International Journal of
Information Systems and Project Management
ISSN (print):2182-7796, ISSN (online):2182-7788, ISSN (cd-rom):2182-780X
Available online at www.sciencesphere.org/ijispm

Project portfolio risk management: a structured literature review with future directions for research

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Abstract:
Project Portfolio Risk Management (PPRM) has been identified as a relevant area regarding project portfolio success. This paper reports on a structured literature review of PPRM. A structured search and selection process was carried out and conventional content analysis was conducted in the literature analysis of 62 papers published in international journals. PPRM has its theoretical and practical bases in the modern theory of portfolios, decision theory and risk management (RM). The content analysis reveals four main recurrent topics in PPRM: (1) The influence of RM on project portfolio success, based on project portfolio impact level, moderators or contingency factors between RM and project portfolio success, and PPRM dimensions; (2) risk and project interdependencies, highlighting resources, technology, outcome, value, and accomplishment project interdependencies; (3) project portfolio risk (PPR) identification, where four main risk source categories are identified; and (4) PPR assessment, composed of risk measures and the main methods used for risk assessment. Therefore, this study provides an overview of PPRM as a research field, while it also promotes four future research directions: (1) PPRM as part of organizational RM; (2) RM, success dimensions and strategic impact; (3) mechanisms for PPR assessment, and (4) PPRM as a complex and dynamic system.

Keywords:
project portfolio management; project portfolio risk management; structured literature review; research opportunities.

DOI: 10.12821/ijispm080304

Manuscript received: 3 December 2019
Manuscript accepted: 16 May 2020

1. Introduction

Project Management (PM) has gained increasingly more attention in organizations, generating a greater allocation of human and financial resources, organizing work into projects, increasing the number of projects to be implemented and establishing a relationship between projects and the organization's strategy, as well as expanding the scope and complexity of PM [1]. In this context, Project Portfolio Management (PPM) emerged, representing the coordinated management of a set of projects carried out by a specific organization, which allows for strategic management of the projects, throughout which scarce resources are balanced, and for guiding the portfolio to achieve strategic benefits [2-5]. Nevertheless, the positive impacts in the organization may not be as expected due to project and portfolio risk effects [6]. Therefore, one key area for PPM is risk management (RM) [7, 8].

The literature shows that managing risks only at the level of projects is not sufficient because a strategic and holistic view of risk is not considered [9, 10]. It does not include other important considerations about RM in its own project portfolio environment [6, 7, 10], or the effect generated by the interdependencies between projects and between risks [9, 11]. Project portfolio risk has been studied from different perspectives, for example from project portfolio selection with risk considerations[12, 13] and from project portfolio execution [9], as well as from the point of view of project portfolios in project-based companies, such as technology information portfolios [14-16], oil and gas production portfolios [17] and construction project portfolios [18]. It has also been studied from the perspective of project portfolios associated with organizational strategic development or generic portfolios [7, 12, 19, 20]. The above evidences that RM applied to project portfolio decisions is of interest and relevance for the different types of project portfolios identified in organizations.

Thus, a body of literature concerning Project Portfolio Risk Management (PPRM) has been generated, providing knowledge and understanding about objectives, features, and the impacts of PPRM. In this regard, a structured analysis of the literature would allow an overview of the current state of PPRM to be obtained, and a systematic classification of the progress to be made in acquiring knowledge in the PPRM field, thus contributing to a better understanding of the current issues and to the identification of the possible future research opportunities open to PPR researchers. Therefore, this research intends to contribute towards outlining PPRM as a research field, for which two research questions were formulated: (1) What are the main topics and debates in the literature on PPRM? (2) How can future research expand the PPRM research area? A structured review of the literature on PPRM was carried out and Content Analysis (CA) was conducted in order to answer the research questions. While it is recognized that projects, programs and portfolios are interrelated [21, 22], the scope of this literature review was limited only to RM applied to project portfolios.

The remainder of the paper is organized as follows. Section 2 presents the PPRM conceptualization adopted in this research study. In Section 3, the methodology used in the literature search and analysis process are reported. The findings are described in Sections 4 and 5. Section 4 presents analysis of the 62 papers that met the inclusion criteria, which lead on to a description of four recurrent topics identified in the literature on PPRM, while in Section 5 future directions for research are identified and described. Finally, the conclusions are summarized in Section 6.

2. Project portfolio risk management conceptualization

A project portfolio is a collection of single projects and programs that are carried out in an integrated way, through which an organization seeks to achieve its strategic objectives, by managing the interfaces between projects and balancing scarce resources across projects and programs, as well as risks and benefits [7, 23]. In this regard, Bathallath et al. [24] highlight the importance of project interdependency management in the success of project portfolios. From a PPM process perspective, three generic, interdependent and recursive main phases are described in the literature [25, 26]: portfolio structuring, resource management and portfolio steering. Portfolio structuring is associated with strategic planning cycles, which include portfolio planning, and the selection of projects according to the organization's strategy. Resource management implies resource allocation across projects, with the resource management carried out in an integrated way. Portfolio steering comprises a permanent execution and coordination of the portfolio, monitoring the different aspects defined as key aspects for each portfolio.

Establishing the difference between the concepts of risk and uncertainty is of the greatest importance because this determines the RM scope, as well as defining the characteristics of the risk assessment and the design of response strategies [7, 11, 14, 27]. Different risk perspectives have been identified in the project portfolio context: a first perspective proposes that the variability that can be quantified in terms of probabilities is considered as risk, while the variability that cannot be quantified at all is best thought of as uncertainty [28]. In this perspective, risk and uncertainty represent outcomes. A second perspective proposes that all uncertainty components can be measured and split in three components: insignificant events (events without major effects on the project portfolio), positive events, and risk events, where the latter are those that can threaten project portfolio success [11]. A third perspective proposes risk as a consequence of uncertainty, this approach being quite popular [7]. This third perspective has been widely used in project portfolio selection with risk considerations, where the uncertainty is represented using stochastic variables. These denote the inputs, while the risk is the output that represents the extent to which the expected results are affected as a consequence of the behavior of the inputs [29–32]. In all the approaches identified, the risk is characterized by its measurable attributes, such as probability distribution, occurrence likelihood or impact [11, 20, 33].

RM is concerned with how decision-makers define the type and level of risks that they consider appropriate for each decision at each time. RM is, therefore, focused on how to make choices concerning risks, considering the possible reward and its possibility of success by means of managing people, processes, data, and projects [28, 34]. In this regard, previous studies show the limitations of the traditional RM approach, since it is oriented to individual projects, ignoring the integration levels and the interaction of information, while the domain of PPRM allows RM activities to be consolidated, thus avoiding a duplication of effort and resources [6, 7, 9]. The origins of PPRM can be traced to the works of Markowitz [35]. Hofman et al. [7], Sanchez and Robert [36], and Teller [27], among others, has identified PPRM as one of the fundamental areas of work and research in PPM, and as a fundamental topic in relation to project portfolio success.

Consequently, this research has adopted the perspective that PPRM must focus, among other things, on the identification and balance of the risks of the project portfolio, while seeking to maximize the value delivered to the company, reflected in the impact achieved on strategic goals. As such, PPRM must focus on reducing negative risk impacts and potentializing opportunities, while considering and evaluating the interdependencies among risks and among projects, as well as the management capabilities of the organization [7, 9, 11, 37].

3. Methodology

3.1 Research design

This study follows a structured literature review process. In the PM field, structured literature reviews have been adopted, among others, by Araújo et al. [38], Laursen and Svejvig [39], and Miterev et al. [40]. Svejvig and Andersen [41] summarized the literature review process in five steps: planning and scope definition; conceptualization of topic; searching, evaluating, and selecting literature; literature analysis; and report and disseminate. Fig. 1 summarizes the literature review process.

3.2 Data collection

In the *planning and scope definition step*, it was defined that only articles published in scientific journals would be considered. According to Rowley and Slack [42], in professional disciplines, articles in scholarly and research journals should form the core of the literature review, since this literature source has been peer-refereed prior to acceptance for publication, and contains critical treatment of concepts and models. The articles selected should include PPRM as their main topic or, if the main topic is not PPRM, their main objective should show a specific and explicit relationship with PPRM. It was also defined that the literature search would be carried out using the SCOPUS and Web of Science -WoS- databases, given that they cover a wide range of peer-reviewed and high quality scientific journals.

Some publications, such as Hällgren [43] and Söderlund [44], carried out their literature review process based, respectively, on the most relevant journals related to project management and on management and organization journals outside the conventional project management publications. However, and similarly to Laursen and Svejvig [39], the literature review carried out in this study had the goal of including a wider range of publications related to PPRM, and therefore the scope of the search process was not restricted to specific journals.

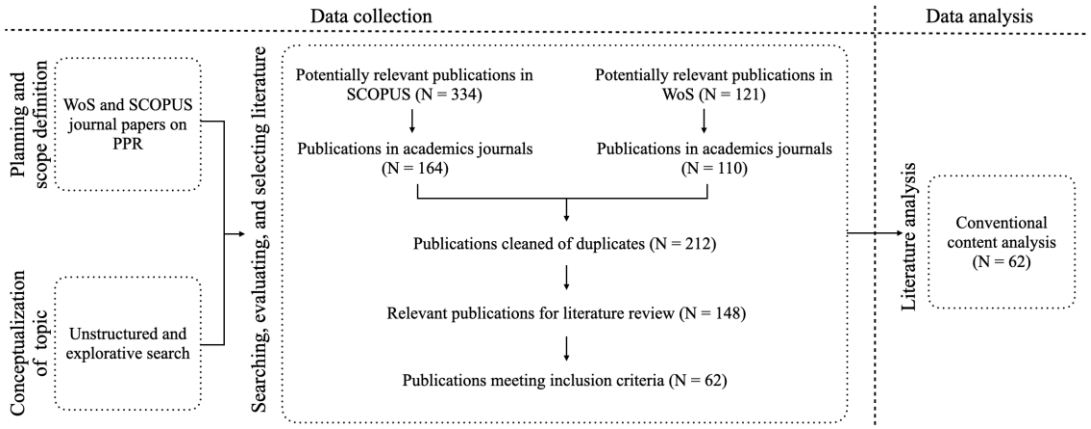

Fig. 1. Structured literature review

The second step is associated with *conceptualization of topic*, for which RM, PPM, and PPRM were conceptualized as key concepts, as well as the risk and uncertainty approaches in the PPRM context. Project portfolio selection with risk considerations is a research topic that has seen important developments and it represents the beginning of RM being applied to project portfolio decisions, with Markowitz' work seminal in the area [28]. The main publications used specifically to conceptualize the PPRM topic were: [2, 7, 9, 45-47].

Selecting literature corresponds to the third step. Based on the contextualization of the topic, it was defined that, for papers related to PPR applied to portfolio execution, in its function as an emergent topic [6, 7, 9, 27], the year filter would not be applied. Although, for project portfolio selection with risk considerations, the year filter selected was 2015 onwards (up to the end of December 2018), since this is a topic with a large number of publications, and according to Dobrovolskiene and Tamošiuniene [48] earlier works are generally included in the latest research. The keywords identified as part of the conceptualization of topic were used in an iterative evaluation of different search strings. The string search that best grouped the publications on PPRM was "project portfolio" and "risk" in the categories of keywords, title and abstract.

349 works that met the search equation used were identified in SCOPUS and 121 in WoS. Selecting only words published in academic journals and discarding paper duplicates between databases, 212 publications were identified. Applying the year constraint defined in the *planning and scope definition* step (2015 - 2018) for project portfolio selection with risk consideration publications, coupled with the abstract and introduction section reading of the papers selected, 62 papers were selected for the literature analysis process (30 related to project portfolio selection with risk considerations and 32 associated with PPR applied to project portfolio execution). Table 1 presents the five journals in which more than one paper was selected, representing a total of 18 of the 62 papers selected for this study.

The remaining 44 papers were each published in a different journal, such as 'Operations research', 'Omega (United Kingdom)', 'Production and operations management' or 'International journal of fuzzy systems', among others. The publications selected are identified with the character '*' in the list of references.

Table 1. Journals in which more than one paper published

Journal	Number of publications
Project Management journal	6
International Journal of Project Management	5
Sustainability (Switzerland)	3
International Journal of Managing Projects in Business	2
International Journal of Information Systems and Project Management	2
International Journal of Project Organisation and Management	2

3.3 Data analysis

Literature analysis was based on CA. CA allows for the interpretation of the meaning or usage of written data, organizing information into relevant categories for each specific research work, and establishing an understanding of the topic being studied [49, 50]. Three main approaches can be used to conduct CA: conventional, summative, or directed [49]. Summative CA is the most quantitative approach, seeking as it does to explore the contextual use of words, and the findings may be explained using descriptive statistics associated with the frequency of use of particular words or phrases in specific contexts. Directed CA requires that data codes and categories be defined in order to apply them deductively to code the data; as a fundamental purpose, it adds credibility to a theoretical framework or conceptually extends a theory. Conventional CA "provides a much more comprehensive picture of the phenomenon, through new insights exclusively grounded in the data, than the other two types" [49, p. 830].

In this regard, conventional CA was implemented for the literature analysis reported in this paper. Conventional CA is the most inductive type of CA, it being a descriptive approach [49]. In this approach preconceived categories are not defined; conversely, categories and new insights emerge from critical and reflexive analysis [49, 50]. In order to identify recurrent overarching topics and future directions, a sequential cumulative process was implemented. The literature analysis was based on a chronological analysis of the publications (from oldest published papers to most recent papers), and, for each analyzed publication, one or more preliminary categories and subcategories associated to current topics and related to future directions were identified.

To the extent that publications were analyzed, the categories identified (both recurrent topics in PPRM and future directions of PPRM) from each paper were contrasted among categories identified in the publications analyzed previously, defining a preliminary set of categories and their composition and attributes. To carry out this analytic process, a set of five papers were analyzed for each analysis cycle, and, once the preliminary categories were established, a new analysis cycle was carried out based on the next five papers.

As part of the literature analysis cycles, sometimes it was necessary to re-analyze some papers previously analyzed, in order to confirm, extend, or redefine the information established from those papers regarding the possible new categorization structure. Thus, as publication analysis progressed, it was necessary to define, add, merge, divide, or reconstruct the categories or the subcategories in accordance with the new information obtained from each newly analyzed publication, forthwith until a final categorization was reached.

Once a final categorization had been defined, the information regarding subcategories was analyzed in order to obtain a consolidated description of each general category, both regarding recurrent topics in PPRM and future directions of PPRM. The results concerning recurrent topics and future directions are shown in sections 4 and 5 respectively, in which each final established category corresponds to one subsection of each section.

In order to define the categories regarding recurrent topics in PPRM, for each publication the following issues were analyzed: the general problem that framed each study, the specific research question or research objective documented, and the background reported. Then, the method, approach, or methodology developed or applied and the results of each

study were analyzed, on the one hand, regarding the respective research objective, and, on the other hand, regarding a general perspective of PPRM as a research field.

To complement this, the analysis carried out regarding the general problem and the specific research question or research objective became an input for the identification of future directions. Thus, general research problems identified and RM requirements were contrasted with the results described in each paper analyzed, in order to identify and consolidate the future directions of PPRM. So, based on that information, a specific analysis of the limitations, assumptions, conclusions, or future directions reported by each publication or identified as part of the paper analysis, was carried out.

4. Analysis of project portfolio risk management

In order to answer the first research question: 'What are the main topics and debates in the literature on PPRM?', four main categories (topics) were derived from the inductive analysis, providing knowledge and understanding of the relevant concepts, approaches and methods regarding PPRM, so that it is natural that the categories present some overlapping between them. The main current topics identified were 'Influence of RM on project portfolio success', 'Risk and project interdependencies', 'PPR identification and categorization', and 'PPR assessment'.

4.1 Influence of RM on project portfolio success

Portfolio value cannot be measured only in monetary terms; it is also necessary that other measures and strategies to assess strategic impact be identified [19]. Table 2 summarizes the categories identified in the literature associated with RM and its relation and influence on project portfolio success.

Table 2. Categories of influence between RM and project portfolio success

Categories	Subcategories		References
Project portfolio impact level	Company strategic objectives and project portfolio expected results		[19, 36, 51]
	PPM objectives or project portfolio success dimensions		[9, 27]
Moderators or contingency factors between RM and project portfolio success	Risk management quality	Risk transparency	[8, 27]
		Risk coping capacity	
		RM efficiency	
	External turbulence and Portfolio dynamics		[6]
PPRM dimensions	Role Clarity		[8, 27, 52]
	Formalization		
	Risk management process		
	Integration of risk management		
	Risk management culture		

A concept related to portfolio risk and portfolio success is 'portfolio health', which represents the level of the project portfolio's performance in each evaluation period [36, 53]. Project performance analysis based on project success key indicators is considered as part of project health analysis [29]. As such, a healthy portfolio achieves adequate performance in its projects and at the portfolio level. In this regard, risks and unappropriated RM decisions could impact portfolio health [47]. Finally, in project-oriented companies, the PPR analysis is equivalent to the corporate or

operative risk analysis, because in this type of organization project portfolio success is directly associated with business operation success, since, in these companies the project portfolio is the central axis of operations [9, 15, 54].

4.2 Risk and project interdependencies

Although integration and cooperation between projects in a portfolio can increase efficiency, this, in turn, requires greater effort in PPRM because it also generates an increase in PPR [55]. Risks that can otherwise be considered as having a low impact on an isolated project may be correlated with the occurrence of the same risk in other projects in the portfolio, as well as with the materialization of other risks in the same project or in other projects [56]. The difference between correlation and interaction was an important aspect identified in the study, since the effect on PPR is significantly different for each case [57].

Interdependencies between projects are common, either in technical aspects related to project execution, or in commercial aspects associated with business issues. Interactions or synergies between projects can bring positive or negative contributions to the expected benefit and, as a whole, to the project portfolio [57, 58]. In temporal terms, two types of relationships between projects have been defined: inter-temporal or dependencies, associated with the impacts generated from the execution of previous projects; and intra-temporal or interdependencies, related to the common aspects between projects [9, 54, 59]. The relationship between projects can also be divided into inputs for PPM and outputs for project portfolio [11, 19]. Based on the works of Heinrich et al. [59], Olsson [54], Sanchez et al. [19], Guan et al. [11], Ghasemi et al. [9] and Neumeier et al. [55], Table 3 synthetizes the type of project interdependencies.

Table 3. Categorization of project interdependencies

		Inter-temporal	**Intra-temporal**
Input	*Resources:* Sharing resources between projects		X
	Technology: Using a specific technology in several projects		X
	Outcome: Using the end result, knowledge or capabilities gained from other projects	X	
Output	*Value:* Total value of two projects being greater or less than the sum of their individual values		X
	Accomplishment: Increase of probability of success of a project as a result of undertaking another project	X	X

4.3 PPR identification and categorization

The concept related to systematic risks and non-systematic risks, derived from the Modern Portfolio Theory, is presented as the basic conceptual factor with regard to a project portfolio's risk sources [15, 53]. Project portfolio non-systematic risk, or independent risk, corresponds to the inherent risks of each project, while systematic risk, or interdependence risk, is related to the project portfolio's exposure to environmental and market conditions, corresponding to risks that affect the portfolio globally. However, systematic risk has two permutations in the literature: on the one hand, it is exclusively associated with environmental factors [15], while, on the other hand, apart from environmental factors, it includes risks from the relationships between projects [53].

Interdependent risks can generate two impacts. On the one hand, risk integration generates PPR reduction, but, on the other hand, new risks arise from the interaction, thus generating an increase in PPR [11]. For this reason, 'systematic risks' and 'non-systematic risks' represent a dichotomist risk categorization that allows for the establishment of the level (project or portfolio) at which the portfolio can be impacted, or impact level.

Regarding risk sources in the PPM context, different risk categorization structures have been proposed [7, 9, 11–13, 16, 17, 20, 53, 60], for both generic project portfolios and for specific project portfolios, such as those in IT, construction, or new product development projects. Risk categories identified by these authors are associated to a project portfolio's

level of risk source, without representing a specific relationship to the extent of impacts on the portfolio in general or only on some projects within the portfolio. Table 4 synthetizes the four risk source categories, under which more specific sub-groups of portfolio risk sources can be classified.

Table 4. PPR categories and subcategories

Category	Subcategories
Project portfolio management level	Inadequate aggregation and distribution of information, portfolio imbalance and stakeholder management [9, 20]. Conflicts among managers of projects, conflicts among portfolio element managers and the company´s senior managers, conflicts between stakeholders or organizational culture adverse to change [20, 53]. Lack in project portfolio management capabilities [9, 20, 53].
Project interactions	Resource interdependencies and lack of sufficient resources [9, 13, 20]. Relationship between projects where developing one of them depends on one or more outputs from another project [11, 53].
External conditions	Supplier and contracts [16, 60]. Changes in external conditions, such as norms, competitive environment, policies, or economic conditions [12, 16, 17, 60, 61].
Organizational conditions	Improper portfolio structure, structural reorganizations of company or portfolio, or changes in internal policies [16, 45, 53]. Fund arrival rate [12, 17, 20]. Changes in the basic parameters of projects and programs [16, 20, 60]. Project and program life cycle management processes [12, 20, 60].

4.4 PPR assessment

In order to obtain an adequate representation of risk impact, two characteristics must be considered. The first characteristic is the consideration that risk corresponds to a multidimensional measure [19, 55]. The second is the strategy for risk factors, or uncertainty representation, in order to obtain a measure of risk as a consequence [32]. In order to represent or optimize project portfolio risk, different methods have been used. Table 5 summarizes the main methods used for this purpose.

Some approaches used to assess portfolio risk are based on historical data. However, the literature highlights that generally limited or imprecise information hinders whatever process occurs in this way [56, 63]. In order to address uncertainty from the real-world perspective, alternative approaches like Montecarlo simulation, fuzzy logic, and occurrence likelihood evaluation have been used, capturing, as they do, uncertainty as an input to decision-making models based on expert judgment [9, 67–70]. Recent studies show that the fuzzy approach has not yet been fully applied in the project selection problem [71], and it has not been implemented for risk analysis in the project portfolio execution context. Montecarlo simulation also shows a very low level of incorporation into the portfolio execution phase, while being widely implemented in project portfolio selection with risk considerations, as incorporated by Neumeier et al. [55] and Panadero et al. [29].

Expected shortfall, tail conditional expectation, standard deviation, semi-standard deviation, semi-variance, value at risk (VaR), and conditional value at risk have all been identified as project and project portfolio risk measures, of which the VaR method is most frequently used in RM [66, 72, 73]. However, it is important to consider that the conditional value at risk method “provides more information than VaR and is a commonly used risk measure in portfolio optimization models” [72, p. 1654]. In this regard, the set of projects selected for a specific strategic period may be different if the risk measure used is one or another, meaning that each risk measure may lead to a different set of projects to be selected [66].

Table 5. Main methods used for risk assessment or optimization in the project portfolio context

Method	Description
Modern Portfolio Theory [62–66]	This model uses the trade-off between risk and returns to find the efficient frontier. It is based on the traditional Markowitz mean-variance model, but other risk measures have been implemented in order to optimize a portfolio of non-divisible projects. In this regard, this approach establishes the set of projects that minimize the PPR level according to a defined return or that maximize the project portfolio return according to an established risk level.
Data Envelopment Analysis [60]	DEA is a non-parametric model for measuring efficiency or the capacity to have an input and an output and even several inputs and outputs using the ratio of outputs' weighted sum to the inputs' weighted sum. In the project portfolio context, the objective function of this model tends to maximize portfolio efficiency while minimizing the risk, generating an efficient frontier.
Analytic Hierarchy Process [12]	The process of project portfolio selection considers the set of projects and their decision criteria and sub-criteria. A comparison between each pair of criteria is carried out in order to obtain the weight (relative importance) of each criterion and sub-criterion. In the same way, each pair of projects are compared for each criterion. In this context, criteria related to risk for the project or for the portfolio are included as part of the evaluation process.
Complex network theory [10]	This is based on the identification of nodes that represent interdependencies between projects, establishing a structure of how projects are connected to each other. Based on the role analysis of nodes in a portfolio as a network, the method seeks to minimize the risk level while improving the efficiency of the portfolio through cooperation between projects, for which small communities or subgroups of projects are established.
Bayesian networks [9, 11, 18]	Bayesian networks assess cascading effects. They allow for technical, resource, and risk interdependencies to be assessed through a transitive dependencies model. In a Bayesian network, nodes correspond to random variables and arcs specify direct causal relationships between the linked nodes. A Bayesian network has conditional probability distributions for all variables.

5. Future directions for research

In answer to the second research question: 'How can future research expand the PPRM research area?', four directions for future research on PPRM were identified, which should not be regarded as an exhaustive set of future directions given that each can be expanded upon and, indeed, other future directions could be identified through different or complementary analysis. Fig. 2 summarizes these future directions and outlines each main focus, also showing the relationship between future directions and the main current topics identified in the previous section.

5.1 PPRM as part of organizational RM

There is a gap between RM processes, the requirements of a project portfolio threats/opportunities management, and the strategic management of threats and opportunities [54, 74]. A RM system at the project portfolio level should generate high visibility of the state of the project portfolio for top management, and it should allow planning and execution of threats/opportunities management in an integrated and coordinated manner throughout both the project life cycle and the project portfolio life cycle [54, 75]. In this sense, the integration of PPRM into the project and program level and into the organizational level using Enterprise RM systems, and other methodologies that allow a global and dynamic vision, should be explored, both in a theoretical sense and in its practical dimension. As a complement to this, risk visualization systems - the relationship with performance variables, with decision variables and their behavior over time, need to be explored. Indeed, the proposal by Silva et al. [76] and Wang et al. [10] can be seen as an example of this.

RM skills as management and dynamic capabilities according to the dynamic and changing environment of current organizations, and according to the culture and competitive environment of each organization, can be considered as relevant topics in the decision-making process [74, 77]. However, descriptions of how to incorporate dynamic capabilities in practice are rare, for which reason empirical studies on this topic are needed [16].

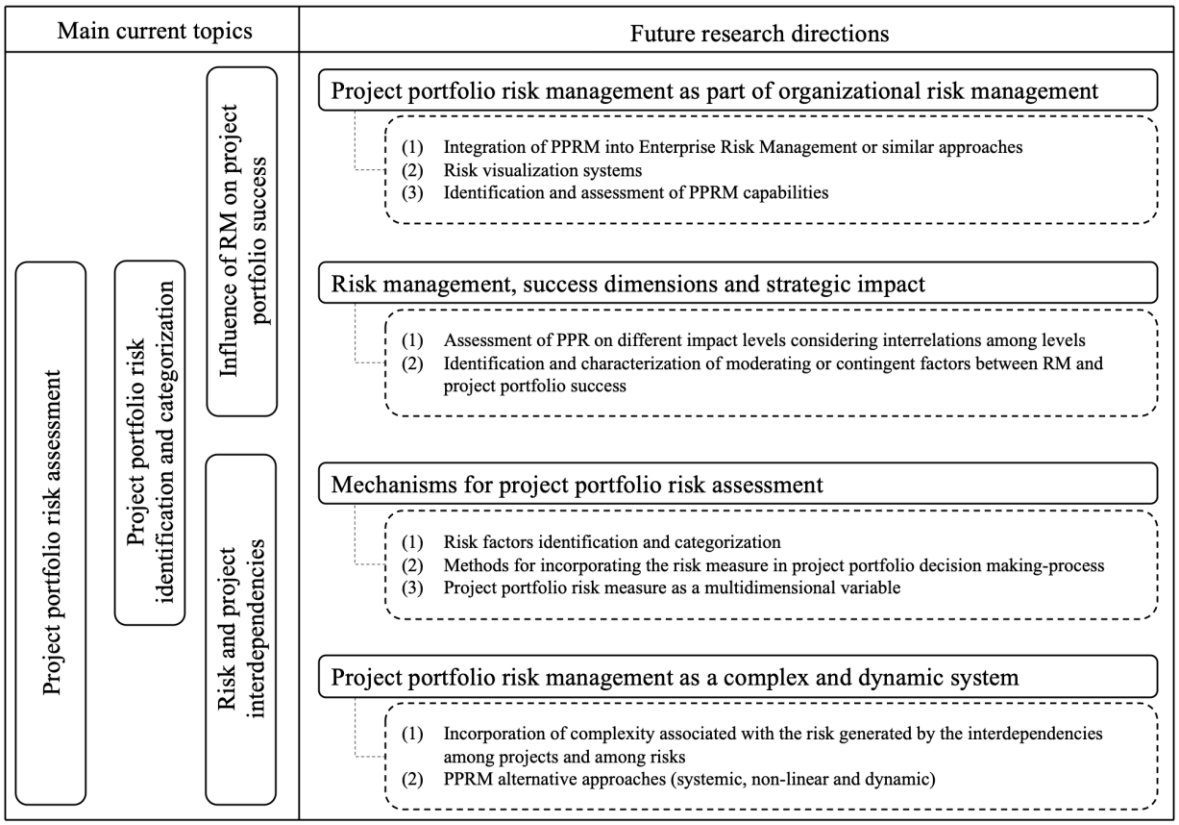

Fig. 2. PPRM main currents topics and future directions identified

5.2 RM, success dimensions and strategic impact

Different levels associated with the impact of PPRM have been explored. Thus, future research could focus on establishing hierarchies between the identified levels, as well as interrelations between levels and intra-relations within each level, which, in turn, would allow the impact of the risk factors in each decision level to be established. To pursue this, empirical studies, historical information analysis and expert judgment, among other means, can be used to obtain methods, methodologies and indicators that allow for the identification and evaluation, both qualitatively and quantitatively, of the relationships between each level and the effect of the threats/opportunity factors on each of the decision levels. In this regard, conceptual frameworks have been proposed to determine the impact of the risks and opportunities on strategic and operative aspects that allow the performance of the portfolio to be monitored from a strategic perspective [8, 19, 78]. The extension of these proposals to practical applications that allow for their validation in the real context of each organization is necessary [7, 78].

From another perspective, research focused on the evaluation of RM, riskiness, or the interdependencies between projects as contingent factors between PPM and project portfolio success will allow the importance of the PPRM to be qualified and quantified, and will identify which conditions, environment characteristics or project portfolio characteristics represent aspects to be considered for adequate PPRM [52, 77, 79]. Additionally, to identify and underline the time effects, longitudinal studies would have to be employed [79], which could allow for assessment of the time effect between RM and project portfolio success. Likewise, the identification and characterization of moderating or contingent factors between RM and project portfolio success has been and should continue to be a focus of attention. Thus, empirical studies based on practice and those methodological proposals oriented to establishing the

influence of different moderating factors must be developed. Identification of these factors allows for spotting RM capabilities and establishing strategies to deal with threats and opportunities [8, 19, 74].

5.3 Mechanism for PPR assessment

Different categories of risk factors have been proposed in the literature. However, additional studies are required to broaden the sample size and expand upon the approaches used to obtain results that can be generalized and that determine that the categories defined are feasible in practice [9, 15, 20]. PPR categorization should be developed based on practice and expert judgment.

PPR assessment raises the need to integrate different dimensions [12, 80]. In this regard, the definition of the weight for each of the risk dimensions is a determining factor that can generate major differences in the final result. Besides this, moderating factors must be taken into account, such as the fact that the project portfolio size may have a moderating effect on the allocation of weights [15, 61]. Thus, two aspects should continue to be explored. The first is associated with the types of methods and risk measures to be implemented according to the context and information available for each project portfolio, taking into account the differences established in the literature between risk measures [63, 81].

The second aspect to be considered is associated with the use of methods that allow for the incorporation of multidimensionality. Since the incorporation of risks into project portfolios is considered a multi-criteria problem, both optimization approaches and multi-attribute approaches should continue to be explored [48, 53, 82], in the perspective of seeking to consolidate the risk inherent in a measure or a subset of measures for the project portfolio and not just in each isolated project.

5.4 PPRM as a complex and dynamic system

It is generally assumed that projects are independent, with dependencies considered only when related to the sequence between projects, rarely exploring other types of dependencies [9, 55, 82]. The gaps in the literature regarding these issues, mainly associated with generic frameworks not adapted to the characteristics of the PPM environment, require that risk identification and RM go beyond this, considering the complexity associated with risks generated by the interaction between projects, risks at the project level and at strategic levels [9, 55].

Exploring alternatives to the traditional process-based approach is necessary: in the literature there are approaches to project portfolios, such as networks, knowledge networks, biological networks or complex and adaptive systems [9, 10, 55, 78], and it is necessary to deepen analysis of these alternative approaches and their application. The identification and exploration of other alternative approaches that allow a systemic, non-linear and dynamic representation, which supports the decision-making process, should also be considered [10, 55].

Approaches such as those proposed by Wang et al. [10], which look at finding the balance between project portfolio efficiency and risk through the identification of project subgroups, have great theoretical and practical importance. They make it possible to reduce not only the complexity of the decision-making process, but also to reduce the risk associated with interdependencies, generating a globally positive impact on PPR. In addition to this, approaches based on the concept of learning from information in projects and portfolios that have already been executed, such as artificial neural networks, can also help to understand the relationship between variables that make up the decision-making process [83].

6. Conclusions

The research reported in this paper has two main contributions to make. Firstly, it identifies the main topics and debates in the literature on PPRM. In this regard, this study has shown that PPRM has its theoretical and practical bases in the modern theory of portfolios, decision theory and RM. In addition to this, risk interdependencies, project interdependencies, and relationships between RM and project portfolio success have been shown to represent fundamental topics of PPRM. Likewise, PPR identification, categorization, and assessment were also identified as relevant to PPRM. The literature outlines some proposals oriented to defining methods, methodologies or approaches in order to support these topics. Secondly, it focuses on identifying future research directions, four of which are identified:

(1) PPRM as part of organizational RM; (2) RM, success factors and strategic impact; (3) Mechanisms for PPR assessment, and (4) PPRM as a complex and dynamic system. Therefore, the present study contributes to the current PPRM research by outlining the main topics and considering key characteristics and attributes for this field, as well as by identifying future directions, which give an informed overview for addressing PPRM challenges as a research area.

The present research process included works developed specifically in the PPRM field, as well as a structured search of those works analyzed. Conventional CA allowed for an understanding of each publication and made it possible to have a global and systemic insight into the current developments in PPRM. Between 2008 and 2014, a substantial part of the works focused on demonstrating the importance of the area, as well as exploring conceptual proposals. In recent years have specific proposals been published which identify, categorize and assess PPR, where the publications by Hofman et al. [35], Ghasemi et al. [9], and Wang et al. [10] can be seen as an example of this.

The structured literature review process carried out followed steps which are well-recognized in the literature, and which are specifically described in Svejvig and Andersen [41]. However, the step associated with the "conceptualization of topic" incorporated an unstructured and explorative search leading to the scope's definition. A set of string searches was defined and evaluated in order to obtain a string search that adequately represented the defined scope of the literature review. The above also allowed for the process of searching, evaluating, and selecting literature to be based on specific issues related to the topic under study, and not only on the authors' previous knowledge of the topic. In this regard, the incorporation of an unstructured and explorative search also brings a methodological contribution by this research towards the "conceptualization of topic" step within structured literature review processes.

Some limitations can be attributed to the findings presented. Although a structured search and analysis process was developed, Laursen and Svejvig [39] and Xia et al. [84] suggest that literature reviews can never be exhaustive and, therefore, in this process some articles or groups of articles may have been left out of the analysis. Possible exclusions may be the result of several factors: the keywords used, the search equation structure, the search scope or methodological deficiencies that could potentially be identified by other researchers. Overcoming these issues could be seen as opportunities for future work or for extensions of the research presented here. Besides this, in the literature analysis process related to qualitative analysis and CA, the cognitive bias cannot be fully eliminated, thus, the results obtained provide suggestions, but do not limit present and future directions for the PPRM research field [84].

Acknowledgements

This research was sponsored by the University of Valle, Colombia, and Colfuturo-Colciencias, Colombia.

References

*Indicates that the study is part of the structured literature review.

[1] M. Voss, "Impact of customer integration on project portfolio management and its success - Developing a conceptual framework," *International Journal of Project Management*, vol. 30, no. 5, pp. 567-581, 2012.

[2] S. Clegg, C. P. Killen, C. Biesenthal and S. Sankaran, "Practices, projects and portfolios: Current research trends and new directions," *International Journal of Project Management*, vol. 36, no. 5, pp. 762-772, 2018.

[3] M. Martinsuo, "Project portfolio management in practice and in context," *International Journal of Project Management*, vol. 31, no. 6, pp. 794-803, 2013.

[4] S. Meskendahl, "The influence of business strategy on project portfolio management and its success - A conceptual framework," *International Journal of Project Management*, vol. 28, no. 8, pp. 807-817, 2010.

[5] N. Hadjinicolaou and J. Dumrak, "Investigating Association of Benefits and Barriers in Project Portfolio Management to Project Success," *Procedia Engineering*, vol. 182, pp. 274-281, 2017.

*[6] J. Teller, A. Kock and H. G. Gemünden, "Risk management in project portfolios is more than managing project

risks: A contingency perspective on risk management," *Project Management Journal*, vol. 45, no. 4, pp. 67-80, 2014.

*[7] M. Hofman, S. Spalek and G. Grela, "Shedding New Light on Project Portfolio Risk Management," *Sustainability*, vol. 9, no. 10, pp. 1798-1816, 2017.

*[8] J. Teller and A. Kock, "An empirical investigation on how portfolio risk management influences project portfolio success," *International Journal of Project Management*, vol. 31, no. 6, pp. 817-829, 2013.

*[9] F. Ghasemi, M. Sari, V. Yousefi, R. Falsafi and J. Tamošaitienė, "Project Portfolio Risk Identification and Analysis, Considering Project Risk Interactions and Using Bayesian Networks," *Sustainability*, vol. 10, no. 5, pp. 1609-1631, 2018.

*[10] Q. Wang, G. Zeng and X. Tu, "Information Technology Project Portfolio Implementation Process Optimization Based on Complex Network Theory and Entropy," *Entropy*, vol. 19, no. 6, pp. 1-23, 2017.

*[11] D. Guan, P. Guo, K. Hipel and L. Fang, "Risk reduction in a project portfolio," *Journal of Systems Science and Systems Engineering*, vol. 26, no. 1, pp. 3-22, 2017.

*[12] K. Chatterjee, S. Hossain and S. Kar, "Prioritization of project proposals in portfolio management using fuzzy AHP," *Opsearch*, vol. 55, no. 2, pp. 478-501, 2018.

*[13] M. Relich and P. Pawlewski, "A fuzzy weighted average approach for selecting portfolio of new product development projects," *Neurocomputing, vol.* 231, pp. 19-27, 2017.

*[14] R. J. Peters and C. Verhoef, "Quantifying the yield of risk-bearing IT-portfolios," *Science of Computer Programming*, vol. 71, no.1, pp. 17-56, 2008.

*[15] H. Costa, M. Barros and G. Travassos, "Evaluating software project portfolio risks," *Journal of Systems and Software*, vol. 80, no. 1, pp. 16-31, 2007.

*[16] Y. Petit and B. Hobbs, "Project Portfolios in Dynamic Environments: Sources of Uncertainty and Sensing Mechanisms," *Project Management Journal, vol.* 41, no. 4, pp. 46-58, 2010.

*[17] F. F. Razi, A. T. Eshlaghy, J. Nazemi, M. Alborzi and A. Poorebrahimi, "A hybrid grey-based fuzzy C-means and multiple objective genetic algorithms for project portfolio selection," *International Journal of Industrial and Systems Engineering*, vol. 21, no. 2, pp. 154-179, 2015.

*[18] A. Namazian and S. Yakhchali, "Modified Bayesian Network – Based Risk Analysis of Construction Projects: Case Study of South Pars Gas Field Development Projects," *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering*, vol. 4, no. 4, pp. 1-11, 2018.

*[19] H. Sanchez, B. Robert and R. Pellerin, "A project portfolio risk-opportunity identification framework," *Project Management Journal*, vol. 39, no. 3, pp. 97-109, 2008.

*[20] M. Hofman and G. Grela, "Project portfolio risk identification-application of Delphi method," *Journal of Business and Economics*, vol. 6, no. 11, pp. 1857-1867, 2015.

[21] Project Management Instituted, *The Standard for Portfolio Management*, 4th ed. Pennsylvania, United States: Project Management Institute, Inc., 2017.

*[22] H. Sanchez, B. Robert, M. Bourgault and R. Pellerin, "Risk management applied to projects, programs, and portfolios," *International Journal of Managing Projects in Business*, vol. 2, no. 1, pp. 14-35, 2009.

*[23] A. Hasna and S. Raza, "The status of project portfolio management practices adoption and awareness in Gulf Cooperation Counties: an empirical study," *International Journal of Project Organisation and Management*, vol. 2, no. 2, pp. 174-192, 2010.

*[24] S. Bathallath, Å. Smedberg and H. Kjellin, "Managing project interdependencies in IT/IS project portfolios: A review of managerial issues," *International Journal of Information Systems and Project Management*, vol. 4, no. 1, pp.

67-82, 2016.

[25] D. Jonas, A. Kock and H. G. Gemünden, "Predicting project portfolio success by measuring management quality-a longitudinal study," *IEEE Transactions on Engineering Management*, vol. 60, no. 2, pp. 215-226, 2013.

[26] J. Kopmann, A. Kock, C. P. Killen, and H. G. Gemünden, "The role of project portfolio management in fostering both deliberate and emergent strategy," *International Journal of Project Management*, vol. 35, no. 4, pp. 557-570, 2017.

*[27] J. Teller, "Portfolio risk management and its contribution to project portfolio success: An investigation of organization, process, and culture," *Project Management Journal*, vol. 44, no. 2, pp. 26-51, 2013.

[28] M. Crouhy, D. Galai and R. Mark, *The essentials of risk management*, 2nd Ed. New York, United States: McGraw-Hill, 2014.

*[29] J. Panadero, J. Doering, R. Kizys, A.A. Juan and A. Fito, "A variable neighborhood search simheuristic for project portfolio selection under uncertainty," *Journal of Heuristics*, Vol. 23, no. 3, pp. 1-23, 2020.

*[30] A. Tofighian, H. Moezzi, M. Khakzar and M. Shafiee, "Multi-period project portfolio selection under risk considerations and stochastic income," *Journal of Industrial Engineering International*, vol. 14, no. 3, pp. 571-584, 2018.

*[31] S. Yan and X. Ji, "Portfolio selection model of oil projects under uncertain environment," *Soft Computing*, Vol. 22, no. 17, pp. 5725-5734, 2018.

*[32] J. P. Paquin, D. Tessier and C. Gauthier, "The Effectiveness of Portfolio Risk Diversification: An Additive Approach by Project Replication," *Project Management Journal*, vol. 46, no. 5, pp. 94-110, 2015.

*[33] P. Smalley, S. Begg, M. Naylor, S. Johnsen, and A. Godi, "Handling risk and uncertainty in petroleum exploration and asset management: An overview," *AAPG Bulletin*, vol. 92, no. 10, pp. 1251-1261, 2008.

[34] T. Coleman, *A practical guide to risk management*, 1st ed. Charlottesville, United States: Research Foundation of CFA Instituted, 2011.

*[35] M. Hofman and G. Grela, "Project portfolio risk categorisation – Factor analysis results," *International Journal of Information Systems and Project Management*, vol. 6, no. 4, pp. 39-58, 2018.

*[36] H. Sanchez and B. Robert, "A matrix for monitoring the strategic performance of project portfolios," *International Journal of Project Organisation and Management*, vol. 2, no. 2, pp. 135-153, 2010.

*[37] K. Benaija and L. Kjiri, "Hybrid Approach for Project Portfolio Selection Taking Account of Resources Management and Interactions between Projects," *Journal of Digital Information Management*, vol. 13, no. 6, pp. 451-461, 2015.

[38] M. C. B. de Araújo, L. H. Alencar and C. M. Mota, "Project procurement management: A structured literature review," *International Journal of Project Management*, vol. 35, no. 3, pp. 353-377, 2017.

[39] M. Laursen and P. Svejvig, "Taking stock of project value creation: A structured literature review with future directions for research and practice," *International Journal of Project Management*, vol. 34, no. 4, pp. 736-747, 2016.

[40] M. Miterev, J. R. Turner and M. Mancini, "The organization design perspective on the project-based organization: a structured review," *International Journal of Managing Projects in Business*, vol. 10, no. 3, pp. 527-549, 2017.

[41] P. Svejvig and P. Andersen, "Rethinking project management: A structured literature review with a critical look at the brave new world," *International Journal of Project Management*, vol. 33, no. 2, pp. 278-290, 2015.

[42] J. Rowley and F. Slack, "Conducting a Literature Review," *Management Research News*, vol. 27, no. 6, pp. 21-29, 2004.

[43] M. Hällgren, "The construction of research questions in project management," *International Journal of Project*

Management, vol. 30, no. 7, pp. 804-816, 2012.

[44] J. Söderlund, "Pluralism in Project Management: Navigating the Crossroads of Specialization and Fragmentation," *International Journal of Management Reviews*, vol. 13, no. 2, pp. 153-176, 2011.

*[45] M. Hofman and G. Grela, "Taxonomy of the project portfolio risks-an empirical investigation," *Procedia Computer Science*, vol. 121, pp. 137-144, 2017.

*[46] J. P. Paquin, C. Gauthier and P. P. Morin, "The downside risk of project portfolios: The impact of capital investment projects and the value of project efficiency and project risk management programmes," *International Journal of Project Management*, vol 34, no. 8, pp. 1460-1470, 2016.

[47] L. Hansen and P. Svejvig, "Towards rethinking Project portfolio management," in *EURAM* , Iceland, 2018.

*[48] N. Dobrovolskiene and R. Tamošiuniene, "Sustainability-Oriented financial resource allocation in a project portfolio through multi-criteria decision-making," *Sustainability*, vol. 8, no. 5, pp. 485-502, 2016.

[49] D. Leung and B. Chung, "Content Analysis: Using Critical Realism to Extend Its Utility," in *Handbook of Research Methods in Health Social Sciences*, 1st ed. Singapore: Pranee Liamputtong, Springer, 2019, ch 47, pp. 827-841.

[50] H. Hsieh and S. Shannon, "Three approaches to qualitative content analysis," *Qualitative Health Research*, vol. 15, no. 9, pp. 1277-1288, 2005.

*[51] J. A. Santos, P. Ohlhausen and M. Bucher, "Aligning innovation and Project Management by the Value Index," *International Journal of Technology Intelligence and Planning*, vol. 4, pp. 413-430, no. 4, 2008.

*[52] J. Rank, B. Unger and H. G. Gemünden, "Preparedness for the future in project portfolio management: The roles of proactiveness, riskiness and willingness to cannibalize," *International Journal of Project Management*, vol. 33, no. 8, pp. 1730-1743, 2015.

*[53] J. Drake and T. Byrd, "Risk in Information Technology Project Portfolio Management," *Journal of Information Technology Theory and Application*, vol. 8, no. 3, pp. 1-11, 2006.

*[54] R. Olsson, "Risk management in a multi-project environment: An approach to manage portfolio risks," *International Journal of Quality & Reliability Management*, vol. 25, no. 1, pp. 60-71, 2008.

*[55] A. Neumeier, S. Radszuwill and T. Garizy, "Modeling project criticality in IT project portfolios," *International Journal of Project Management*, vol. 36, no. 6, 833-844, 2018.

*[56] D. Cooley, C. Galik, T. Holmes, C. Kousky and R. Cooke, "Managing dependencies in forest offset projects: Toward a more complete evaluation of reversal risk," *Mitigation and Adaptation Strategies for Global Change*, vol. 17, no. 1, pp. 17-24, 2012.

*[57] N. Hall, D. Long, J. Qi and M. Sim, "Managing Underperformance Risk in Project Portfolio Selection," *Operations Research*, vol. 63, no. 3, pp. 660-675, 2015.

*[58] Y. Lopes and A. Almeida, "Assessment of synergies for selecting a project portfolio in the petroleum industry based on a multi-attribute utility function," *Journal of Petroleum Science and Engineering*, vol. 126, pp. 131-140, 2015.

*[59] B. Heinrich, D. Kundisch and S. Zimmermann, "Analyzing Cost and Risk Interaction Effects in IT Project Portfolios," *Banking and Information Technology*, vol. 15, no. 2, pp. 8-20, 2014.

*[60] M. Sharifighazvini, V. Ghezavati, S. Raissi and A. Makui, "Integration of a new mcdm approach based on the dea, fanp with monlp for efficiency-risk assessment to optimize project portfolio by branch and bound: A real case-study," *Economic Computation and Economic Cybernetics Studies and Research*, vol. 52, no.1, pp. 261-278, 2018.

*[61] F. F. Razi and S. Shariat, "A hybrid grey based artificial neural network and C&R tree for project portfolio selection Farshad," *Benchmarking: An International Journal*, vol. 24, no. 3, pp. 651-665, 2017.

*[62] C. Brester, I. Ryzhikov and E. Semenkin, "Multi-objective Optimization Algorithms with the Island Metaheuristic for Effective Project Management Problem Solving," *Organizacija*, vol. 50, no. 4, pp. 364-373, 2017.

*[63] J. Kettunen and A. Salo, "Estimation of Downside Risks in Project Portfolio Selection," *Production and Operations Management*, vol. 26, no. 10, pp. 1839-1853, 2017.

*[64] B. J. Tang, H. L. Zhou and H. Cao, "Selection of overseas oil and gas projects under low oil price," *Journal of Petroleum Science and Engineering*, vol. 156, pp. 160–166, 2017.

*[65] W. Xu, G. Liu, H. Li and W. Luo, "A Study on Project Portfolio Models with Skewness Risk and Staffing," *International Journal of Fuzzy Systems*, vol. 19, no. 6, pp. 2033-2047, 2017.

*[66] V. Yousefi, S. Haji, J. Saparauskas and S. Kiani, "The impact made on project portfolio optimisation by the selection of various risk measures," *Engineering Economics*, vol. 29, no. 2, pp. 68-175, 2018.

*[67] K. Shafi, S. Elsayed, R. Sarker and M. Ryan, "Scenario-based multi-period program optimization for capability-based planning using evolutionary algorithms," *Applied Soft Computing Journal*, vol. 56, 717-729, 2017.

*[68] V. Mohagheghi, S. Mousavi, B. Vahdani and M. Shahriari, "R&D project evaluation and project portfolio selection by a new interval type-2 fuzzy optimization approach," *Neural Computing and Applications*, vol. 28, no. 12, pp. 3869-3888, 2017.

*[69] L. S. Mazelis and K. S. Solodukhin, "Optimization models of rolling planning for project portfolio in organizations taking into account risk and corporate social responsibility," *Journal of Applied Economic Sciences*, vol. 10, no. 5, pp. 795-805, 2015.

*[70] L. S. Mazelis, K. S. Solodukhin, A. D. Tarantaev and A. Y. Chen, "Fuzzy multi-period models for optimizing an institution's project portfolio inclusive of risks and corporate social responsibility," *Global Journal of Pure and Applied Mathematics*, vol. 12, no. 5, pp. 4089-4105, 2016.

*[71] V. Mohagheghi, S. M. Mousavi and B. Vahdani, "A new multi-objective optimization approach for sustainable project portfolio selection: A real-world application under interval-valued fuzzy environment," *Iranian Journal of Fuzzy Systems*, vol. 13, no. 6, pp. 41-68, 2016.

*[72] J. D. Molina, J. Contreras and H. Rudnick, "A risk-constrained project portfolio in centralized transmission expansion planning," *IEEE Systems Journal*, vol. 11, no. 3, pp. 1653-1661, 2017.

*[73] V. Mohagheghi, S. M. Mousavi and B. Vahdani, "A New Optimization Model for Project Portfolio Selection Under Interval-Valued Fuzzy Environment," *Arabian Journal for Science and Engineering*, vol. 40, no. 11, pp. 3351-3361, 2015.

*[74] M. Arena, G. Azzone, E. Cagno, A. Silvestri and P. Trucco, "A model for operationalizing ERM in project-based operations through dynamic capabilities," *International Journal of Energy Sector Management*, vol. 8, no. 2, pp. 178-197, 2014.

*[75] M. I. Bolos, D. C. Sabau-Popa, E. Scarlat, I. A. Bradea and C. Delcea and E. Scarlat, "A business intelligence instrument for detection and mitigation of risk related to projects financed from structural funds," *Economic Computation & Economic Cybernetics Studies & Research*, vol. 50, no. 2, pp. 165-178, 2016.

*[76] C. G. da Silva, J. Meidanis, A. V. Moura, M. A. Souza, P. Viadanna, M. R. Oliveira, M. Oliveira, L. H. Jardim, G. A. Costa Lima and R. S. de Barros, "An improved visualization-based approach for project portfolio selection," *Computers in Human Behavior*, vol. 73, pp. 685-696, 2017.

*[77] S. Floricel and M. Ibanescu, "Using R & D portfolio management to deal with dynamic risk," *R&D Management*, vol. 38, no. 5, pp. 452-467, 2008.

*[78] H. Sanchez and B. Robert, "Measuring portfolio strategic performance using key performance indicators," *Project Management Journal*, vol. 41, no. 5, pp. 64-73, 2010.

[79] A. Kock, W. Heising and H. G. Gemünden, "A Contingency Approach on the Impact of Front-End Success on Project Portfolio Success," *Project Management Journal*, vol. 47, no. 2, pp. 115-129, 2016.

*[80] E. V. Broilo and I. G. Nazarova, "Methodological approach to assessing performance of the organization projects," *Indian Journal of Science and Technology*, vol. 9, no. 27, pp. 1-12, 2016.

*[81] J. A. Sefair, C. Y. Méndez, O. Babat, A. L. Medaglia and L. F. Zuluaga, "Linear solution schemes for Mean-SemiVariance Project portfolio selection problems: An application in the oil and gas industry," *Omega*, vol. 68, pp. 39-48, 2017.

*[82] T. Heydari, S. M. Seyed Hosseini and A. Makui, "Developing and solving an One-Zero non linear goal programming model to R and D portfolio project selection with interactions between projects," *International Business Management*, vol. 10, no. 19, pp. 4516-4521, 2016.

*[83] F. Costantino, G. Di Gravio and F. Nonino, "Project selection in project portfolio management: An artificial neural network model based on critical success factors," *International Journal of Project Management*, vol. 33, no. 8, pp. 1744-1754, 2015.

[84] N. Xia, P. X. Zou, M. A. Griffin, X. Wang and R. Zhong, "Towards integrating construction risk management and stakeholder management: A systematic literature review and future research agendas," *International Journal of Project Management*, vol. 36, no. 5, pp. 701-715, 2018.

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