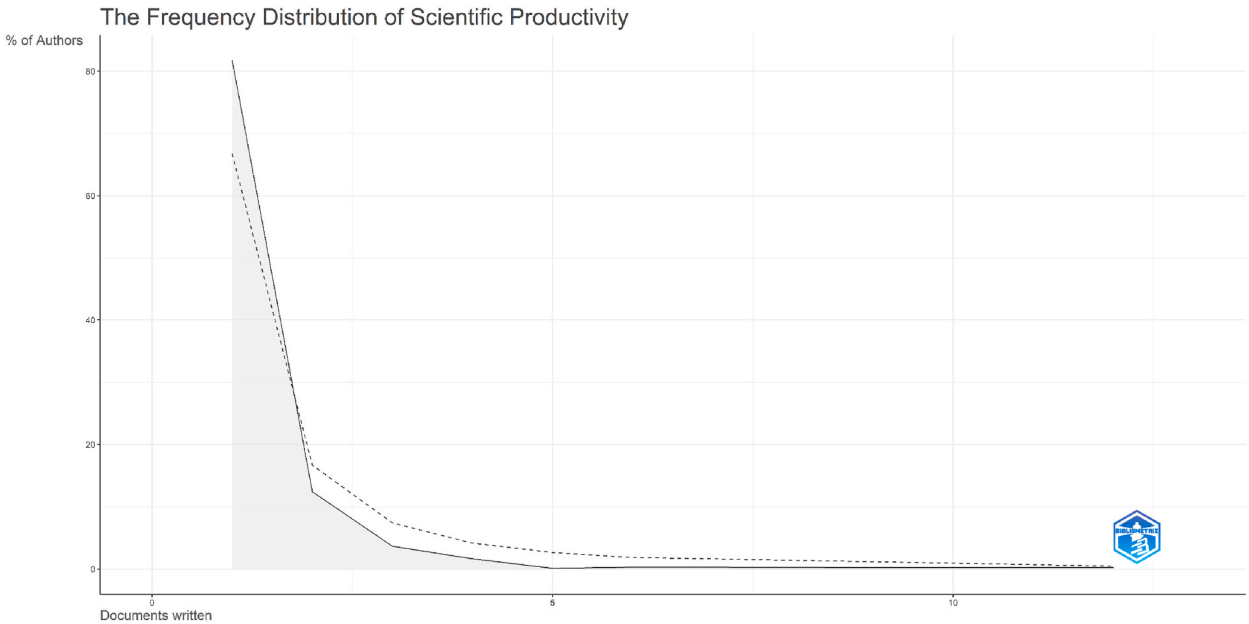

Fig. 7. Frequency distribution of the scientific productivity.
Source: Own, based on Bibliometrics 4.0, 2022 [46].

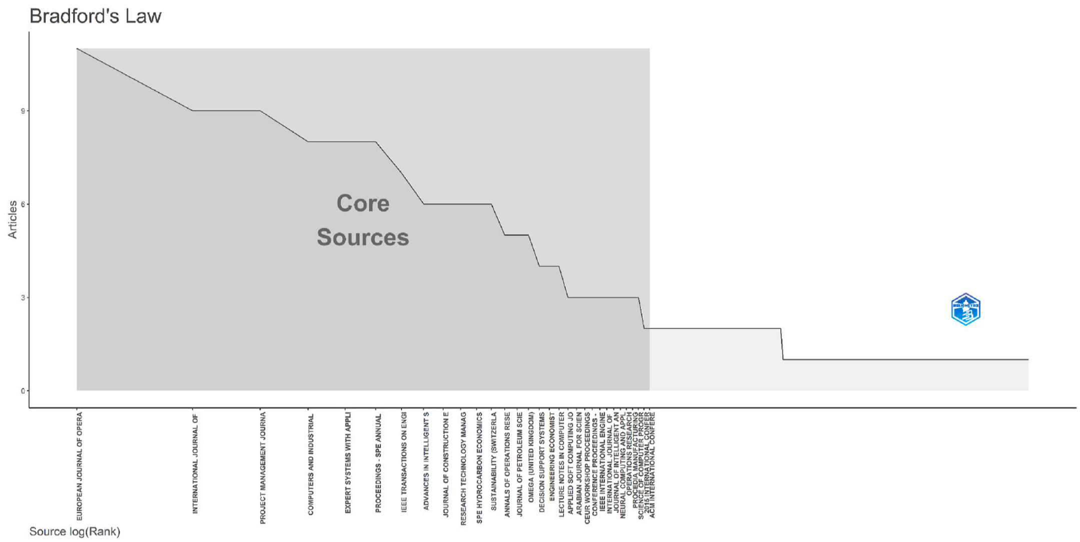

Fig. 8. Bradford's law source distribution.
Source: Own, based on Bibliometrics 4.0 2022 [46].

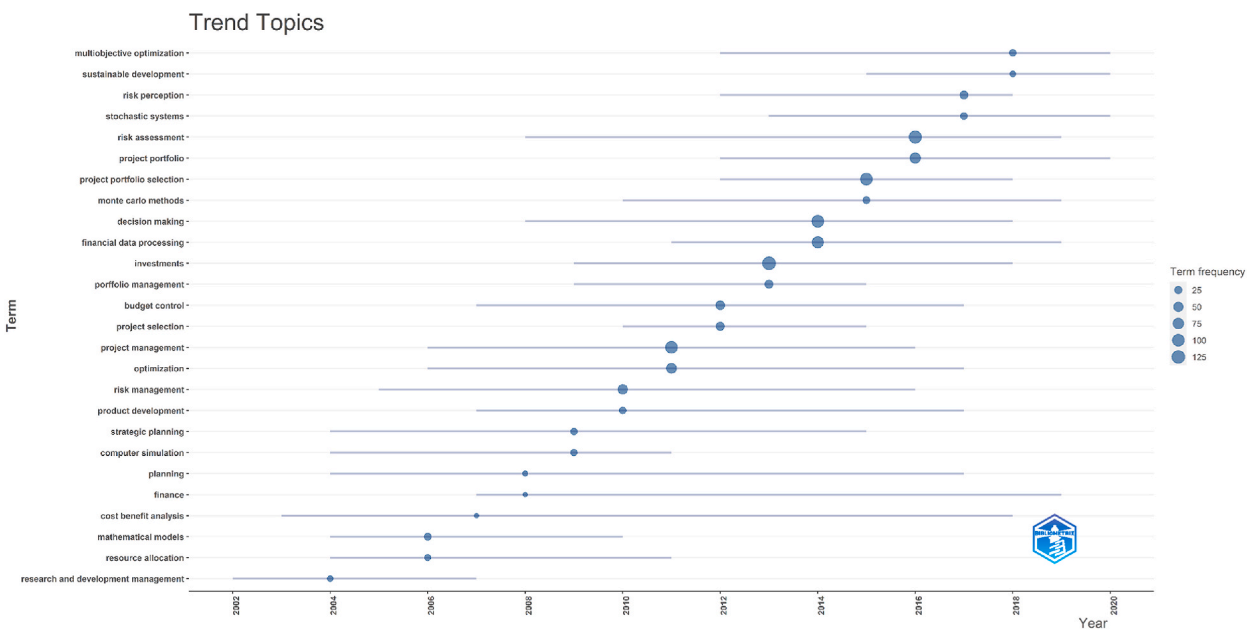

Fig. 9. Trend topics.
Source: Own, based on Bibliometrics 4.0 2022 [46].

The results for the upper left quadrant contain highly developed but isolated topics. In the PPRM area, there is only one cluster consisting of optimization (23.1%), portfolio selection (15%) and capital planning (50%).

The lower-left quadrant signifies emerging or declining themes with weaker development. In PPRM, two clusters represent this quadrant. The purple cluster includes concepts like utility function (100%), Corporate Social Responsibility (100%), and Project Portfolio (13.8%). The light brown cluster features concepts like asset management (100%), Integer Programming (33.3%), and Stochastic Optimization (20%), primarily representing emerging or disappearing themes in the domain.

Finally, the lower-right quadrant, composed by one cluster, seemed to be important for PPRM but is not well developed so far. It corresponds to basic-transversal themes: Project Portfolio Management (68.2%), Risk Management (70%) and Project Portfolio (31%).

4.3.4. Co-occurrence network analysis

Fig. 13 utilizes a sphere network layout to identify main research trends in the PPRM domain, represented by four clusters

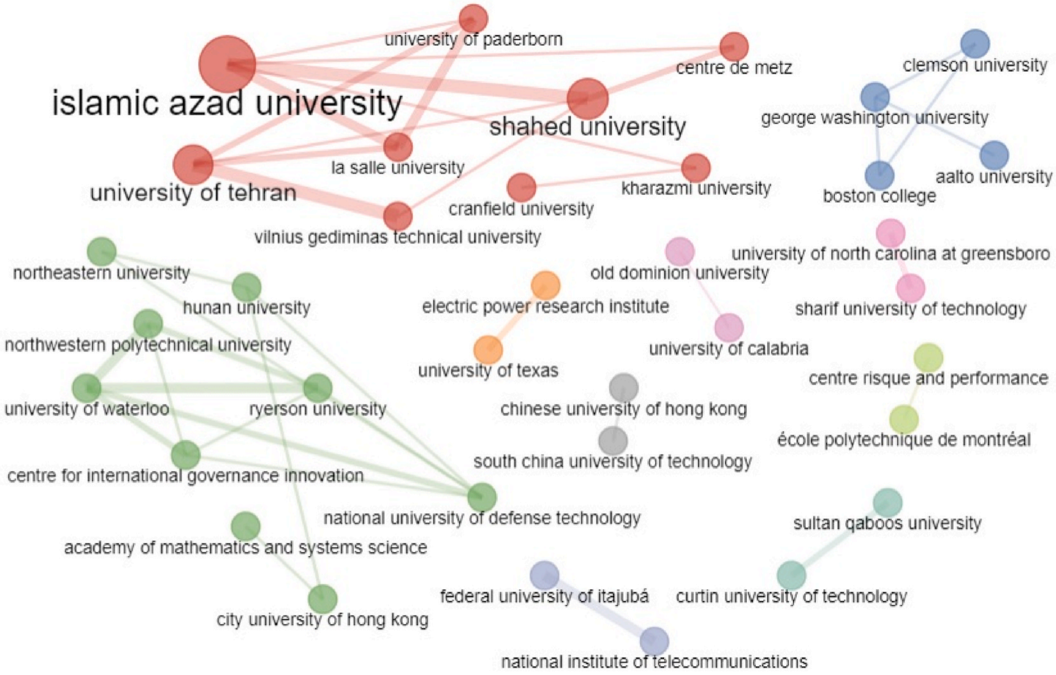

Fig. 10. Historical direct citation network.
Source: Own, based on Bibliometrics 4.0, 2022 [46].

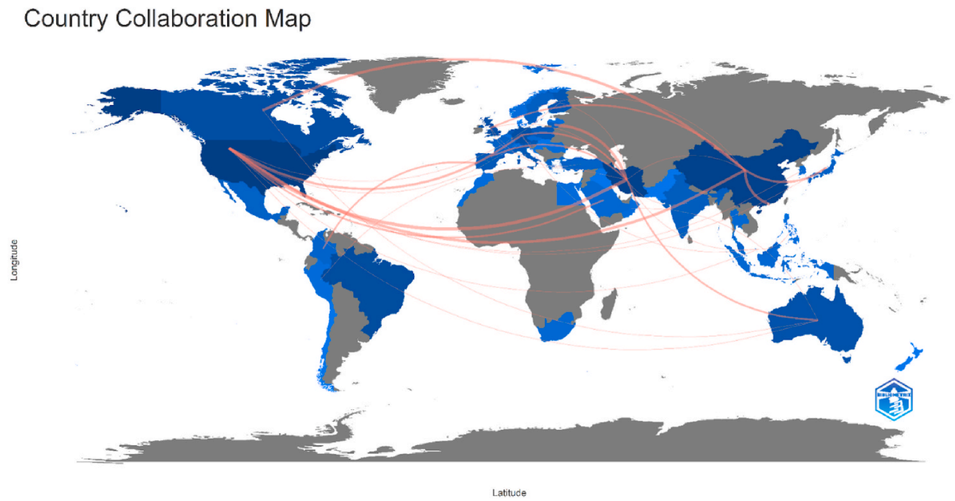

Fig. 11. Country/Region collaboration map.
Source: Own, based on Bibliometrics v 2021 [46].

displayed in red, purple, blue, and green, with red being the most prominent and green the least. Node size and link line width correspond to co-occurrence extent and relationship strength between nodes, respectively [50]. This visualization offers insights into the interconnections and relative importance of topics within the PPRM domain.

In Fig. 12, the term "Project Portfolio Selection" emerges as a prominent topic in the PPRM domain, represented by the largest red node with strong co-occurrence relationships. This central node connects to related concepts like project selection and uncertainty, forming a significant network. The purple network is led by Portfolio Management and Project Management. The blue network revolves around the concept of Project Portfolio but is smaller in comparison. Lastly, the green network, comprising only two nodes, appears to have limited influence within the overall system.

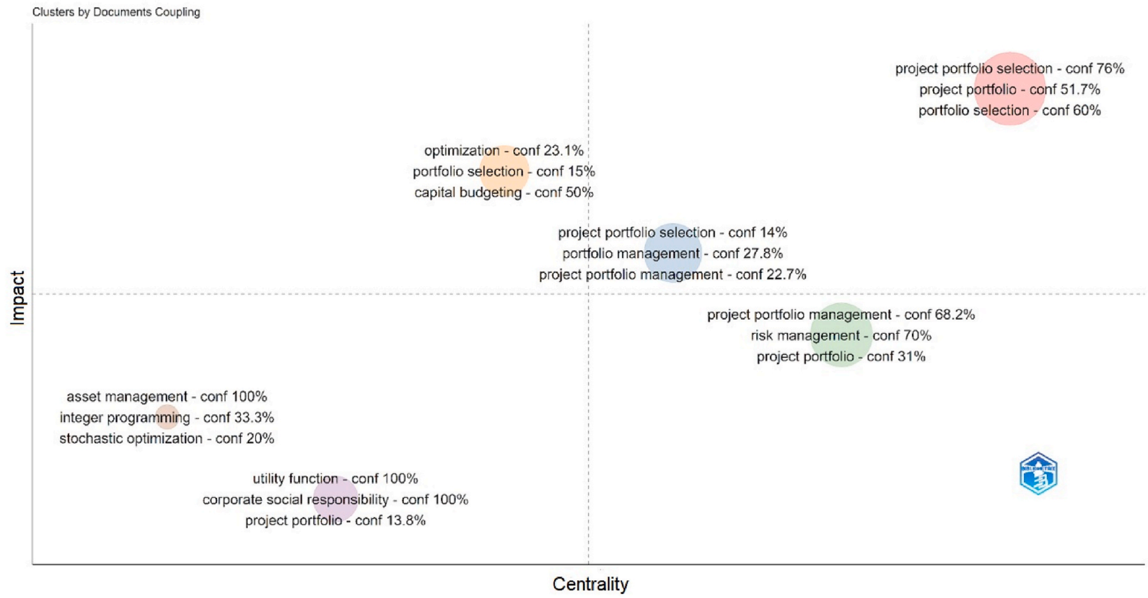

Fig. 12. Clusters by document coupling.
Source: Own, based on Bibliometrics 2022 [46].

Fig. 13. Co-occurrence Network Analysis (base on keywords).
Source: Own, based on Bibliometrics 2022 [46].

4.3.5. *Co-citation network analysis*

As recommended by Ref. [65], this approach is commonly employed to analyze intellectual structures in scientific fields. Results reveal evolving research clusters formed through co-citation pairs from various authors.

Fig. 14 shows that the co-cited papers in three clusters tend to share the PPRM as common theme.

5. Discussion

Project Portfolio Risk Management integrates strategic aspects of Portfolio, Risk considerations [3,66], and achieving organizational objectives [67]. Understanding the field's status and trends is crucial for comprehensive insights.

Scientometric analysis in Project Portfolio Risk Management (PPRM) remains limited, lacking comprehensive evidence and rigorous exploration of the field's dynamics and trends [68]. Despite new methods, there's a need for defining the field's status and guiding practitioners and scholars. This study's methodology and limitations prompt the question of its contribution to effective PPRM domain analysis.

Aiming to achieve the above, the results are discussed under six aspects that conform the main issues to support the contributions made by the authors: PPRM research themes, Performance Analysis, Science Mapping, Network Analysis, limitations, and Future Studies.

5.1. Discussion on PPRM research themes

The analysis, as in Ref. [17], utilized keyword co-occurrence to explore and depict the main research trends in the Project Portfolio Risk Management (PPRM) domain, as shown in Fig. 13. The three main clusters, centered around the keywords "Project Portfolio Selection" (red cluster), "Portfolio Management" (purple cluster), and "Project Portfolio" (blue cluster), were the focus of the investigation, allowing for an in-depth exploration and discussion of research areas and themes in PPRM.

Research theme 1 – Project Portfolio Selection problem: The study's research theme centers on the project portfolio selection problem, a "hot topic" derived from Financial Portfolio Theory, notably Markowitz's seminal work in 1952 [34,39]. Fig. 14 analysis highlights Markowitz as a highly cited author in the domain. As emphasized by Refs. [39,69], this problem involves selecting the right risk measure for evaluating project portfolio risk during investment, requiring optimal modeling of risk correlations and uncertainties associated with inputs or calculations.

Fig. 13's keyword co-occurrence network validates the research theme of Project Portfolio Selection, which encompasses optimization, mathematical programming, multi-objective optimization, stochastic programming, and robust optimization. This theme involves modeling risk correlation between projects and optimizing portfolio selection, considering both risks and benefits, much like Financial Portfolio Assessment [60,70].

Fig. 9's results highlight a research theme centered on keywords like uncertainty, risk, fuzzy logic, simulation, and decision-making. This theme focuses on defining and modeling risk and uncertainty in Project Portfolio Selection. Notably, the presence of fuzzy logic and simulation as key keywords suggests their use in explicitly representing risk and uncertainty arising from input data in portfolio selection models [[40,60]]. These findings underscore the importance of addressing risk and uncertainty through various modeling techniques to enhance decision-making in the context of Project Portfolio Selection.

The Project Portfolio Selection Problem emerged prominently in the Trend Topics analysis, with top-ranking keywords including multiobjective optimization, stochastic systems, project portfolio selection, and Monte Carlo methods.

Research theme 2 – Risk Management as a Project Portfolio Management Process: It stems from the second cluster in the keywords co-occurrence network, centered around the keyword "Portfolio Management." As highlighted by [[34,69]], it involves adopting an approach derived from Project Risk Management theory to analyze project portfolio risk. This second research theme is characterized by keywords such as Project Management, Risk Management, and Project Portfolio Risk, among others. It emphasizes the importance of incorporating risk management principles into the broader context of Project Portfolio Management.

The second approach in Portfolio Risk Management adopts principles from Project Risk Management and treats it as a process within Project Portfolio Management. It involves studying risk management processes, such as planning, identification, assessment, and response, specifically in the context of project portfolios. This research theme, highlighted by Ref. [30], primarily focuses on the portfolio execution phase, including Resource Management and Steering, allowing researchers and practitioners to gain insights into effective Project Portfolio Risk Management practices.

This cluster explores research related to shared resources between projects, interactions between risk factors, shared risk factors among projects, and risk propagation within the portfolio [30,71,72]. It emphasizes the importance of adequate risk management processes, which have been shown to positively impact project portfolio success according to Ref. [32].

Research theme 3 – Risk analysis considering social and environmental issues: This research theme is derived from the third cluster identified in the keywords co-occurrence network which is based on the keyword “project portfolio”.

5.2. Discussion on Performance Analysis

The Sources Growth metric, depicted in Fig. 3, reflects the growth rate of Project Portfolio Risk Management research in scientific journals. It quantifies the frequency of knowledge dissemination in the domain over the study period by tracking the cumulative occurrences of publications in each journal per publication year. The European Journal of Operational Research stood out as the leading journal in the PPRM field from 1970 to 2022, highlighting its substantial contribution and development in this area. This observation is consistent with findings in other fields [33].

Fig. 8's Source Distribution results were utilized to identify the core sources in PPRM. This indicator, based on Bradford's Law, reveals a pattern in the journals contributing to the domain. By sorting the number of articles into three groups, this study successfully determined the most representative journals and the nucleus of journals in the field.

The contribution of authors in the PPRM domain is evident from Fig. 5, which displays their yearly production with a red line denoting their timeline. This visualization captures the output and continuity of the most prominent authors. However, the extent to which this author profile indicates impact continuity and consistency requires discussion.

In line with [73,74], the analysis of authors' impact considers two crucial aspects: productivity (measured by the number of articles published within a specific period) and impact (evaluated by the yearly citation count). This study thoroughly examined both aspects,

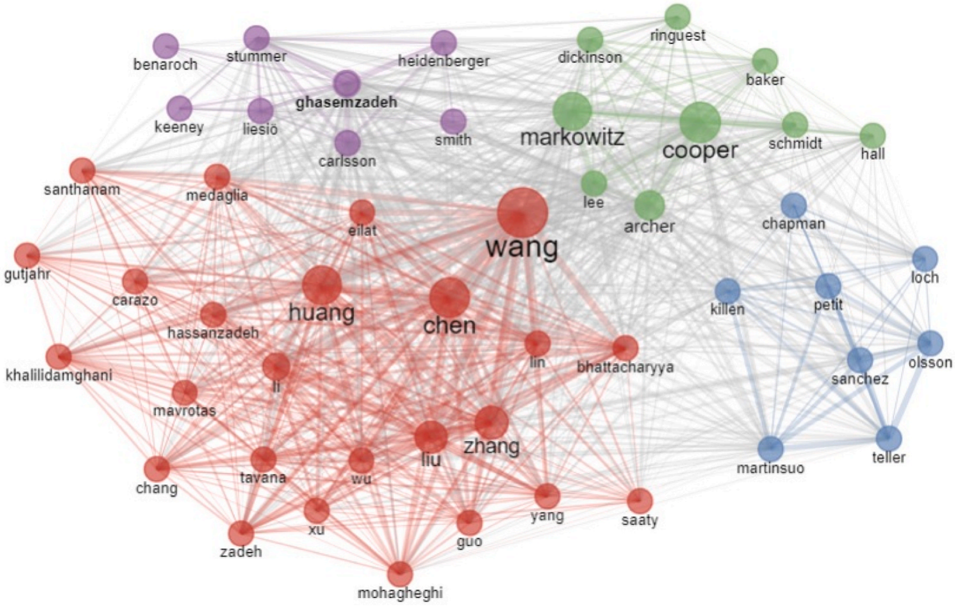

Fig. 14. Co-citation network analysis.
Source: Own, based on Bibliometrics 2022 [46].

revealing notable contributions from authors like Mohagheghi and Mousavi Sm, with papers cited between five to ten times within a five-year span. However, upon reviewing the results in Fig. 5 regarding their overall prevalence, Salo Ahti emerged as the most representative author, with papers spanning from 2005 to 2017. This demonstrates Ahti's sustained and substantial influence on the PPRM domain over time.

Examining the Frequency Distribution of Scientific Productivity, following Lotka's Law, revealed unequal author contributions within the PPRM field (Fig. 7). Confirming Lotka's principle, most authors (about 80%) have modest publication records, while a minority (under 10%) make substantial contributions, forming a prolific group driving relevant literature. This pattern underscores the distinct scientific productivity dynamics of the PPRM domain.

5.3. Discussion on science mapping

Keywordsmaps were crucial in quantifying and visualizing the thematic evolution of PPRM, providing insights into its conceptual subdomains [[64,75,76]]. This study contributed significantly by identifying major themes across four periods, offering an up-to-date overview of its thematic structure. The analysis allowed examination of topic usage, emergence, and evolution. Fig. 6 displayed 13 topics with diverse patterns, encompassing both obsolete and emerging terms. Interestingly, no specific keywords dominated the 51-year period, but certain terms emerged in the past two decades and have maintained relevance.

Two key indicators, Co-citation Network Analysis and Country/Region Collaboration Map, were utilized to explore the collaborative structure and international impact in PPRM. The Co-citation Network Analysis (Fig. 14) revealed strong clusters of 20 and 19 authors, demonstrating influential collaborations. The Country/Region Collaboration Map (Fig. 11) highlighted global distribution resulting from international cooperation, identifying countries emphasizing PPRM research. These indicators facilitated Science Mapping and Network Analysis, providing valuable insights into the collaborative and global landscape of PPRM research [63,65].

5.4. Discussion on network analysis

Network metrics were employed to analyze collaborative aspects in the evolution of PPRM science. Scientific collaboration among researchers, as emphasized by authors [77,78], shaped the domain. Fig. 14 revealed the Scientific Authorship Collaboration Network with 14 clusters. Notably, the most robust research relationships were observed among four members. The largest cluster consisted of five authors, while other clusters showed less significant linkages, primarily involving only two authors.

International research cooperation's significant impact underscores the importance of studies like this in assessing global PPRM research activities. Fig. 12's Clusters by Document Coupling analysis effectively examined impact and centrality, presenting a Coupling Map. To ensure validation criteria were met, as suggested by Ref. [79], mapped clusters had a minimum size, providing substantial evidence and distinguishing them from others. Specifically, the clusters in this study contained a minimum of five papers per year.

The Co-occurrence Network Analysis, akin to Ref. [47], identified "Project Portfolio Selection" as a "Hot topic" in PPRM. However, the thematic evolution demonstrated changing high-frequency words over time, suggesting no persistent prevalence of specific keywords in the PPRM domain.

5.5. Discussion on limitations

Despite following a valid protocol and employing comprehensive analysis strategies, the present study has some limitations. The chosen time scope may have missed important early contributions to PPRM. Future analyses should include historical background information for a more comprehensive understanding of the domain's development.

Bibliometric studies face challenges in accurately representing science mapping and research fronts in knowledge domains. Additionally, the increasing use of preprints [80] necessitates considering their inclusion in the analysis for a more comprehensive assessment.

Indicators used in Figs. 5, 10 and 14 share a common limitation with most knowledge fields in terms of citation analysis accuracy. Some authors might receive high citation counts not for original discoveries but for reviews, leading to potentially misleading results about their contributions to the field [81]. This unsolved problem in citation analysis affects the assessment of research impact in various disciplines, including PPRM.

The H-index gauged scholarly interest in PPRM, yet its limitations must be acknowledged. The search protocol involved precise keywording techniques: refining, reviewing, clustering, and incorporating trends. These steps enhanced search term accuracy and cleanliness.

The H-index effectively measures scholarly interest in PPRM, but its limitations, such as treating old and recent records equally, can distort current impact interpretation. To counter this, supplementary indicators were included for a holistic impact assessment.

Opting for a single database was a deliberate choice, as multiple databases weren't deemed necessary. Rigorous filtering removed overlaps or repetitions. The chosen databases sufficed for the study's goals, showing no notable differences or shortcomings, thus posing no significant constraint.

Despite the limitations acknowledged, once the research protocol was accomplished through the use of a large number of records to support the findings, we believe that the results and discussion have provided evidence for a comprehensive picture of the domain.

5.6. Discussion for future studies

To enhance the quality of future scientometric studies, several limitations must be addressed. Seminal literature and preprints are often overlooked when defining the time scope, warranting their inclusion for a comprehensive analysis. Accuracy issues related to bibliometric techniques and knowledge field classification based on journal scopes should also be carefully considered. To mitigate these concerns, future studies are encouraged to adopt accuracy measurement approaches as suggested by authors like Boyack and Klavans [80]. Emphasizing these aspects will lead to more robust and reliable insights into the research domain.

Relying solely on database journal codes poses a notable limitation, potentially causing inaccurate subject assignments. Despite mitigation efforts through keywording, database selection, and software, delimitation and subject assignment challenges persist in bibliometric research. Acknowledging this limitation is crucial, prompting a thoughtful assessment of the extent to which results and conclusions remain accurately extrapolatable or validatable.

We consider that, regarding the use of H index to measure the interest of scholars, future studies must use additional metrics to complement and contrast the findings to overcome the probable noise that appears when giving the same importance to old and resent records.

6. Conclusions

Following PRISMA guidelines for replicability, this scientometric study examines source dynamics, highlighting increasing interest in Project Portfolio Risk Management (PPRM). Notably, the "European Journal of Operational Research" reflects this trend. Leading researchers exhibit an H Index of 9, underscoring their impact. Despite limitations, these findings offer valuable insights with cross-domain applicability.

Project Portfolio Selection, a pivotal PPRM theme, emphasizes risk assessment and optimization, influenced by Markowitz's seminal contribution. Scholars delve into modeling project risk correlations, mitigating uncertainties in input values during investment-phase portfolio assessments.

PPRM amalgamates mathematical theories—Optimization and Modeling—for Project Portfolio Selection. Terms like Optimization, Risk, Uncertainty, Fuzzy Logic, Simulation, and Decision-making illuminate Risk correlation and Portfolio Optimization benefits. Defining and modeling Risk and Uncertainty in Project Portfolio Selection is pivotal. Fuzzy Logic and simulation depict Uncertainty, evaluating Risk. This research optimizes project portfolios by factoring in risk, uncertainty, and decision-making.

Risk management within PPRM involves handling shared resources, interactions, and propagation of risks within portfolios. Effective risk processes enhance portfolio success. Key terms—project management, risk management, project portfolio risk—are integral to this theme. Exploring shared resources and risk interactions aids risk mitigation in project portfolios.

The risk analysis theme evaluates project impact on social and environmental aspects in portfolios. It delves into shared resources, risk interactions, propagation, and overall social and environmental implications in analysis.

Keyword maps were used to analyze the thematic evolution and structure of PPRM over four periods. The study identified major themes and their emergence and trends. Results revealed diverse topics, with certain terms remaining relevant in the past two decades. The absence of persistent keywords over the 51-year period indicates the dynamic nature of PPRM research.

The Science Mapping and Network Analysis of PPRM offered valuable insights into its structure, collaboration, and impact. These approaches provided a deeper understanding of thematic landscape, intellectual collaboration, and global distribution, revealing strong author clusters and collaborative networks. The global distribution of research articles emphasized the significance of international cooperation, identifying countries where PPRM research thrives and offering insights into its global landscape and impact. Among 14 clusters, four members formed the strongest research relationships, while others showed limited linkages with two authors. This underscores the importance of collaboration and the influence of key authors in advancing PPRM research.

The field's productivity distribution followed patterns observed in other disciplines. Applying the Lotka Law, we found a concentration of scientific productivity among a few authors, while a larger group contributed less. This power-law distribution indicates the presence of a select group of highly productive authors in the field.

The Lotka Law analysis facilitated comparisons with established trends in scientific literature. It revealed that the field exhibited similar patterns to the wider scientific community, suggesting that it operates according to fundamental principles observed in other disciplines. Applying the Lotka Law provided valuable insights into productivity distribution, confirming parallel trends within the field. These findings enhance our understanding of the field's scholarly landscape and its adherence to established principles of scientific productivity.

Co-occurrence Network Analysis identified "Project Portfolio Selection" as a "hot topic," yet thematic evolution analysis showed changing high-frequency words over 51 years, indicating the dynamic nature of PPRM research focus.

To delve deeper into the network analysis, Document Coupling and Co-occurrence analyses were conducted, providing insights into impact and centrality. These analyses identified thematic categories such as motor, isolated, basic, and transversal themes, revealing the structural dynamics within PPRM. Additionally, the Co-citation Network Analysis unveiled clusters formed by co-citation patterns among authors, deepening our understanding of the intellectual structure of PPRM.

Despite adhering to a valid protocol and bibliometric principles, this study encountered limitations, some mitigated through established techniques. However, persistent limitations common in bibliometric studies warrant attention from future research, as emphasized in the future studies discussion.

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article. </p>

Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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