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IJISPM

UMinho Editora

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The IJISPM publishes leading scholarly and practical research articles that aim to advance the information systems management and project management fields of knowledge, featuring state-of-the-art research, theories, approaches, methodologies, techniques, and applications.

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The journal content provides relevant information to researchers, practitioners, and organizations, and includes original qualitative or qualitative articles, as well as purely conceptual or theoretical articles. Due to the integrative and interdisciplinary nature of information systems and project management, the journal may publish articles from a number of other disciplines, including strategic management, psychology, organizational behavior, sociology, economics, among others. Articles are selected for publication based on their relevance, rigor, clarity, novelty, and contribution to further development and research.

Authors are encouraged to submit articles on information technology governance, information systems planning, information systems design and implementation, information technology outsourcing, project environment, project management life-cycle, project management knowledge areas, criteria and factors for success, social aspects, chief information officer role, chief information officer skills, project manager role, project manager skills, among others.

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EDITORIAL

It is our great pleasure to bring you the third number of the 13th volume of IJISPM. In this issue, readers will find important contributions on IT project portfolio risk, 4IR technologies project management, project tools misalignment, and public investment projects selection.

Systemic risk might jeopardize your IT project portfolio: A qualitative evaluation of risk measures

Julia Amend, Florian Guggenmos, Nils Urbach, Gilbert Fridgen

IT project portfolios consist of various projects which depend on each other. Including additional IT projects, which are interdependent with existing ones, affects the IT portfolio's systemic risk, which arises from these interdependencies. To handle this risk, organizations must quantitatively analyze the systemic risk of their IT portfolio. However, an overview and evaluation of risk measures for quantitatively analyzing systemic risk in IT portfolios has been missing. In our study, we first conducted a structured literature review to identify risk measures. We then determined evaluation criteria based on mathematical considerations on how risk measures can be modeled and insights from our literature review. Subsequently, we performed a qualitative, criteria-based evaluation to clarify which risk measure fits specific use cases. Finally, we delineated our findings as three recommendations. Our research supports organizations in better analyzing systemic risk in their IT portfolios by selecting the most appropriate risk measure according to their data or use case, contributing to a more successful IT portfolio management.

A framework for managing projects that integrate 4IR technologies

Mothepane Tshabalala, Carl Marnewick

The Fourth Industrial Revolution (4IR) signifies a new phase in project management. The swift progression of 4IR technologies requires a reassessment of current methods to address the complexities of contemporary project management adequately. The ability of project managers to rapidly adjust to emerging technology and evolving standards is crucial in determining the successful outcome of projects. It is imperative for proficient project managers to recognise the significance of their capacity to predict and respond effectively to these changes, as well as their subsequent effects on ongoing and forthcoming projects, to achieve success in their professional domain. The objective of this study was to examine the effects of the 4IR on the project management discipline. A qualitative technique was employed for the collection and analysis of data. A theoretical framework for project management in the 4IR was developed. The framework identifies (i) what constitutes 4IR projects in terms of characteristics, challenges and success factors, (ii) what skills and competencies are required to deliver these projects, and lastly, (iii) what tools and techniques can be employed to deliver these projects. There is a need for such a framework which offers valuable perspectives and a comprehensive plan for the effective management of 4IR projects, specifically targeting project management professionals.

Sources of project tool misalignment in multistakeholder projects

Juha-Antti Rankinen, Harri Haapasalo

Inter-organizational collaboration is recognized as one of the key success factors for complex project delivery. Simultaneously, tools and technologies play a growing role in project management and operations, especially as project work is increasingly being conducted in hybrid and remote settings. These tools play a critical role in achieving productive collaboration, and when properly selected, implemented, and aligned, they offer opportunities for increased project productivity. However, the selection of correct tools can be tricky, and at worst, tools can end up hampering project operations. This study empirically identifies key project tool-related challenges and clarifies the role of tools in relation to stakeholder collaboration. The results emphasize two-dimensional alignment for the selection and implementation of tools: by aligning with both project objectives and the teams executing the project, tools are better set to fulfill their role as a link that supports project organization toward its goals and fosters productive inter-organizational collaboration.

A decision support process for the selection of sustainable public ICT project investments

Muhammed Rasit Ozdas, Ozel Sebetci, Tamer Eren, Hadi Gokcen

The allocation of limited public resources to public investments necessitates selecting projects with the highest social and economic value, along with the greatest likelihood of success. However, the literature lacks well-defined criteria to measure the alignment of such projects with national policies, social benefits, and institutional capabilities. This paper aims to fill this gap by presenting a process methodology and a set of criteria for evaluating and prioritizing public sector ICT projects. A project selection process is defined with a comprehensive criteria set, and it was tested on 11 carefully selected information and communication technology projects. A process has been defined consisting of prerequisite elimination, criteria weighting, project scoring, and verification. Both AHP and TOPSIS methods were utilized. The study also attempts to measure social benefits with respect to Türkiye's national priorities, through more tangible sub-criteria. To the best of our available knowledge, the study provides the most comprehensive set of criteria for selecting ICT investment projects in the public sector. The findings reveal that projects aligned with national priorities and providing high social benefits were ranked highest. The fact that project criteria provide feedback from a broad perspective shows that information systems can also support project maturation, along with project selection.

We would like to take this opportunity to express our gratitude to the distinguished members of the Editorial Board, for their commitment and for sharing their knowledge and experience in supporting the IJISPM.

Finally, we would like to express our gratitude to all the authors who submitted their work for their insightful visions and valuable contributions.

We hope that you, the readers, find the International Journal of Information Systems and Project Management an interesting and valuable source of information for your continued work.

The Editor-in-Chief,

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RESEARCH ARTICLE

Systemic risk might jeopardize your IT project portfolio: A qualitative evaluation of risk measures

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Abstract
IT project portfolios consist of various projects which depend on each other. Including additional IT projects, which are interdependent with existing ones, affects the IT portfolio's systemic risk, which arises from these interdependencies. To handle this risk, organizations must quantitatively analyze the systemic risk of their IT portfolio. However, an overview and evaluation of risk measures for quantitatively analyzing systemic risk in IT portfolios has been missing. In our study, we first conducted a structured literature review to identify risk measures. We then determined evaluation criteria based on mathematical considerations on how risk measures can be modeled and insights from our literature review. Subsequently, we performed a qualitative, criteria-based evaluation to clarify which risk measure fits specific use cases. Finally, we delineated our findings as three recommendations. Our research supports organizations in better analyzing systemic risk in their IT portfolios by selecting the most appropriate risk measure according to their data or use case, contributing to a more successful IT portfolio management.

Keywords
IT portfolio; IT project; systemic risk; risk measure; qualitative evaluation.

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1. Introduction

The Standish Group (2020) asserts that only 35% of all IT projects are successful in terms of budget and time, emphasizing the IT projects' failures and the importance of project management. Furthermore, Flyvbjerg and Budzier (2011) note that around 16% of all IT projects exceed their budgets by 200%, and despite this, the project cost overruns remain unsolvable (Flyvbjerg et al., 2022). The successful management of IT projects is further challenged when they involve emerging technologies, such as blockchain, artificial intelligence, or quantum computing (Häckel et al., 2017; Häckel et al., 2018; Khan et al., 2022; Rotolo et al., 2015), and, for instance, target digital transformation in organizations (Azhari & Raharjo, 2023; Kohnke et al., 2024; Ngereja et al., 2024; Tarannum et al., 2025). Due to the more challenging management of such types of projects, those bear major risks for organizations. Yet, they also incorporate immense opportunities, such as the potential to drive long-term competitiveness (Fridgen & Moser, 2013; Häckel et al., 2017; Irsak & Barilovic, 2023; Omol, 2024; Otay et al., 2023; Tarannum et al., 2025).

Even though it is desirable to make IT projects successful, a single project's success might be insufficient for organizational success since it neglects a strategic and holistic view of risk, considering that projects are embedded in a complex portfolio environment with a vast of interdependencies (Micán et al., 2020). Thus, organizations must be successful in managing their whole IT project portfolio, hereafter referred to as "IT portfolio", to achieve overall organizational success (Archer & Ghasemzadeh, 1999; Bathallath et al., 2016; Karrenbauer & Breitner, 2022; Schulte et al., 2024). Due to the existing interdependencies between the IT projects included in an IT portfolio, one single IT project failure can affect other IT projects. It can even endanger the whole IT portfolio's success since such a failed IT project can lead to domino effects or so-called cascade failures and induce systemic risk (Ellinas, 2019; Ellinas et al., 2015). Hence, organizations must thoroughly know their IT portfolio, the included IT projects, and their interdependencies to make a well-founded decision regarding project selection and optimize value creation (Bathallath et al., 2016; Karrenbauer & Breitner, 2022; Kundisch & Meier, 2011; Martinsuo & Geraldi, 2020; Vieira et al., 2024). Further, they must perform a systemic risk analysis before deciding whether it is beneficial or harmful to include a new IT project.

For such systemic risk analysis, various risk measures exist to calculate different risk scenarios for different IT portfolio constellations (Bai et al., 2023; Beer et al., 2015; Guggenmos et al., 2019). Yet, organizations usually lack in-depth data with appropriate quality on the interdependencies of single IT projects (Cooley et al., 2012; Guggenmos et al., 2019; Hill et al., 2000; Micán et al., 2020), complicating a thorough systemic risk analysis. Further, until now, the literature lacks an overview of suitable risk measures for analyzing systemic risk in IT portfolios. Even though systemic risk has been extensively researched across several domains, including the financial sector (Acemoglu et al., 2015; Curcio et al., 2023; Hautsch et al., 2015; Zhang et al., 2023), critical infrastructure (Buldyrev et al., 2010; Crucitti et al., 2004; Gao et al., 2011; Motter & Lai, 2002), supply chain networks (Ash & Newth, 2007; Verschuur et al., 2022; Zare-Garizy et al., 2018), IT security in smart factories (Bürger et al., 2019; Miehle et al., 2019), and epidemiology (Brockmann & Helbing, 2013; Kermack & McKendrick, 1927; Pastor-Satorras & Vespignani, 2001), according to (Guggenmos et al., 2019) research for IT portfolios is still in its infancy.

Due to this knowledge gap, we propose the following research question:

Which risk measures are suitable for quantitatively analyzing systemic risk in IT portfolios?

To answer our research question, in Section 2, we describe the essential theoretical foundations of IT portfolios. In Section 3, we elucidate our methodological approach for identifying risk measures and evaluation criteria as well as for performing the qualitative evaluation. In Section 4, we shed light on our findings. We then reflect on our evaluation's results, discuss the implications for theory and practice, and delineate the limitations and future research potentials (Section 5). Finally, we conclude our study by summarizing key insights and contributions (Section 6).

2. Background

Risk management is pivotal for successfully implementing IT projects (Baccarini et al., 2004; Didrage, 2013; Pimchangthong & Boonjing, 2017) but is insufficient since it lacks a strategic and holistic view of risk going beyond the single project perspective and considering the interdependencies between projects (Ghasemi et al., 2018; Guan et al., 2017; Micán et al., 2020; Q. Wang et al., 2017). Thus, successfully managing the vast of interdependencies between projects in IT portfolios is critical for success (Bathallath et al., 2016; Drake & Byrd, 2006; Frey & Buxmann, 2012; Mark & Ingmar, 2004; Vieira et al., 2024). However, literature knows various definitions of *risk*, often depending on the application case. One established definition for risk is provided by March and Shapira (March & Shapira, 1987), who define risk as "*reflecting variation in the distribution of possible outcomes, their likelihoods, and their subjective values*". Following this definition, risks are uncertain events that might occur in partially successful or canceled IT projects (Al-Ahmad et al., 2009; Stoica & Brouse, 2013).

With an IT portfolio management view, the question remains open whether and how a single project's risk can affect the risk of other projects depending on it. The various dependencies between projects in an IT portfolio lead to the concept of a *complex network*, often used by researchers to model IT portfolios and consisting of nodes (projects) and edges (different types of dependencies) (Beer et al., 2015; Ellinas, 2019; Micán et al., 2020; Radszuwill & Fridgen, 2017; Q. Wang et al., 2017; Wolf, 2015). Due to the interdependencies in complex networks, a specific risk type is apparent, namely *systemic risk*, a well-known phenomenon in the financial sector (Acharya et al., 2017; Eisenberg & Noe, 2001; Freixas et al., 2000). It is defined as "*the risk or probability of breakdowns in an entire system, as opposed to breakdowns in individual parts or components, and is evidenced by comovements (correlation) among most or all the parts*" (Kaufman & Scott, 2003).

Regarding the concept of *dependencies* researchers use various classifications. Some studies focus on a single type of dependency (Lee & Kim, 2001; Santhanam & Kyparisis, 1996; Tillquist et al., 2002; Zuluaga et al., 2007), while others present a framework of different types (Vieira et al., 2024; Wehrmann et al., 2006; Zimmermann, 2008). For instance, according to Wehrmann et al. (2006) and Beer et al. (2015), dependencies in IT projects are classified into *intra-temporal dependencies* (within one-time step) and *inter-temporal dependencies* (between different time steps), whereas other researchers differentiate between *resource dependencies, technical dependencies,* and *benefits (synergies)* (Lee & Kim, 2001; Martinsuo & Geraldi, 2020; Santhanam & Kyparisis, 1996; Tillquist et al., 2002; Zuluaga et al., 2007). We refer to Vieira et al. (2024) for a more detailed review of project dependencies. Regardless of the type of dependency, those are the reasons why a single project failure can also affect another project, which directly depends on its positive outcome. In the case of this first failed project, the failure can also affect other indirect (also called transitive) dependent projects, which in turn can influence other projects and result in a domino effect. These domino effects and the so-called *cascade failures* describe the spread of failures due to the network's interconnectedness as one systemic risk element (Guggenmos et al., 2019).

The risk of such cascade failures must be considered in all four phases (planning, selection, execution, and evaluation) of the IT project portfolio management process through appropriate systemic risk measures. For instance, Archer and Ghasemzadeh (1999) propose considering project interactions through direct dependencies or resource competition within the selection phase in their project portfolio selection framework. Although research into IT portfolio management has been ongoing for many decades, new technologies, such as artificial intelligence, have contributed to major advances being made in recent years (Costantino et al., 2015; Ha & Madanian, 2020; Pappert & Kusanke, 2023; Prifti, 2022). According to Ha and Madanian (2020), fuzzy approach and artificial neural networks are the top trends approaches in project portfolio selection, while other approaches include Bayesian network, ant colony, decision tree, and machine learning.

This study looks closely at existing systemic risk measures and evaluates their suitability to support the IT project portfolio management process.

3. Method

3.1. Identification of risk measures in IT portfolios

We conducted a structured literature review (SLR) in scientific databases to approach our research question and identify relevant systemic risk measures to quantitatively analyze systemic risk in IT portfolios. This represents our main literature stream (stream 1). Additionally, we searched journals in the field of project management (PM) (stream 2) and information systems (IS) (stream 3) to ensure that we captured potentially relevant literature that was not part of the scientific databases. In our SLR, we focused on the term "projects" since this leads to more results and projects are similar regarding their systemic risk characteristics of "IT projects", allowing for knowledge transfer. We further did not exclude literature that had a single project perspective. The reason is that the interconnectedness is also apparent for tasks in projects, which has already been stated by Bathallath (Bathallath et al., 2016). Thus, knowledge from the single project perspective is transferable to the portfolio perspective.

Figure 1 illustrates the process of our SLR. For the main literature stream (stream 1), we used the following search string ("IT project" OR "project" OR "IT portfolio" AND "systemic risk" OR "cascade failure"), searching in the fields "title", "abstract", and "keywords" to identify relevant studies. We performed a query-based literature search in three scientific databases, namely *ScienceDirect*, *Association for Information Systems (AIS) Electronic Library*; and *Institute of Electrical and Electronics Engineers (IEEE Xplore).* For the additional literature streams 2 and 3, we used the same search string applied on "all fields". To identify the relevant literature for stream 2, we first identified relevant journals in the PM field by utilizing the Scopus database (search term for journal title: "project", "projects" and "project management") to ensure that we capture all project-related journals. We identified eleven PM journals (see Fig. 1). For Stream 3, we drew on the Senior Scholars' Basket of Journals postulated by the Association for Information Systems (AIS). Thus, we considered eleven top IS journals (also see Fig. 1).

Stream 1 resulted in 642 studies. We applied our two exclusion criteria (duplicates and missing focus on analyzing projects or portfolios) when screening titles and abstracts. By doing this, we ranked 635 as "not relevant". The majority of the non-relevant results (approximately 70%) focused on systemic risks in the financial sector (specifically stock portfolios or interbank networks). As a result, we classified seven studies as potentially relevant. After a deeper examination of the full texts, we included four of these as our primary literary sources because they investigate dedicated quantitative risk measures in projects and portfolios. For stream 2, focusing on PM literature, we found 18 studies, of which seven were potentially relevant after applying our two exclusion criteria. After a deeper examination, we included two out of these seven as our primary literary sources, as they also present dedicated risk measures. For Stream 3, which focused on top IS journals, we identified 35 studies from which no study was relevant after applying our exclusion criteria. Subsequently, for Stream 1 and Stream 2, we identified three additional potentially relevant studies using forward and backward searches for citations in the primary sources set, as Webster and Watson (2002) recommended. We checked for duplicates and screened the full texts of these three added studies. As a result, we identified eight risk measures in sum.

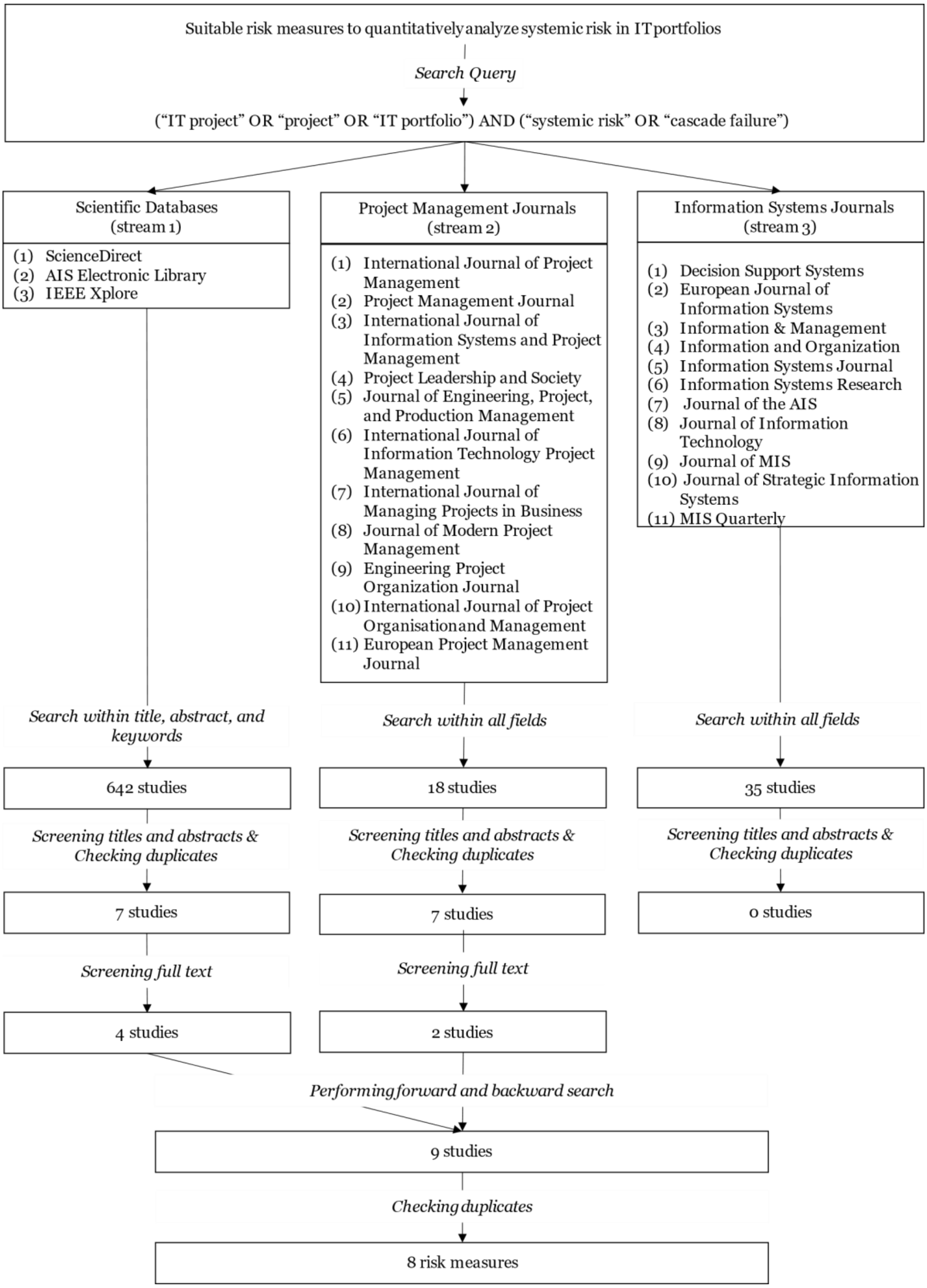


Fig. 1. Process of the structured literature review

3.2. Identification of evaluation criteria for risk measures in IT portfolios

We must first define suitable evaluation criteria to compare the identified systemic risk measures.

To do this, we analyzed how research models systemic risk in IT project portfolios from a mathematical perspective. As already mentioned, researchers mostly model IT project portfolios as complex networks using different sub-types of graph theory like Petri nets, Bayesian networks, or just simple graphs consisting of nodes and edges (Beer et al., 2015; Ellinas, 2019; Micán et al., 2020; Radszuwill & Fridgen, 2017; Q. Wang et al., 2017; Wolf, 2015). Since the systemic risk measures identified in our SLR are also based on graph theory, we focused and limited our evaluation criteria to aspects of systemic risk and their representation in graphs.

We enriched this "abstract" mathematical perspective through screening literature from our SLR regarding evaluation criteria. As a result, we detected Wolf (2015) as a relevant source since he had already derived such a set of evaluation criteria. We further analyzed how the authors of our identified risk measures handled systemic risk. In this step, we took special care to obtain an unbiased result to avoid the generation of a self-fulfilling prophecy.

3.3. Evaluation of risk measures in IT portfolios

We chose a qualitative criteria-based evaluation approach to evaluate the eight identified risk measures, distinguishing between two degrees of fulfillment: "fulfilled" (✓) and "not fulfilled" (✗). Even though we know that reality is more complex than "black or white", we did not include other degrees like "partially fulfilled", as it would be difficult to define a meaningful limit or a specific "partially fulfilled" level and to trace it consistently in our subsequent qualitative assessment of the criteria. In these individual cases, however, we have explicitly explained why we decided on "fulfilled" or "not fulfilled". Appendix A provides insights into the detailed evaluation results, including the justifications for each identified risk measure for why we regard an evaluation criterion as "fulfilled" or "not fulfilled". Further, we refrained from quantitative analysis, as this would require us to calculate all eight risk measures to be examined using a sample portfolio and compare their output. As all risk measures require a large number of different parameters as a database, we could not find real-world data containing all the required parameters. We also decided against generating (random) sample data, as creating the sample data would also strongly bias the evaluation. Therefore, we will stick to a purely qualitative analysis and justify the evaluation of the criteria using, for example, the formulas or parameters on which the risk measures are based.

4. Results

4.1. Risk measures

Based on our SLR, we identified eight risk measures, which we categorized into four categories (Table 1). In terms of systemic risk, Wolf (2015) focused on centrality measures and concluded that the alpha centrality introduced by Bonacich and Lloyd (2001) (RM1) is a suitable risk measure to identify critical projects in IT portfolios. Building on this work, Beer et al. (2015) (RM2) drew on graph theory to assess systemic risks in IT portfolios resulting from direct and indirect dependencies. They combined modern portfolio theory introduced by Markowitz (1952) and alpha centrality to evaluate IT portfolios' overall risks. We summarize these two risk measures in the category "Centrality Measures". Further, we would like to mention Guo et al. (2019) (RM3), who provide an approach based on Motter and Lai (2002) to investigate projects in general. They modeled and analyzed cascading failures in projects for impact evaluation and prediction of cascading failures.

Table 1. An overview of identified risk measures for IT portfolios

Risk measure	Literature Source	Description
Centrality Measures		
RM1: The Alpha Centrality	Bonacich and Lloyd (2001) – backward search	RM1 measures the influence or importance of a node within a network. It supports the identification of key players or influential nodes within a network.
RM2: An Integrated System Risk Quantification Approach	Beer et al. (2015) – scientific databases	RM2 bases on graph theory and targets a rigorous assessment of systemic risk resulting from different types of direct and indirect dependencies within IT portfolios.
Flow Redistribution Models		
RM3: A Load Capacity Model	Guo et al. (2019) – scientific databases	RM3 focuses on investigating cascading failures in projects by first abstracting the project as a weighted directed network with tasks and task interactions and afterward drawing on a cascade model that considers the project's self-protection mechanism.
RM4: A Portfolio Selection Model	Bai et al. (2023) – forward search	RM4 draws on a project portfolio network, in which the initial load and capacity of the projects are considered to simulate the cascading failure process. Finally, it selects the best portfolio option based on the indicator "Strategic Goal Loss Rate" of each project portfolio.
Percolation Models		
RM5: The TD Method	Guggenmos et al. (2019) – scientific databases	RM5 applied the "Susceptible or Infective (SI) model" as a network diffusion model used in epidemiology in the context of IT portfolios to examine systemic risk.
RM6: An Activity Network Approach	Ellinas (2019) – forward search	RM6 draws on an activity network approach usually used for linear cause-and-effect phenomena and is now used to evaluate project systemic risk as nonlinear cause-and-effect phenomena resulting from a cascading failure process.
Other Models		
RM7: A Bayesian Network Approach	Neumeier et al. (2018) – PM journals	RM7 applies Bayesian network modeling to assess the criticality and dependencies of single projects in IT portfolios.
RM8: A Vulnerability Assessment Model	Guo et al. (2020) – PM journals	RM8 uses complex network theory and abstracts the megaproject as a weighted directed network to quantify the vulnerability of megaprojects.

Also following Motter and Lai (2002), Bai et al. (2023) (RM4) proposed a similar approach to investigate the effect of projects' cascading failures in the accomplishment of strategic goals. We summarize both risk measures in the category "Flow Redistribution Models". The next category summarizes "Percolation Models". Guggenmos et al. (2019) (RM5) built on an established epidemiological network diffusion model. They developed the so-called TD method to quantitatively assess systemic risk in IT portfolios. In addition, Ellinas (2019) (RM6) provided a broader perspective on system risk in projects and further supports the assessment of project complexity. Finally, we assigned two risk measures to our last category "Other Models". First, Neumeier et al. (2018) (RM7) applied a Bayesian network for modeling IT portfolios and measuring the criticality of single projects within a portfolio. Second, Guo et al. (2020) (RM8) introduced a risk measure that focuses on megaprojects' vulnerability. Table 1 provides an overview of the identified risk measures and their categories.

4.2. Evaluation criteria

We identified seven suitable criteria to evaluate risk measures by utilizing our mathematical considerations and the work of Wolf (2015) as a starting point. We complemented our findings with the insights from our literature review.

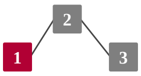
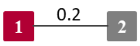
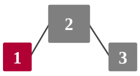
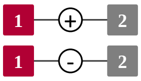
From a mathematical perspective, we conclude that systemic risk measures first must consider dependencies between projects (represented by edges between nodes). Second, these dependencies can be either (un)directed, (un)weighted, or both. Third, to consider network effects, the systemic risk measures must also consider indirect dependencies. These conclusions correspond to Wolf's (2015) findings.

Wolf (2015) presented five criteria, which were the following: The measurements account for direct dependencies (Criterion 1) and indirect dependencies (Criterion 2) between IT projects. Further, the measurement considers the direction (Criterion 3) and the intensity of the dependency (Criterion 4) between IT projects. Finally, in case of an existing dependency, the measurement's result of a specific IT project increases with the criticality of other dependent IT projects (Criterion 5). Based on our literature review insights, we can confirm the suitability of those criteria and must not exclude one. Specifically, our literature review resulted in three main findings: First, previous literature (Beer et al., 2015; Ellinas, 2019; Radszuwill & Fridgen, 2017) indicates inter alia the importance of direct and indirect dependencies by modeling risk in IT portfolios and, therefore, confirms Criterion 1 and 2. Further, regarding Criterion 3, e.g., Ellinas (2019), Guggenmos et al. (2019), and Guo et al. (2019) also build on directed dependencies. Regarding Criterion 4, we can also refer to Ellinas (2019), Guggenmos et al. (2019), and Guo et al. (2019), who consider weighted dependencies within their calculations. For Criterion 5, we mainly build on Bonacich and Lloyd (2001), Beer et al. (2015), Neumeier et al. (2018), and Guo et al. (2020), who confirmed the importance of this characteristic.

Although Wolf's (Wolf, 2015)(2015) evaluation criteria provided a good starting point, we recognized that Wolf's (2015) work misses two essential aspects, resulting in two additional evaluation criteria. First, the literature emphasizes the criticality of an individual IT project as depending not only on the dependency structure but also on project-inherent characteristics (Criterion 6) (Bai et al., 2023; Beer et al., 2013; Neumeier et al., 2018). For example, these studies classify large IT projects as more critical. Further, these studies define the "size" of individual projects based on various parameters, such as already invested or planned budget or employees required. Similarly, emerging IT innovation projects generally have a higher risk of failure (the probability of failure is independent of other projects). Second, Häckel and Hänsch (2014), Radszuwill and Fridgen (2017) and Micán et al. (2020) note that dependencies do not necessarily imply a negative impact. Still, they may also have positive effects, termed "synergies". Although synergies do not primarily affect risks, it is essential to consider both opportunities and risks in an integrated manner because significant synergistic effects can offset the risks caused by dependencies. Thus, a risk measure must simultaneously consider the positive and negative effects, as these may offset each other (Criterion 7).

Table 2 illustrates the study's final set of seven evaluation criteria for risk measures in IT portfolios.

Table 2. Evaluation criteria for risk measures in IT portfolios

ID	Figure	Evaluation Criteria	Primary Source	Description
1		The risk measure considers *direct dependencies* between projects.	Wolf (2015)	Successful accomplishment of individual IT projects is impossible if direct dependencies exist between them.
2		The risk measure for each IT project considers not only direct but also *indirect dependencies*.	Wolf (2015)	Regardless of whether the risk measure examines the individual IT project's criticality or the overall IT portfolio's risk, it must consider indirect dependencies. It is insufficient to consider only the IT projects' direct dependencies.
3		The risk measure considers *directed dependencies* between two IT projects.	Wolf (2015)	A failure in IT project 1 can affect IT project 2 but not vice versa if a directed dependency exists.
4		The risk measure considers the *dependencies' intensity.*	Wolf (2015)	The intensity indicates how strong the IT projects depend on each other. Hereby, both ordinally scaled and cardinally scaled intensities are possible.
5		The risk measure for each IT project considers the *criticality of other dependent IT projects*.	Wolf (2015)	The risk measure must classify an IT project as more critical if other critical IT projects depend on it (cf. recursive calculation) due to its potential for more damage. Additionally, risk measures that focus on the overall risk must consider each IT project's criticality. An offsetting (e.g., addition) of the individual risk measures of all IT projects is insufficient.
6		The risk measure considers at least one *IT project (inherent) parameter.*	Beer et al. (2015), Neumeier et al. (2018), Bai et al. (2023)	IT project's inherent properties contribute to its criticality. In our evaluation, we do not distinguish whether the risk measure considers the project size, its duration, its probability of failure, volatility (variance), other risk parameters (e.g., value at risk), or a flag indicating 'must-have' IT projects, e.g., due to regulatory.
7		The risk measure should provide an integrated view by considering the *positive and negative effects of dependencies*.	Radszuwill and Fridgen (2017)	Generally, risk measures do not account for positive effects. However, positive effects such as synergies can overcompensate negative effects due to dependencies. Thus, it is significant for the risk measure to consider both effects simultaneously.

4.3. Evaluation

Our performed evaluation demonstrated that none of the risk measures fulfilled all seven evaluation criteria. Nevertheless, three risk measures (RM2, RM3, and RM6) fulfilled six of the seven evaluation criteria, only lacking the simultaneous consideration of dependencies' positive and negative effects (Criterion 7). In addition, we observed that besides these, no other analyzed risk measures met Criterion 7.

Table 3. Summarized evaluation results for the eight risk measures

Risk Measures	1	2	3	4	5	6	7
Centrality Measures							
RM1: The Alpha Centrality	✓	✓	✓	✓	✓	✗	✗
RM2: An Integrated Systemic Risk Quantification Approach	✓	✓	✓	✓	✓	✓	✗
Flow Redistribution Models							
RM3: A Load Capacity Model	✓	✓	✓	✓	✓	✓	✗
RM4: A Portfolio Selection Model	✓	✓	✗	✗	✗	✓	✗
Percolation Models							
RM5: The TD Method	✓	✓	✓	✓	✓	✗	✗
RM6: An Activity Network Approach	✓	✓	✓	✓	✓	✓	✗
Other Models							
RM7: A Bayesian Network Approach	✓	✓	✓	✓	✗	✓	✗
RM8: A Vulnerability Assessment Model	✓	✓	✓	✓	✗	✓	✗

The overarching evaluation results of the eight risk measures are summarized in Table 3.

We provide detailed insights into our qualitative, criteria-based evaluation in the following. Specifically, we present the degree of fulfillment of the risk measures based on each risk measure's formulas or parameters. More details regarding the justifications are part of Appendix A.

4.3.1 Centrality measures

Centrality measures are widely used to analyze networks. Even though a multitude of centrality measures (e.g., degree centrality, closeness centrality, betweenness centrality, or eigenvector centrality) exist, the alpha centrality introduced by Bonacich and Lloyd (2001) remains the most popular measure. In the context of IT portfolios, alpha centrality is the most suitable measure (Wolf, 2015). Thus, we included the "Alpha Centrality" Bonacich and Lloyd (2001) and an "Integrated System Risk Quantification Approach" by Beer et al. (2015), which is based on alpha centrality, in our first category.

RM1: The Alpha Centrality by Bonacich and Lloyd

Alpha centrality, introduced by Bonacich and Lloyd (2001), is based on eigenvector centrality and differs marginally from Katz's (Katz, 1953)(1953) centrality measure. Following Bonacich and Lloyd (2001), the alpha centrality is calculated according to Equation (1).

$$\boldsymbol{x} = (\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1} * \boldsymbol{e} \tag{1}$$

Hereby, the vector $\boldsymbol{x}$ represents the centrality scores for each project. Parameter $\boldsymbol{A}$ indicates the adjacency matrix, which is not limited to symmetric binary entries and reflects the intensity of the IT project dependencies. Matrix $\boldsymbol{I}$ corresponds to the identity matrix and vector $\boldsymbol{e}$ represents an exogenous impact that is independent of the network structure. We adhere to Bonacich and Lloyd (2001) and regard $\boldsymbol{e}$ as a vector of ones such that the alpha centrality weights all nodes equally. The scalar $\alpha \in [0, 1/\lambda_{max})$ represents a ratio for the relative relations between the exogenous and endogenous status of the nodes. The higher the value of alpha, the more significant the influence of matrix $\boldsymbol{A}$. The parameter λ_{max} represents the maximum eigenvalue of $\boldsymbol{A}$. With $\boldsymbol{e} = (1,1,\dots,1)^T$ for each element x_i of vector $\boldsymbol{x}$ applies $x_i \geq 1$. The alpha centrality examines direct dependencies due to consideration of $\boldsymbol{A}$ (criterion 1: ✓). Further, it also takes into account, indirect dependencies due to the term $(\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1}$ (criterion 2: ✓). Since matrix $\boldsymbol{A}$ is not necessarily symmetrical or binary, the alpha centrality regards the direction (criterion 3: ✓) and the intensity of the dependencies (criterion 4: ✓). As the alpha centrality is based on a similar concept idea as the eigenvector centrality, we reformulate equation (1) as $\boldsymbol{x} = \alpha\boldsymbol{A}\boldsymbol{x} + \boldsymbol{e}$. The centrality score $\boldsymbol{x}$ is on both sides of Equation 1 and, thus, this is a recursive calculation. Hence the alpha centrality considers the importance of dependent projects (criterion 5: ✓). Assuming $\boldsymbol{e} = (1,1,\dots,1)^T$, the alpha centrality does not consider additional project parameters. In case $\boldsymbol{e}$ is replaced with other parameters, each case must be assessed individually to determine its mathematical correctness. For example, using the standard deviation as a risk indicator leads to invalid results (criterion 6: ×). Alpha centrality does not limit the elements of $\boldsymbol{A}$ to a specific interval. Thus, it may imply both positive and negative effects. Generally, the literature indicates negative effects using positive elements ($a_{ij} > 0$). However, the existence of positive and negative a_{ij} simultaneously does not result in the interpretation of the results (vector $\boldsymbol{x}$) in a meaningful way (criterion 7: ×).

RM2: An Integrated Systemic Risk Quantification Approach by Beer et al.

The consideration of variance is a well-established way to analyze portfolio risk. The portfolio theory of Markowitz (1952) in the financial sector represents a well-known approach for analyzing the risk of stock portfolios concerning inter-stock dependencies. Beer et al. (2015) introduced an integrated risk measure (Equation 2) for IT portfolios that combines the concept of portfolio theory (Markowitz, 1952) and a preference function to determine the risk-adjusted IT project value introduced by Beer et al. (2013) to account for overall portfolio risk.

$$\Phi^*(\mu, \sigma) = \sum_i \mu_i - \gamma \sum_i \sigma_i^2 - \gamma \sum_i \sum_{i \neq j} \sigma_i \sigma_j \tilde{\rho}_{ij} \tag{2}$$

In equation (2), μ_i represents the expected value of the IT project, σ_i its corresponding risk (standard deviation), $\tilde{\rho}_{ij}$ the Bravais-Pearson correlation coefficient between each pair of IT projects weighted by a risk aversion parameter γ. Additionally, to include indirect dependencies within the portfolio risk term $\sum_i \sum_{i \neq j} \sigma_i \sigma_j \tilde{\rho}_{ij}$ they adapted alpha centrality as shown in equation (3).

$$\boldsymbol{x} = (\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1} \circ \boldsymbol{E} \tag{3}$$

In the above equation, the mathematical operator '∘' describes an element-wise multiplication of the matrix $(\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1}$, containing the transitive dependencies ($a_{ij} \triangleq \tilde{\rho}_{ij}$), and the exogenous matrix $\boldsymbol{E}$, containing the covariances $\sigma_i \sigma_j$. Consequently, the IT portfolio risk term $\sum_i \sum_{i \neq j} \sigma_i \sigma_j \tilde{\rho}_{ij}$ now accounts for transitive dependencies in

IT portfolios. Thus, Beer et al. (Beer et al., 2015) were able to calculate an integrated and adequately risk-adjusted IT portfolio value. For a detailed description of the combining of the alpha centrality and the preference function, we refer to Beer et al. (2015). Analogous to the alpha centrality, due to the consideration of $\boldsymbol{A}$ respectively $(\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1}$ the risk measure accounts for direct and indirect dependencies (criterion 1: ✓, criterion 2: ✓). In contrast to the financial sector, the correlation coefficients $\tilde{\rho}_{ij}$ do not have to be symmetrical in IT portfolios and, therefore, indicate the direction of dependencies (criterion 3: ✓). Additionally, the correlation coefficients $\tilde{\rho}_{ij}$ represent the dependencies' intensities (criterion 4: ✓). Due to the use of the alpha centrality, the risk measure also considers the criticality of other projects (criterion 5: ✓). Further, due to the integrated consideration of μ and σ, the risk measure accounts for inherent project parameters (criterion 6: ✓). Finally, the risk measure can only consider positive or negative effects and not both simultaneously (criterion 7: ✘).

4.3.2 Flow redistribution models

Flow redistribution models analyze and optimize the flow of resources and information in a system. These focus on identifying bottlenecks by analyzing redistribution flows, aiming for more efficient utilization of resources. Therefore, such models are primarily used in domains such as logistics, traffic planning, and supply chain management but have also been adapted to analyze cascading failures in projects. Thus, next, we summarize a "Load Capacity Model" by Guo et al. (2019) and a "Portfolio Selection Model" by Bai et al. (2023) in this category.

RM3: A Load Capacity Model by Guo et al.

The risk measure provided by Guo et al. (2019) is based on Motter and Lai (2002). Their model initially assigns each project (represented by a node) a specific capacity, indicating the maximum load that it could handle without failure (Crucitti et al., 2004). During the cascading process, the load of each node is recalculated based on centrality measures, such as betweenness centrality (Crucitti et al., 2004), degree centrality (J. Wang, 2013), or out-degree centrality (Tang et al., 2016). If the capacity of a node is lower than its current load, then its predecessor nodes must also handle its load. If one of these is unable to handle the additional load, the cascading process begins. Otherwise, the failed task can restore itself due to the self-protection mechanism. The risk measure is based on the concept introduced by Ellinas et al. (2015) and Ellinas et al. (2016), who modeled the project as a complex network using nodes to represent tasks and edges to describe task interactions. The cascading process results in a set of failed tasks. Guo et al. (2019) applied two established metrics based on Mirzasoleiman et al. (2011) to quantify the impact of a cascading process on a project. However, these metrics are not included in our analysis because these are not a part of the flow redistribution model.

Upon a task's failure, the risk measure by Guo et al. (2019) calculates the additional load to be shared by the predecessor nodes (criterion 1: ✓, criterion 3: ✓) according to their respective weights indicated by the adjacency matrix (criterion 4: ✓). The calculation of the load redistribution is not based on transitive dependencies. However, due to the cascading process indicated by load redistribution, the risk measure also considers indirect predecessors and successors (criterion 2: ✓). Due to the iterative calculation of the cascade process, the risk measure considers the criticality of single projects and all dependent projects (criterion 5: ✓). The risk measure weighs each edge based on the tasks' duration. Moreover, analogous to Ellinas (Ellinas, 2019), the model considers the node weights as dependent on the tasks' duration. Therefore, the risk measure takes at least one task inherent parameter into account (criterion 6: ✓). Finally, based on the cascade model's design, the risk measure can only examine negative effects (criterion 7: ✘).

RM4: A Portfolio Selection Model by Bai et al.

Bai et al. (2023) built on their earlier model, Bai et al. (2021), to investigate the effect of projects' cascading failures on the achievement of associated strategic goals. For this purpose, they introduced a new risk measure called "Strategic Goal Loss Rate (SGLR)", indicating the degree S_L, the initial achievement degree (S_0), and the end loss degree (S_l) of the strategic subgoals (equation (4)).

$$S_L = \frac{S_l}{S_0} \tag{4}$$

However, the SGLR was not included in our analysis because it is not part of the cascade model. For a detailed description of SGLR, we refer to Bai et al. (2023). In the cascade model, they consider two types of nodes for complex networks, namely projects and strategic (sub) goals. Analogous to Guo et al. (2019), they base their cascade failure process on a capacity–load model based on Motter and Lai (2002). Bai et al. (2023) use enumeration to identify valid portfolios, meaning those portfolios must meet the organization's strategic (sub)goals. Subsequently, they ran a cascade failure process for each possible portfolio with different failure intensities. Finally, they identified the optimal portfolio using the minimum SGLR. Although Bai et al. (2023) did not design their approach in the context of IT projects, this approach can be applied in this context.

By taking into consideration $d_{j,k}$, which represents the relationships between projects and portfolios, the cascade model of Bai et al. (Bai et al., 2023) accounts for direct dependencies between project j and all other projects k (criterion 1: ✓). Further, since they consider the betweenness centrality in the calculation of the initial risk load of each project, the cascade model also accounts for indirect dependencies (criterion 2: ✓). However, the calculation of direct project interdependencies using $d_{j,k}$ respectively the definition of $d_{j,k} = 1$ indicates that the model does not account for the direction of inter-project dependencies (criterion 3: ×) or their intensity (criterion 4: ×). Analogous to criterion 2, Bai et al. (Bai et al., 2023) additionally account for the criticality of other dependent projects by including the neighbors' weights ω_k, while calculating the initial risk loads (criterion 5: ✓). Moreover, they consider the budget during the calculation of valid portfolios as an additional factor to be taken into account (criterion 6: ✓). Once again, based on the definition of $d_{j,k} = 1$, the cascade model does not account for positive and negative dependencies between two projects j and k (criterion 7: ×).

4.3.3 Percolation models

The third category of percolation models study the phenomenon of percolation in various systems. Percolation occurs when liquids, gases, or other substances flow through a porous medium or network of compounds. These models assist in analyzing and understanding the flow or spread of substances through a medium. Percolation models are used in various fields, such as physics, chemistry, and geology. Additionally, these are relevant in epidemiology to simulate the spread of diseases or in computer science to model the propagation of information or viruses in networks. The cascade effects in portfolios are comparable to the aforementioned application fields of percolation models. Therefore, the "TD Method" by Guggenmos et al. (2019) and an "Activity Network Approach" by Ellinas (2019) have applied these to the field of IT portfolio management.

RM5: The TD Method by Guggenmos et al.

The TD method introduced by Guggenmos et al. (2019) transfers a physical model from epidemiology to IT portfolios modeled as a graph. It is based on the SI (susceptible-infected) cascade model proposed by Kermack and McKendrick (1927), which is a well-known model for simulating the spread of diseases in a society. The TD method distinguishes two states: "on track" (T) and "in difficulty" (D). A project in state T is on track, which implies that it is on time, within scope and within budget. However, it can reach a state of "difficulty" (state D). If a project is in state D, for example, owing to a temporal delay, it can affect other projects that depend on it (e.g., require results of the project in state D). The TD method assumes that projects in state D can affect other projects currently in state T. The TD method does not consider the transition from state D to state T, which implies that a project returns to track. This method calculates a criticality measure (CM) (equation (5)), indicating a project's specific criticality based on a user-specific parameter γ to modify the impact of the speed of propagation.

$$CM_i = 1 + \sum_{t=1}^{n} \frac{\Delta elements_{i,t}^{D}}{t^{\gamma}} \tag{5}$$

The TD method considers direct dependencies indicated by the graph's edges (criterion 1: ✓). Further, the TD method calculates the failure cascade for each timestep t based on the projects in state D in $t-1$ ($\Delta elements_{i,t}^{D}$ in equation (5)). Therefore, it also accounts for indirect dependencies (criterion 2: ✓). Further, the calculation of the cascade process is based on a directed graph (criterion 3: ✓). However, in contrast to Neumeier et al. (2018), the graph does not necessarily have to be acyclic. The original SI cascade model of Kermack and McKendrick (1927) defines the parameter β as constant over time and all edges. It represents the specific infection rate of a disease. However, the TD method reinterprets the infection rate as a non-static parameter. In the TD method, the value of β is based on a dependency's intensity (criterion 4: ✓). Due to the iterative calculation of the cascade process, the criticality measure CM_i does not only consider the criticality of project i, but also of all the dependent projects ($\Delta elements_{i,t}^{D}$ in equation (5)) (criterion 5: ✓). Moreover, the risk measure does not consider any projects' inherent parameters (criterion 6: ✗). Finally, due to probabilities, the risk measure can only consider positive or negative effects and not both simultaneously (criterion 7: ✗).

RM6: An Activity Network Approach by Ellinas

Ellinas (2019) proposed an analytical model to identify the number of affected tasks, namely nodes, within a project. Through the parameter α the tasks' quality completion can be adjusted in a flexible manner. The model builds upon Ellinas et al. (2015) and Ellinas et al. (2016) and is an advancement of assumptions and data applications of the former models. Their model is based on a specific cascade model and results in two risk measures for each task i. On the one hand, they rank each task's criticality according to its spreading power C_i^{SP} (equation (6)), indicating the task-specific potential to cause cascade effects in later tasks. On the other, they rank all tasks according to their sensitivity C_i^{S} (equation (7)), indicating their susceptibility to failures based on previous tasks.

$$C_i^{SP} = C_i^{SP(topo)} * C_i^{SP(temp)} \tag{6}$$

$$C_i^{S} = C_i^{S(topo)} * C_i^{S(temp)} * C_i^{S(float)} \tag{7}$$

Equations (6) and (7) consider both the topological (topo) effects representing the task's position in the network, the activity-on-the-node network (AON) indicated by a directed graph, and the temporal (temp) effects representing the task's specific duration. The task's sensitivity, further considers the float between two consecutive tasks, representing the viable time to deploy mitigations. Hereby, the AON represents the float by the Euclidean space of the network (length of the edges). For a detailed description of all parameters and the underlying cascade model, we refer to Ellinas et al. (2015) and Ellinas (2019). The calculation of $C_i^{SP(topo)}$ and $C_i^{S(topo)}$ the risk measure considers direct predecessors and successors (criterion 1: ✓). Due to the calculation of cascading effects, the risk measure also considers exclusively indirect predecessors and successors (criterion 2: ✓). Ellinas (2019) uses an adjacency matrix, and due to the directed AON, the risk measure takes into account the direction of dependencies (criterion 3: ✓). The length of the edges regards the time between two tasks and represents the dependency's strength (criterion 4: ✓). Due to the iterative calculation of the cascade process, the risk measure not only considers the criticality of single projects but also of all dependent projects (criterion 5: ✓). Moreover, the risk measure considers at least one task inherent parameter due to the duration of each task (criterion 6: ✓). Finally, due to the design of the cascade model and the calculation of C_i^{SP} and C_i^{S}, the risk measure can only examine negative effects (criterion 7: ×).

4.3.4 Other models

Two models could not be assigned to the above three categories. However, these are relevant risk measures for analyzing cascade failures in complex networks, that is, in IT portfolios. A "Bayesian Network Approach" by Neumeier et al. (2018) and a "Vulnerability Assessment Model" by Guo et al. (2020) are part of this last category.

RM7: A Bayesian Network Approach by Neumeier et al.

Neumeier et al. (2018) introduced a new risk measure for projects to analyze a single IT project's criticality in a portfolio context by applying Bayesian networks. They modeled the portfolio as a directed acyclic graph containing technical dependencies between IT projects and resource dependencies between IT projects and shared resources. Furthermore, the Bayesian network comprises two states: success (T) and failure (F). The risk measure calculates the total cost of failure (TCF) (equation (8)), which describes the extent of economic loss that a specific IT project (here project i) can cause to the IT portfolio, and an integrated cost-risk measure (risk exposure (RE)) (equation (9)).

$$TCF(P_i) = CF(P_i) + \sum_{j \in RP_{i,j}} ECF\left(P_j = F \middle| P_i\right) \tag{8}$$

$$RE = TCF(P_i) * P(P_i = F) \tag{9}$$

They calculated conditional probability tables (CPTs) to build their Bayesian network, which consists of conditional dependencies between directly dependent projects (criterion 1: ✓). During the calculation of the TCF they did not only consider direct dependent projects but all reachable projects (parameter RP in equation (8)) in the IT portfolio (criterion 2: ✓). Lastly, due to the directed graph, the risk measure also takes into consideration directed dependencies (criterion 3: ✓). Furthermore, their risk measure considers a dependency's strength as the conditional dependencies between the projects, containing the edges' intensity (criterion 4: ✓). Further, while calculating the TCF, they sum up costs of failure of project i (parameter $CF(P_i)$ in equation 8) with the expected costs of failure (parameter $ECF\left(P_j = F \middle| P_i\right)$ in equation (8)) of all "attainable projects" indicating indirect dependent projects. Therefore, the risk measure also considers the ECF of other dependent projects but not their criticality as represented by the TCF (criterion 5: ×). Moreover, the risk measure considers the project's inherent probability of failure, as indicated in equation (9) (criterion 6: ✓). Finally, due to probabilities, the risk measure can only consider positive or negative effects (criterion 7: ×).

RM8: A Vulnerability Assessment Model by Guo et al.

A Vulnerability Assessment Model by Guo et al. (2020) is a risk measure that allows the quantitative assessment of project vulnerabilities in megaprojects. They abstracted a megaproject as a weighted directed network and developed a new vulnerability metric. Additionally, they mathematically display communities within a network, representing a stronger relationship between single tasks in projects than loosely connected projects. This community assessment is crucial for the overall vulnerability assessment because it indicates tasks within a project and projects within a megaproject. The risk measure v_z (equation (10)) combines an "outer" vulnerability (v_z^C) that regards interdependencies between a megaproject's projects and an "inner vulnerability" (v_z^D) that considers the internal state of a project to calculate the vulnerability of project z. Further, they defined the maximum vulnerability of all components as the megaproject's vulnerability v_G. For a detailed description of the calculations, we refer to Guo et al. (2020).

$$v_z = \frac{1}{(1 - v_z^D)} * v_z^C \; if \; 0 \leq v_z^D \leq 1 \tag{10}$$

By calculating v_z^C, the risk measure accounts for direct dependencies between project z and all other projects (criterion 1: ✓). Further, by calculating v_z^D, which uses the network efficiency, RM8 also considers indirect dependencies (criterion 2: ✓). The authors modeled the megaproject as a directed network and v_z^C also considers the dependencies' directions (criterion 3: ✓). Analogous to Guo et al. (Guo et al., 2019), the risk measure considers the weights of dependencies on the related projects' duration (criterion 4: ✓). Since the calculation of v_z^C is not recursive, and the risk measure only accounts for direct dependencies, it does not consider other projects' criticality (criterion 5: ×). The risk measure weights each edge based on the tasks' durations, analogous to Guo et al. (2019). Moreover, the risk measure considers the duration of the tasks and projects. Besides, v_z^D indicates a project's efficiency, assuming several tasks may fail (criterion 6: ✓). Due to the calculation of v_z^C, based on weighted edges indicated by an adjacency matrix, the risk measure cannot simultaneously deal with positive and negative effects (criterion 7: ×).

5. Discussion

5.1. Reflection of evaluation results

First, we note that RM1, as part of the category "centrality measures", has been previously stated as a suitable risk measure for IT portfolios by Wolf (2015), which we confirmed with our study since it fits five out of seven criteria. Still, the alpha centrality is inferior to other risk measures. For instance, the alpha centrality did not fulfill Criterion 7 of our evaluation. However, Radszuwill and Fridgen (2017) have investigated how alpha centrality allows for the assessment of synergies, even if not for simultaneous consideration of synergies and risks. Further, we showed that the evaluation criteria Wolf (2015) used do not account for all aspects of systemic risk in IT portfolios, demonstrating that the update and enrichment of the evaluation criteria were reasonable.

Next, through our study, we could detect differences between centrality measures and all other risk measures investigated, further referred to as "simulation-based" risk measures. For instance, centrality measures compute centrality scores, making the computation easy, fast, and straightforward for organizations regarding required input parameters and calculation time. However, the static approach of centrality measures is both a benefit and an impediment simultaneously. In contrast, simulation-based risk measures are more dynamic and provide more flexibility owing to their simulation options. Further, the simulation approach of those measures allows for improved detection and understanding of reciprocal effects, enabling organizations to better represent reality compared to centrality measures. However, to exploit the benefits of simulation-based risk measures, organizations must possess the required input data of an acceptable quality (Micán et al., 2020).

Further, obtaining the input data required for more complex and dynamic risk measures is challenging for organizations. However, attaining this data is sometimes impossible for organizations and requires more effort than organizations are willing to take. Therefore, the first step in analyzing IT portfolios should be elaborating on data availability and quality, which is relevant because the appropriateness and correctness of the presented and evaluated risk measures depend on it. In cases where organizations cannot provide the required information (quality), they should not move forward in analyzing IT portfolios but instead focus on improving their data quality. Otherwise, valid risk management cannot be guaranteed.

Finally, organizations should be aware of the potential risk measures available and their respective strengths and weaknesses. For instance, a risk measure's failure to fulfill specific evaluation criteria compared to others could make the organizations perceive the risk measure as inappropriate, which may not always be the case for every organization. This supposedly poor risk measure can still be a promising risk measure for organizations where the non-fulfilled evaluation criteria are irrelevant or the required input data for those criteria cannot be provided.

5.2. Implications for practice and theory

The overview and evaluation of the risk measures for quantitatively analyzing systemic risk in the IT portfolio enables organizations to apply the most suitable measures according to their available data or use case. Specifically, organizations can use Table 2 and Table 3 as a foundation for their project selection decisions. For these decisions, we want to raise awareness among organizational leaders and provide support for the quantitative analysis of systemic risk in IT portfolios. Thus, we present the following three recommendations:

Recommendation 1: Organizations should know how to quantify their IT portfolio.

All of our identified and evaluated risk measures are quantitative and require respective data for their calculations. Further, all risk measures are based on some kinds of complex networks; thus, for organizations, it is reasonable to know the peculiarities of complex networks and how a real-world IT portfolio can be represented through those. For this quantitative representation and assessment of the IT portfolio, organizations must be capable of providing the obtained data, especially regarding dependencies, for the calculation in sufficient quality. Otherwise, no reliable risk analysis results can be achieved.

Recommendation 2: Organizations should select the most appropriate risk measure according to their available data and use case.

Our overview of the risk measures for analyzing systemic risk in the IT portfolio enables organizations to apply the most suitable measures according to their available data or use case. Specifically, organizations can use Table 2 and Table 3 as a foundation for their decision. On the one hand, they can map their available data with the data required for each risk measure and determine which risk measure is potentially usable according to their database. Second, suppose organizations already know what they want to assess (e.g. single projects' criticality or project selection). In that case, they can determine the suitable risk measure according to their preferred analysis focus and use case.

Recommendation 3: Organizations should be aware that no currently existing risk measure can consider risk and synergies simultaneously, demanding separate risk analyses and a subsequent reflection on the results.

Even though our findings support organizations in applying the most suitable risk measure, organizations are still challenged regarding decisions on integrating emerging IT innovation or digitalization projects in the IT portfolio. One reason for this challenge is that our determined risk measures cannot fulfill the simultaneous consideration of synergies and risks (Criterion 7). Thus, organizations would benefit from performing separate analyses for risks and synergies, as also suggested by Radszuwill and Fridgen (2017). After those separate analyses, organizations must reflect on the results to balance the risk-driven and opportunity-driven perspectives and make their project selection decision. However, in our opinion, this can only be an interim solution approach until risk measures are available to consider risks and synergies simultaneously, as the knowledge gap also stated by Micán et al. (2020) could not be solved until now.

Additionally, this study makes two theoretical contributions. First, we provide an overview of risk measures to quantitatively analyze systemic risk in IT portfolios that has yet been missing in such a form. We thus add novel knowledge to the existing knowledge base. Second, we updated and enriched the evaluation criteria set proposed by Wolf (2015), suggesting an improved set of criteria to evaluate risk measures in the context of IT portfolios. Through this reassessed set of evaluation criteria, we updated the existing knowledge base.

5.3. Limitations and future research potential

Like each research endeavor, this study is subject to certain limitations. The structured literature review identified eight risk measures suitable for analyzing systemic risk in IT portfolios. However, derivatives or other risk measures may also be appropriate for quantifying the systemic risk in IT portfolios, which we have not included yet. Second, for our evaluation criteria, we primarily drew on the set of evaluation criteria by Wolf (2015), which we updated and enriched. However, certain aspects may not have been covered by our evaluation criteria. Nevertheless, to the best of our knowledge, these criteria cover the main aspects of systemic risk.

Overall, we acknowledge that the current body of literature provides a sufficient understanding of promising risk measures for assessing the criticality of individual IT projects or the entire IT portfolio. Nevertheless, further research is warranted in this field. First, even though previous researchers have already demanded means to analyze risks and synergies in an integrated manner (Micán et al., 2020), this knowledge gap still exists. Second, to support future research in developing suitable risk measures, researchers should utilize our set of evaluation criteria as input for requirements. Third, collecting the necessary data of adequate quality from IT projects and IT portfolios takes time and effort for organizations. Thus, developing risk measures to illustrate reality as well as possible may unnecessarily maximize complexity and is unreasonable. Instead, it is more desirable to drive research for risk measures that are more pragmatic to achieve a better cost-benefit ratio for organizations. Lastly, future research should focus on assessing how digital technologies (such as AI and machine learning) can support the process of data collection required for calculating the risk measures or how those technologies can contribute to more pragmatism, including an easier calculation of various IT portfolio scenarios and management-optimized display of results.

6. Conclusion

Considering the high percentage of project failures (The Standish Group, 2018, 2020) and the fact that these are partly attributed to the interdependencies of the projects (Beer et al., 2015; Ellinas et al., 2015; Guggenmos et al., 2019), it underscores the need to quantitatively analyze systemic risk in IT portfolios to support the successful management of the IT portfolio. However, an overview of suitable risk measures for analyzing systemic risk in IT portfolios has yet to be provided.

We filled this knowledge gap and performed a SLR to identify risk measures that enabled us to determine the most critical IT projects in an IT portfolio and the overall IT portfolio risk considering systemic risk. To evaluate the eight identified risk measures, we used a set of seven evaluation criteria derived from mathematical considerations on how risk measures can be modeled and complemented with insights from the SLR. Our qualitative, criteria-based evaluation revealed that none of the identified risk measures fulfilled all evaluation criteria, and no risk measure fulfilled Criterion 7, focusing on the simultaneous consideration of risks and synergies.

Our study provides the yet missing overview of risk measures suitable for quantitatively analyzing systemic risk in IT portfolios. We further provided an updated set of evaluation criteria that shall function as input for the future development of risk measures. Moreover, our research findings support organizations in determining the most suitable risk measure regarding their available data and use case, contributing to more successful IT portfolio management and, ultimately, to overall organizational success.

References

Acemoglu, D., Ozdaglar, A., & Tahbaz-Salehi, A. (2015). Systemic risk and stability in financial networks. *American Economic Review*, *105*(2), 564–608.

Acharya, V. V., Pedersen, L. H., Philippon, T., & Richardson, M. (2017). Measuring Systemic Risk. *The Review of Financial Studies*, *30*(1), 2–47.

Al-Ahmad, W., Al-Fagih, K., Khanfar, K., Alsamara, K., Abuleil, S., & Abu-Salem, H. (2009). A taxonomy of an IT project failure: root causes. *International Management Review*, *5*(1).

Archer, N., & Ghasemzadeh, F. (1999). An integrated framework for project portfolio selection. *International Journal of Project Management*, *17*(4), 207–216.

Ash, J., & Newth, D. (2007). Optimizing complex networks for resilience against cascading failure. *Physica a: Statistical Mechanics and Its Applications*, *380*, 673–683.

Azhari, A., & Raharjo, T. (2023). A Systematic Literature Review on Digital Transformation Projects Discovering Project Goals and Problems. *Journal of Theoretical and Applied Information Technology*, *101*(21), 6855–6870.

Baccarini, D., Salm, G., & Love, P. E. (2004). Management of risks in information technology projects. *Industrial Management & Data Systems*, *104*(4), 286–295.

Bai, L., Han, X., Wang, H., Zhang, K., & Sun, Y. (2021). A method of network robustness under strategic goals for project portfolio selection. *Computers & Industrial Engineering*, *161*.

Bai, L., Han, X., Zhang, Y., & Xie, X. (2023). Optimal Project Portfolio Selection Considering Cascading Failure Among Projects. *IEEE Transactions on Engineering Management*, 1–11.

Bathallath, S., Smedberg, Å., & Kjellin, H. (2016). Managing project interdependencies in IT/IS project portfolios: a review of managerial issues. *International Journal of Information Systems and Project Management*, *4*(1), 67–82.

Beer, M., Fridgen, G., Müller, H.-V., & Wolf, T. (2013). Benefits Quantification in IT Projects. *WIRTSCHAFTSINFORMATIK*.

Beer, M., Wolf, T., & Zare Garizy, T. (2015). Systemic Risk in IT Portfolios – An Integrated Quantification Approach. In *Proceedings of the 36th International Conference on Information Systems (ICIS),* Fort Worth, Texas, USA.

Bonacich, P., & Lloyd, P. (2001). Eigenvector-like measures of centrality for asymmetric relations. *Social Networks*, *23*(3), 191–201.

Brockmann, D., & Helbing, D. (2013). The hidden geometry of complex, network-driven contagion phenomena. *Science*, *342*(6164), 1337–1342.

Buldyrev, S. V., Parshani, R., Paul, G., Stanley, H. E., & Havlin, S. (2010). Catastrophic cascade of failures in interdependent networks. *Nature*, *464*(7291), 1025–1028.

Bürger, O., Häckel, B., Karnebogen, P., & Töppel, J. (2019). Estimating the impact of IT security incidents in digitized production environments. *Decision Support Systems*, *127*, 113144.

Cooley, D. M., Galik, C. S., Holmes, T. P., Kousky, C., & Cooke, R. M. (2012). Managing dependencies in forest offset projects: Toward a more complete evaluation of reversal risk. *Mitigation and Adaptation Strategies for Global Change*, *17*(1), 17–24.

Costantino, F., Di Gravio, G., & Nonino, F. (2015). Project selection in project portfolio management: An artificial neural network model based on critical success factors. *International Journal of Project Management*, *33*(8), 1744–1754.

Crucitti, P., Latora, V., & Marchiori, M. (2004). Model for cascading failures in complex networks. *Physical Review E*, *69*(4).

Curcio, D., Gianfrancesco, I., & Vioto, D. (2023). Climate change and financial systemic risk: Evidence from US banks and insurers. *Journal of Financial Stability*, *66*, 101132.

Didrage, O. (2013). The Role and the Effects of Risk Management in IT Projects Success. *Informatica Economica*, *17*(1), 86–98.

Drake, J. R., & Byrd, T. A. (2006). Risk in information technology project portfolio management. *Journal of Information Technology Theory and Application*, *8*(3).

Eisenberg, L., & Noe, T. H. (2001). Systemic Risk in Financial Systems. *Management Science*, *47*(2), 236–249.

Ellinas, C. (2019). The domino effect: an empirical exposition of systemic risk across project networks. *Production and Operations Management*, *28*(1), 63–81.

Ellinas, C., Allan, N., Durugbo, C., & Johansson, A. (2015). How robust is your project? From local failures to global catastrophes: A complex networks approach to project systemic risk. *PloS One*, *10*(11).

Ellinas, C., Allan, N., & Johansson, A. (2016). Project systemic risk: Application examples of a network model. *International Journal of Production Economics*, *182*, 50–62.

Flyvbjerg, B., & Budzier, A. (2011). Why your IT project may be riskier than you think. *Harvard Business Review*, *89*, 23–25.

Flyvbjerg, B., Budzier, A., Lee, J. S., Keil, M., Lunn, D., & Bester, D. W. (2022). The Empirical Reality of IT Project Cost Overruns: Discovering A Power-Law Distribution. *Journal of Management Information Systems*, *39*(3), 607–639.

Freixas, X., Parigi, B. M., & Rochet, J.-C. (2000). Systemic Risk, Interbank Relations, and Liquidity Provision by the Central Bank. *Journal of Money, Credit and Banking*, *32*(3), 611.

Frey, T., & Buxmann, P. (2012). IT project portfolio management-a structured literature review. In *Proceedings of the 20th European Conference on Information Systems (ECIS),* Barcelona, Spain.

Fridgen, G., & Moser, F. (2013). Using IT fashion investments to optimize an IT innovation portfolio's risk and return. *Journal of Decision Systems*, *22*(4), 298–318.

Gao, J., Buldyrev, S. V., Havlin, S., & Stanley, H. E. (2011). Robustness of a network of networks. *Physical Review Letters*, *107*(19), 195701.

Ghasemi, F., Sari, M. H. M., Yousefi, V., Falsafi, R., & Tamošaitienė, J. (2018). Project Portfolio Risk Identification and Analysis, Considering Project Risk Interactions and Using Bayesian Networks. *Sustainability*, *10*(5), 1609.

Guan, D., Guo, P., Hipel, K. W., & Fang, L. (2017). Risk reduction in a project portfolio. *Journal of Systemic Science and Systems Engineering*, *26*(1), 3–22.

Guggenmos, F., Hofmann, P., & Fridgen, G. (2019). How ill is your IT Portfolio?–Measuring Criticality in IT Portfolios Using Epidemiology. In *Proceedings of the 40th International Conference on Information Systems (ICIS),* Munich, Germany.

Guo, N., Guo, P., Dong, H., Zhao, J., & Han, Q. (2019). Modeling and analysis of cascading failures in projects: A complex network approach. *Computers & Industrial Engineering*, *127*, 1–7.

Guo, N., Guo, P., Madhavan, R., Zhao, J., & Liu, Y. (2020). Assessing the Vulnerability of Megaprojects Using Complex Network Theory. *Project Management Journal*, *51*(4), 429–439.

Ha, H., & Madanian, S. (2020). The potential of artificial intelligence in it project portfolio selection.

Häckel, B., & Hänsch, F. (2014). Managing an IT portfolio on a synchronised level, or: The costs of partly synchronised investment valuation. *Journal of Decision Systems*, *23*(4), 388–412.

Häckel, B., Lindermeir, A., Moser, F., & Pfosser, S. (2017). Mindful engagement in emerging IT innovations. *ACM SIGMIS Database: The DATABASE for Advances in Information Systems*, *48*(1), 53–74.

Häckel, B., Pfosser, S., Stirnweiß, D., & Voit, C. (2018). Determining optimal strategies for investments in an emerging IT innovation. In *Proceedings of the European Conference on Information Systems (ECIS),* Portsmouth, UK.

Hautsch, N., Schaumburg, J., & Schienle, M. (2015). Financial network systemic risk contributions. *Review of Finance*, *19*(2), 685–738.

Hill, J., Thomas, L., & Allen, D. (2000). Experts' estimates of task durations in software development projects. *International Journal of Project Management*, *18*(1), 13–21.

Irsak, M., & Barilovic, Z. (2023). Digital Transformation Project in a Function of Raising Competitive Advantage. *Economic and Social Development: Book of Proceedings*, 49–57.

Karrenbauer, C., & Breitner, M. H. (2022). Value-driven IT Project Portfolio Management: Process Model, Evaluation Framework, and Decision Support. In *Proceedings of the International Conference on Information Systems (ICIS),* Copenhagen, Denmark.

Katz, L. (1953). A new status index derived from sociometric analysis. *Psychometrika*, *18*(1), 39–43.

Kaufman, G. G., & Scott, K. E. (2003). What is systemic risk, and do bank regulators retard or contribute to it? *The Independent Review*, *7*(3), 371–391.

Kermack, W. O., & McKendrick, A. G. (1927). A contribution to the mathematical theory of epidemics. *Proceedings of the Royal Society of London a: Mathematical, Physical and Engineering Sciences*, *115*(772), 700–721.

Khan, A. A., Laghari, A. A., Shaikh, Z. A., Dacko-Pikiewicz Zdzislawa, & Kot, S. (2022). Internet of Things (IoT) Security With Blockchain Technology: A State-of-the-Art Review. *IEEE Access*, *10*.

Kohnke, O., Nieland, T., Straatmann, T., & Mueller, K. (2024). How do management factors influence digital adoption in the case of a large-scale digital transformation project–A process perspective. *Journal of Management & Organization*, *30*(5), 1564–1584.

Kundisch, D., & Meier, C. (2011). IT/IS project portfolio selection in the presence of project interactions–review and synthesis of the literature.

Lee, J. W., & Kim, S. H. (2001). An integrated approach for interdependent information system project selection. *International Journal of Project Management*, *19*(2), 111–118.

March, J. G., & Shapira, Z. (1987). Managerial Perspectives on Risk and Risk Taking. *Management Science*, *33*(11), 1404–1418.

Mark, J., & Ingmar, L. (2004). Best Practices in IT Portfolio Management. *MIT Sloan Management Review*.

Markowitz, H. (1952). Portfolio selection. *The Journal of Finance*, *7*(1), 77–91.

Martinsuo, M., & Geraldi, J. (2020). Management of project portfolios: Relationships of project portfolios with their contexts. *International Journal of Project Management*, *38*(7), 441–453.

Micán, C., Fernandes, G., & Araújo, M. (2020). Project portfolio risk management: a structured literature review with future directions for research. *International Journal of Information Systems and Project Management*, *8*(3), 67–84.

Miehle, D., Häckel, B., Pfosser, S., & Übelhör, J. (2019). Modeling IT Availability Risks in Smart Factories. *Business & Information Systems Engineering*, 1–23.

Motter, A. E., & Lai, Y.-C. (2002). Cascade-based attacks on complex networks. *Physical Review E*, *66*(6 Pt 2).

Neumeier, A., Radszuwill, S., & Garizy, T. Z. (2018). Modeling project criticality in IT project portfolios. *International Journal of Project Management*, *36*(6), 833–844.

Ngereja, B. J., Hussein, B., & Wolff, C. (2024). A comparison of soft factors in the implementation and adoption of digitalization projects: a systematic literature review. *International Journal of Information Systems and Project Management*, *12*(2), 70–86.

Omol, E. J. (2024). Organizational digital transformation: from evolution to future trends. *Digital Transformation and Society*, *3*(3), 240–256.

Otay, İ., Onar, S. Ç., Öztayşi, B., & Kahraman, C. (2023). A novel interval valued circular intuitionistic fuzzy AHP methodology: Application in digital transformation project selection. *Information Sciences*, *647*, 119407.

Pappert, L., & Kusanke, K. (2023). Modern Project Portfolio Management– Analyzing the Potential of Artificial Intelligence. In A. Kalenborn, M. Fazal-Baqaie, O. Linssen, A. Volland, E. Yigitbas, M. Engstler, & M. Bertram (Eds.), *GI-Edition Proceedings: volume P-340. Projektmanagement und Vorgehensmodelle 2023, PVM 2023: Nachhaltige IT-Projekte : Gemeinsame Tagung der Fachgruppen Projektmanagement (WI-PM) und Vorgehensmodelle (WI-VM) im Fachgebiet Wirtschaftsinformatik der Gesellschaft für Informatik e.V. In Kooperation mit der Fachgruppe IT-*

Projektmanagement der GPM e.V. Und der PMI Germany Chapter e.V. : 16. Und 17. November 2023 in Hagen. Gesellschaft für Informatik.

Pastor-Satorras, R., & Vespignani, A. (2001). Epidemic dynamics and endemic states in complex networks. *Physical Review E*, *63*(6), 66117.

Pimchangthong, D., & Boonjing, V. (2017). Effects of Risk Management Practices on IT Project Success. *Management and Production Engineering Review*, *8*(1), 30–37.

Prifti, V. (2022). Optimizing Project Management using Artificial Intelligence. *European Journal of Formal Sciences and Engineering*, *5*(1), 30–38. https://doi.org/10.26417/667hri67

Radszuwill, S., & Fridgen, G. (2017). Forging a Double-Edged Sword: Resource Synergies and Dependencies in Complex IT Project Portfolios.

Rotolo, D., Hicks, D., & Martin, B. R. (2015). What is an emerging technology? *Research Policy*, *44*(10), 1827–1843.

Santhanam, R., & Kyparisis, G. J. (1996). A decision model for interdependent information system project selection. *European Journal of Operational Research*, *89*(2), 380–399.

Schulte, F., Karrenbauer, C., & Breitner, M. H. (2024). Critical Success Factors for IT Project Portfolio Management: What do we know, what can we learn? In *Proceedings of the 32nd European Conference on Information Systems,* Paphos, Cyprus.

The Standish Group. (2018). *Decision latency theory: It is all about the interval* (Chaos Report). The Standish Group.

The Standish Group. (2020). *CHAOS 2020: Beyond Infinity Report*. The Standish Group.

Stoica, R., & Brouse, P. (2013). IT Project Failure: A Proposed Four-Phased Adaptive Multi-Method Approach. *1877-0509*, *16*, 728–736. https://doi.org/10.1016/j.procs.2013.01.076

Tang, L., Jing, K., He, J., & Stanley, H. E. (2016). Complex interdependent supply chain networks: Cascading failure and robustness. *Physica a: Statistical Mechanics and Its Applications*, *443*, 58–69.

Tarannum, R., Joseph Ngereja, B., & Hussein, B. (2025). A structured taxonomy for effective digital transformation project implementation: Development, validation, and practical insights. *International Journal of Information Systems and Project Management*, *13*(1), 3.

Tillquist, J., King, J. L., & Woo, C. (2002). A representational scheme for analyzing information technology and organizational dependency. *MIS Quarterly*, 91–118.

Verschuur, J., Pant, R., Koks, E., & Hall, J. (2022). A systemic risk framework to improve the resilience of port and supply-chain networks to natural hazards. *Maritime Economics & Logistics*, 1–18.

Vieira, G. B., Oliveira, H. S., Almeida, J. A. de, & Belderrain, M. C. N. (2024). Project Portfolio Selection considering interdependencies: A review of terminology and approaches. *Project Leadership and Society*, *5*, 100115.

Wang, J. (2013). Mitigation strategies on scale-free networks against cascading failures. *Physica a: Statistical Mechanics and Its Applications*, *392*(9), 2257–2264.

Wang, Q., Zeng, G., & Tu, X. (2017). Information Technology Project Portfolio Implementation Process Optimization Based on Complex Network Theory and Entropy. *Entropy*, *19*(6), 287.

Wehrmann, A., Heinrich, B., & Seifert, F. (2006). Quantitatives IT-Portfoliomanagement: Risiken von IT-Investitionen wertorientiert steuern. *WIRTSCHAFTSINFORMATIK*, *48*.

Wolf, T. (2015). Assessing the Criticality of IT Projects in a Portfolio Context using Centrality Measures. In *Proceedings of the 12th International Conference on Wirtschaftsinformatik (WI),* Osnabrück, Germany.

Zare-Garizy, T., Fridgen, G., & Wederhake, L. (2018). A privacy preserving approach to collaborative systemic risk identification: the use-case of supply chain networks. *Security and Communication Networks*, *2018*.

Zhang, X., Wei, C., Lee, C.-C., & Tian, Y. (2023). Systemic risk of Chinese financial institutions and asset price bubbles. *The North American Journal of Economics and Finance*, *64*, 101880.

Zimmermann, S. (2008). IT-Portfoliomanagement–Ein Konzept zur Bewertung und Gestaltung von IT. *Informatik-Spektrum*, *31*(5), 460–468.

Zuluaga, A., Sefair, J. A., & Medaglia, A. L. (Eds.) (2007). *Model for the selection and scheduling of interdependent projects*. IEEE.

Appendix A. Detailed evaluation results

Table A1. Detailed evaluation results for RM1

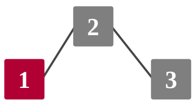
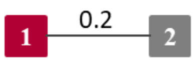
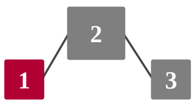
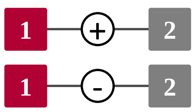
	Criterion	Evaluation	Justification
1	 direct dependencies	✓	The adjacency matrix $\boldsymbol{A}$ represents the graph. Thereby each element $a_{i,j} \neq 0$ represents an existing direct dependency between i and j. By considering $\boldsymbol{A}$, the Alpha centrality considers direct dependencies.
2	 indirect dependencies	✓	While the adjacency matrix $\boldsymbol{A}$ only contains direct dependencies, the term $(\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1}$ results in a matrix containing direct and indirect dependencies. Therefore, the Alpha centrality also considers indirect dependencies.
3	 directed dependencies	✓	While the elements $a_{i,j} \neq 0$ represent existing direct dependencies between i and j the adjacency matrix does not need to be a symmetric matrix ($a_{i,j} = a_{j,i}$). In case of an unsemmetric adjacency matrix $\boldsymbol{A}$, the alpha centrality considers the direction of dependencies.
4	 dependencies' intensity	✓	While the elements $a_{i,j} \neq 0$ represent existing direct dependencies between i and j the adjacency matrix do not need to be binary ($a_{i,j} \in \{0,1\}$) but can take any value ($a_{i,j} \in \mathbb{R}$). Therefore, the alpha centrality considers the weight of dependencies.
5	 criticality of other dependent IT projects	✓	The alpha centrality can be transformed as follows: $$\boldsymbol{x} = (\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1} * \boldsymbol{e} \;\Leftrightarrow\; \boldsymbol{x} = \alpha \boldsymbol{A} \boldsymbol{x} + \boldsymbol{e}$$ Now, the centrality score $\boldsymbol{x}$ is on both sides. Thus, this is a recursive calculation. This means that each centrality score depends on all other centrality scores. Therefore, the alpha centrality considers the centrality (importance) of dependent elements (projects).
6	 IT project (inherent) parameter	×	According to Bonacich and Lloyd (2001), the vector $\boldsymbol{e}$ can reflect the effects of different external status characteristics (e.g. popularity). Therefore, this criterion should be fulfilled. However, the result is not always correct in a mathematical sense. For example, if the vector $\boldsymbol{e}$ contains the standard deviation σ_i as a project-specific risk measure, the calculation leads to "incorrect" results, as the rules for calculating a variance or covariance are disregarded. As the standard deviation is a common measure of risk in project portfolio management, we regard this criterion as not fulfilled.
7	 positive and negative effects of dependencies	×	Since the elements $a_{i,j}$ of $\boldsymbol{A}$ or not limited ($a_{i,j} \in \mathbb{R}$) they can also be positive or negative. Therefore, the alpha centrality might consider dependencies and synergies. However, the calculation of $(\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1}$ while $\boldsymbol{A}$ contains positive and negative elements $a_{i,j}$ at the same time leads to results that can not be interpretated in a meaningful way. Besides that, each element $a_{i,j}$ can only be positive or negative. Therefore, the alpha centrality can not consider dependencies and synergies simultaneously.

Table A2. Detailed evaluation results for RM2

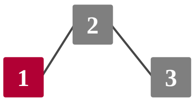
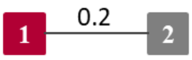
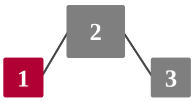
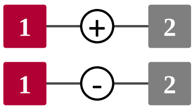
	Criterion	Evaluation	Justification
1	 direct dependencies	✓	Since the portfolio risk term $\sum_i \sum_{i \neq j} \sigma_i \sigma_j \tilde{\rho}_{ij}$ of RM2 base on the alpha centrality the same reasoning applies for the most part. The adjacency matrix $\boldsymbol{A}$ represents the graph. Thereby each element $a_{i,j} \neq 0$ represents an existing direct dependency between i and j. Through the consideration of $\boldsymbol{A}$ RM2 considers direct dependencies.
2	 indirect dependencies	✓	While the adjacency matrix $\boldsymbol{A}$ only contains direct dependencies, the term $(\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1}$ results in a matrix containing direct and indirect dependencies. Therefore, the RM2 also considers indirect dependencies.
3	 directed dependencies	✓	While the elements $a_{i,j} \neq 0$ represent existing direct dependencies between i and j the adjacency matrix does not need to be a symmetric matrix ($a_{i,j} = a_{j,i}$). In case of an asymmetric adjacency matrix $\boldsymbol{A}$**,** RM2 considers the direction of dependencies.
4	 dependencies' intensity	✓	While the elements $a_{i,j} \neq 0$ represent existing direct dependencies between i and j the adjacency matrix does not need to be binary ($a_{i,j} \in \{0,1\}$) but can take any value ($a_{i,j} \in \mathbb{R}$). Therefore, RM2 considers the weight of dependencies.
5	 criticality of other dependent IT projects	✓	The term of the alpha centrality can be transformed as follows: $\boldsymbol{x} = (\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1} * \boldsymbol{e} \Leftrightarrow \boldsymbol{x} = \alpha \boldsymbol{A} \boldsymbol{x} + \boldsymbol{e}$ Now, the centrality score $\boldsymbol{x}$ is on both sides. Thus, this is a recursive calculation. This means that each centrality score depends on all other centrality scores. Therefore, RM2 considers the centrality (importance) of dependent elements (projects).
6	 IT project (inherent) parameter	✓	The portfolio risk term $\sum_i \sum_{i \neq j} \sigma_i \sigma_j \tilde{\rho}_{ij}$ is an adaption of the alpha centrality. $\boldsymbol{x} = (\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1} \circ \boldsymbol{E}$ In the equation, the mathematical operator '∘' describes an element-wise multiplication of the matrix $(\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1}$, containing the transitive dependencies ($a_{ij} \triangleq \tilde{\rho}_{ij}$), and the exogenous matrix $\boldsymbol{E}$, containing the covariances $\sigma_i \sigma_j$ as a project risk measure. Consequently, the IT portfolio risk term $\sum_i \sum_{i \neq j} \sigma_i \sigma_j \tilde{\rho}_{ij}$ now accounts for a project inherent parameter. Further, besides risk (σ), RM2 also considers a second project inherent paramater, namely the expected value (μ). Therefore we regard criterion 6 as fulfilled.
7	 positive and negative effects of dependencies	×	Since RM2 only considers dependencies in its IT portfolio risk term, for criterion 7, the same reasoning applies to alpha centrality. Since the elements $a_{i,j}$ of $\boldsymbol{A}$ are not limited ($a_{i,j} \in \mathbb{R}$) they can also be positive or negative. Therefore, the alpha centrality might consider dependencies and synergies. However, the calculation of $(\boldsymbol{I} - \alpha * \boldsymbol{A})^{-1}$ while $\boldsymbol{A}$ contains positive and negative elements $a_{i,j}$ at the same time leads to results that can not be interpretated in a meaningful way. Besides that each element $a_{i,j}$ can only be positive or negative. Therefore, RM 2 cannot consider dependencies and synergies simultaneously.

Table A3 Detailed evaluation results for RM3

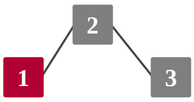
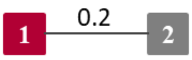
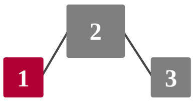
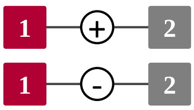
	Criterion	Evaluation	Justification
1	 direct dependencies	✓	Guo et al. (2019) model dependencies between directly consecutive tasks to build a suitable project network. Their cascade model considers direct dependencies by considering the parameters $w_{i,j}$ representing the elements of the graph's adjacency matrix. Therefore, we regard this criterion as fulfilled.
2	 indirect dependencies	✓	Unlike other risk measures, like alpha centrality, RM3 does not explicitly consider the indirect dependencies. However, during the cascade process, the loads are continuously redistributed according to the following rule: $$\begin{cases} \Delta L_{k,p} = L_k(0)\frac{w_{k,p}}{\sum'_{b\in\Gamma'_k} w_{k,b'}} \\ \Delta L_{k,q} = L_k(0)\frac{w_{k,q}}{\sum'_{b\in\Gamma'_k} w_{k,b'}} \end{cases}$$ Thereby, the parameter $\Gamma_k{}'$ represents the set of successor neighbor nodes directly connecting from node k. Through the continuous consideration of all successor nodes during the cascade process, RM3 also considers indirect dependencies and therefore, we regard criterion 2 as fulfilled.
3	 directed dependencies	✓	Also, for RM3, the adjacency matrix does not need to be symmetric. Rather, this approach explicitly relies on asymmetric adjacency matrices since only the subsequent nodes are considered. Therefore, RM3 also considers directed dependencies.
4	 dependencies' intensity	✓	RM3 is based on the idea that tasks that take longer tend to have a greater impact than shorter tasks. Therefore, the authors assume that the node weight ($w_{i,j}$) is relevant to the task duration since edges between the nodes with higher weights tend to have a more significant influence than edges between the nodes with smaller weights (Guo et al., 2019). Therefore, RM3 considers the intensity of dependencies.
5	 criticality of other dependent IT projects	✓	For criterion 5, the same reasoning applies as for criterion 2. Since the cascade process redistributes the loads of all nodes and calculates whether a node fails (node load exceeds its capacity), a node's failure will lead to another load redistribution. Due to this, we conclude that RM3 also considers the criticality of dependent tasks (in this case: successor neighbor tasks) and, therefore, regard criterion 5 as fulfilled.
6	 IT project (inherent) parameter	✓	As mentioned for criterion 4, RM3 calculates the weights of all dependencies based on the tasks' durations, representing a project inherent parameter. Therefore, RM3 fulfills criterion 6.
7	 positive and negative effects of dependencies	×	First, the way how Guo et al. (2019) model their graph (based on the the elements of the adjacency matrics $w_{i,j}$) does not consider synergies. Second, the design of their cascade model only considers the negative effects of dependencies and offers no possibility to consider synergies. Therefore, RM3 does not fulfill criterion 7.

Table A4. Detailed evaluation results for RM4

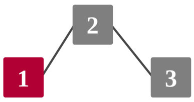
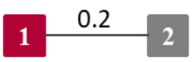
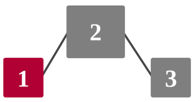
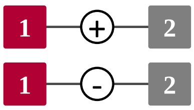
	Criterion	Evaluation	Justification
1	 direct dependencies	✓	Bai et al. (2023) focus on the selection of an optimal project portfolio indicated by the smallest “Strategic Goal Loss Rate” (SGLR). To do this, they model their project portfolio using two different types of nodes and two sets of edges. On the one hand, strategic subgoals are independent of each other, and on the other hand, the projects themselves depend on each other. Further, the strategic subgoals also depend on specific projects. Dependencies between projects exist if and only if they jointly achieve the same strategic subgoal. Therefore, we regard criterion 1 as fulfilled.
2	 indirect dependencies	✓	RM4 also base on load redistribution. The authors calculate the initial load of each project j as follows: $L_j = (1+\alpha)\left(B_j w_j \sum_{k \in M_j} w_k\right)^{\beta}$ In this formula B_j represents the betweenes (centrality) of project j, which bases on the number of shortest paths between all other nodes through node j. Therefore, RM4 implicitly considers indirect dependencies, and we regard criterion 2 as fulfilled.
3	 directed dependencies	×	For criterion 3, we only consider the dependencies between different projects ($d_{j,k}$) and neglect those between projects and strategic sub-goals. The authors define dependencies between projects binary. $d_{j,k} = \begin{cases} 1, & \mathit{if\ project\ j\ and\ project\ k\ can\ achieve\ the\ same\ subgoal} \\ 0, & \mathit{otherwise} \end{cases}$ This results in a symmetric adjacency matrix, and therefore, RM4 does not consider directed dependencies. So, we regard criterion 3 as not fulfilled.
4	 dependencies’ intensity	×	As mentioned for criterion 3, the authors defined the dependencies between projects as binary. This implies that RM4 does not consider individual intensities of dependencies. Therefore, RM4 does not fulfill criterion 4.
5	 criticality of other dependent IT projects	✓	Since the calculation of a project’s (initial and during load redistribution) load depends on dependent projects (implicitly considered by the parameter w_j) RM4 also considers the criticality of other dependent projects. Further, RM4 bases on the same idea as RM3. Consequently, the same reasoning regarding the cascade failure process applies to RM4. Therefore, RM4 fulfills criterion 5.
6	 IT project (inherent) parameter	✓	Before comparing all possible project portfolios regarding the SGLR, the authors reduced the set of potentially relevant project portfolios by applying two rules: 1) All strategic subgoals are achieved. 2) The total budget of the project portfolio does not exceed the enterprise’s budget limitation. To calculate the budget limit, the authors assigned each project a specific budget necessary to carry out the project. By doing so, RM4 considers the budget as a project inherent parameter. Therefore, we regard criterion 6 as fulfilled.
7	 positive and negative effects of dependencies	×	For criterion 7, the same reasoning applies to RM4, as to RM3. The adjacency matrix cannot handle positive and negative effects. Besides, analogous to RM3, RM4 was designed to consider dependencies, not synergies. Therefore, we regard criterion 7 as not fulfilled.

Table A5. Detailed evaluation results for RM5

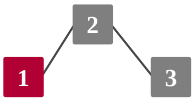
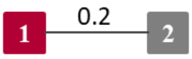
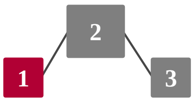
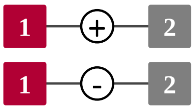
Criterion		Evaluation	Justification
1	 direct dependencies	✓	The TD method, introduced by Guggenmos et al. (2019), is a simulation-based approach. One required input parameter is a graph (complex network) representing the IT project portfolio. This graph considers projects (nodes) and their direct dependencies (edges). Consequently, RM5 fulfills criterion 1.
2	 indirect dependencies	✓	Like the load redistribution models, the TD method does not explicitly consider indirect dependencies. However, through the simulation process, RM5 accounts for these indirect dependencies. In each (time) step of the simulation, the algorithm simulates whether a failure spreads from "infected" nodes to some of its neighbor nodes. By doing this, the process considers indirect dependencies, and we regard criterion 2 as fulfilled.
3	 directed dependencies	✓	According to the authors, the graph, which the TD method uses as an input parameter, is a directed graph. This means that the associated adjacency matrix is not symmetric or does not have to be symmetric. Therefore, RM5 fulfills criterion 3.
4	 dependencies' intensity	✓	Further, the authors decided to use a non-binary adjacency matrix. While in the original SI cascade model, introduced by Kermack and McKendrick (1927), the "infection rate" is constant over time and for all persons, in the TD method, this parameter is only constant over time but individual for each dependency. In the TD method, the dependencies intensities are limited to the interval $[0; 1]$ and represent the probability that a failure spreads to the successor node. Thus, we regard criterion 4 as fulfilled.
5	 criticality of other dependent IT projects	✓	For criterion 5, the same reasoning applies like to criterion 2 and the load redistribution models. The TD method implicitly considers the criticality of other dependent IT projects by the design of the simulation process. This can especially be seen in the calculation of the criticality measure CM_i. $$CM_i = 1 + \sum_{t=1}^{n} \frac{\Delta elements_{i,t}^{D}}{t^{\gamma}}$$ CM_i does not only consider the criticality of project i, but also of all the dependent projects ($\Delta elements_{i,t}^{D}$). Therefore, RM5 fulfills criterion 5.
6	 IT project (inherent) parameter	×	The TD method bases on three input parameters. First, the graph, representing the IT project portfolio. Second, a set of initially failed projects and, third, the number of time steps that should be simulated. Further, the required graph only consists of projects (nodes) and their directed and weighted dependencies (edges). No additional project inherent parameters are used during the simulation, leading to the statement that RM5 does not consider criterion 6.
7	 positive and negative effects of dependencies	×	As mentioned for criterion 4, the authors interpreted the dependencies' weights as a probability for the failures' spread. Since probabilities can only be positive, the TD method cannot consider negative and positive effects at the same time. Although the authors used the TD method only for dependencies, in our opinion, it can also be used with synergies but not at the same time. Therefore, we consider criterion 7 as not fulfilled.

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Table A6. Detailed evaluation results for RM6

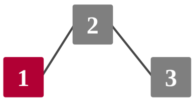
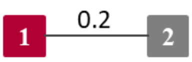
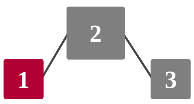
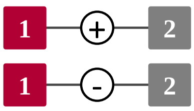
	Criterion	Evaluation	Justification
1	 direct dependencies	✓	The Activity Network Approach, introduced by Ellinas (2019), uses an activity-on-the-node (AON) network notation in the form of a directed graph. In this AON every node i, corresponds to task i and a directed link $e_{i,j}$ accounts for the precedence relationship between tasks i and j. A dependency between task i and j requires that task i must first be completed for task j to start. Therefore, task j is, in relation to task i, a downstream task (similarly, task i is, in relation to task j, an upstream task). As a result, a temporal direction to all possible failures exists, where a failure in task i can only affect downstream tasks but not upstream tasks, as these tasks have already been completed. Therefore, RM6 considers direct dependencies and criterion 1 is fulfilled.
2	 indirect dependencies	✓	For RM6, the authors inter alia use the parameter $C_i^{SP(topo)}$ to calculate the spreading power C_i^{SP} of each node i. $C_i^{SP(topo)}$ considers the position of a task within the AON network by accounting for the effectiveness by which task i can reach, and hence affect its immediate downstream tasks(s) over all possible paths. In addition, longer paths contribute less to the overall spreading power as they are less likely to be traversed compared to shorter, more direct paths. Since this parameter also accounts for indirect dependencies, we regard criterion 2 as fulfilled.
3	 directed dependencies	✓	As already mentioned for criterion 1, RM6 bases on an AON represented by a directed graph. Further, $C_i^{SP(topo)}$ also considers downstream tasks. Therefore, RM6 considers directed dependencies, and we regard criterion 3 as fulfilled.
4	 dependencies' intensity	✓	Besides the network structure $C_i^{SP(topo)}$, the spreading power also considers temporal aspecs $C_i^{SP(temp)}$. The parameter $C_i^{SP(temp)}$ is calculated as the ratio between the duration of task i and the project duration (sum of all task durations). Ellinas (2019) assume that that the longer a task is, the greater its ability to affect its immediate downstream tasks. We conclude that by calculating the spreading power C_i^{SP} RM6 also considers the intensity of dependencies and regard criterion 4 as fulfilled.
5	 criticality of other dependent IT projects	✓	For criterion 5, the same reasoning applies to the TD method (RM5), as to the load redistribution models (RM3 and RM4). RM5 does not explicitly consider the criticality of other dependent projects. However, it considers these implicitly through the design of the cascade process. For instance, the authors calculated new thresholds $\theta_j(new)$ for all downstream tasks j of node i to determine whether some downstream tasks will also fail. Therefore, we conclude that RM6 fulfills criterion 5.
6	 IT project (inherent) parameter	✓	Through the calculation of the spreading power C_i^{SP} respectively its temporal element $C_i^{SP(temp)}$, RM6 accounts for the task duration and, therefore, considers at least one project inherent paramater. So we conclude that RM6 fulfills criterion 6.
7	 positive and negative effects of dependencies	×	Due to the design of the cascade model and the calculation of C_i^{SP} and C_i^{S}, the risk measure can only examine negative effects of dependencies. Analogous to RM5, the authors of RM6 only use their cascade model for dependencies. However, it can also be used with synergies but not simultaneously. Therefore, we consider criterion 7 as not fulfilled.

Table A7. Detailed evaluation results for RM7

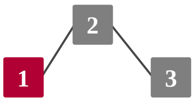
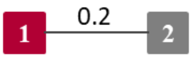
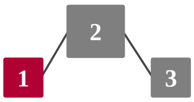
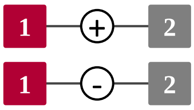
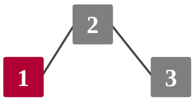
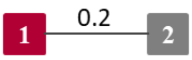
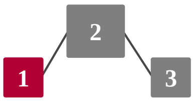
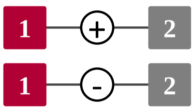
	Criterion	Evaluation	Justification
1	 direct dependencies	✓	RM7, introduced by Neumeier et al. (2018), bases on Bayesian networks. A Bayesian network is a directed acyclic graph (DAG) with nodes and edges. Thereby, edges represent conditional dependencies between nodes. The authors use nodes to model IT projects and shared resources and edges to model dependencies between two IT projects as well as an IT project and a shared resource. Therefore, RM7 considers direct dependencies and criterion 1 is fulfilled.
2	 indirect dependencies	✓	Like the flow redistribution models, RM7 does not explicitly consider indirect dependencies. RM7 considers these implicitly by calculating the total cost of failure (TCF). $TCF(P_i) = CF(P_i) + \sum_{j \in RP_{i,j}} ECF\left(P_j = F \mid P_i\right)$ In this equation, RM7 sums up the expected cost of failure (ECF) of all reachable projects (RP) j of project i. So, we conclude that RM7 considers indirect dependencies and fulfills criterion 2.
3	 directed dependencies	✓	As mentioned for criterion 1, RM7 bases on a directed acyclic graph (DAG). According to the authors, a node X with direct edge to Y is called a parent of Y, and Y is called its child. Therefore, RM7 considers directed dependencies and fulfills criterion 3.
4	 dependencies' intensity	✓	The authors used conditional probability tables (CPT) to build their Bayesian network. These CPTs contain the strength of edges (conditional dependencies) between directly connected nodes. Therefore, RM7 considers dependencies' intensities and fulfills criterion 4.
5	 criticality of other dependent IT projects	×	While calculating the TCF for project $TCF(P_i)$, RM7 sums up costs of failure of project i ($CF(P_i)$) with the expected costs of failure ($ECF\left(P_j = F \mid P_i\right)$) of all reachable projects indicating indirect dependent projects (see criterion 2). Therefore, the risk measure also considers the ECF of other dependent projects. However, since ECF is not the criticality measure (represented by TCF), we conclude that RM7 does not consider the criticality of other dependent IT projects and does not fulfill criterion 5.
6	 IT project (inherent) parameter	✓	Since the Bayesian network builds on conditional dependencies based on the project's inherent failure probabilities, we conclude that RM7 considers one project's inherent parameter. Therefore, RM7 fulfills criterion 6.
7	 positive and negative effects of dependencies	×	For criterion 7, the same reasoning applies as for RM5. Since the dependencies' intensities represent probabilities, RM7 cannot consider positive and negative effects at the same time. Thus, RM7 does not fulfill criterion 7.

Table A8. Detailed evaluation results for RM8

	Criterion	Evaluation	Justification
1	 direct dependencies	✓	RM8, introduced by Guo et al. (2020), builds on a complex network representing a megaproject with many interlinked projects. The authors modeled this network as a directed, weighted graph. In this graph, nodes represent sub-project tasks and edges represent the relationships and the sequential order between these tasks. RM8 considers these dependencies when calculating the “outer” vulnerability (v_z^C). Therefore, we regard criterion 1 as fulfilled.
2	 indirect dependencies	✓	Besides the “outer” vulnerability (v_z^C), RM8 also considers the “inner” vulnerability (v_z^D). The calculation of v_z^D measures the biggest percentage drop in network efficiency. According to the authors, network efficiency reflects the global connectivity of the individual project(s). The calculation of network efficiency is based on the sum of the geodesic distance between all pairs of nodes (here: tasks) in the network. Since the network efficiency considers indirect dependencies, we conclude that RM8 also considers indirect dependencies. Thus, we regard criterion 2 as fulfilled.
3	 directed dependencies	✓	As already mentioned for criterion 1, RM8 builds on a directed graph. RM8 considers these dependencies when calculating the “outer” vulnerability (v_z^C). Therefore, we regard criterion 3 as fulfilled.
4	 dependencies’ intensity	✓	The authors assumed that tasks that take longer tend to have a greater impact than shorter tasks. Therefore, they define the node weight (w_i) as related to the task duration (t_i). Further the node weights should also be represented by the edge weights. Therefore, RM8 uses a weighted adjacency matrix *W*, where $W = [w_{i,j}]$ is an asymmetric $N \times N$ where $w_i = t_i$ and $w_j = t_j$. $w_{i,j} = \begin{cases} (w_i + w_j)/2 & \text{if } n_i \text{ directly connects to } n_j \\ 0 & \text{otherwise} \end{cases}$ This adjacency matrix is, for instance, used to calculate the “outer” vulnerability (v_z^C). Therefore, we conclude that RM8 considers the dependencies’ intensity and regard criterion 4 as fulfilled.
5	 criticality of other dependent IT projects	×	RM8 considers network effects (see v_z^C) as well as network efficiency (see v_z^D). However, calculating the vulnerability v_z does not consider the criticality of other dependent projects (no recursive calculation). $v_z = \frac{1}{(1 - v_z^D)} * v_z^C \; if \; 0 \leq v_z^D \leq 1$ Therefore, we conclude that RM8 does not fulfill criterion 5.
6	 IT project (inherent) parameter	✓	RM8 builds on the tasks’ durations to calculate the dependencies' intensities. Further, the “inner” vulnerability (v_z^D) indicates a project’s efficiency, assuming several tasks may fail. Therefore, we conclude that RM8 considers project inherent parameters and fulfills criterion 6.
7	 positive and negative effects of dependencies	×	For criterion 7, the same reasoning applies to other RMs, which are based on weighted adjacency matrices, like RM1. Since the calculation of v_z^C is based on weighted edges indicated by an adjacency matrix, we conclude that RM8 cannot simultaneously deal with positive and negative effects. Therefore, RM8 does not fulfill criterion 7.

Biographical notes

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RESEARCH ARTICLE

A framework for managing projects that integrate 4IR technologies

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Abstract

The Fourth Industrial Revolution (4IR) signifies a new phase in project management. The swift progression of 4IR technologies requires a reassessment of current methods to address the complexities of contemporary project management adequately. The ability of project managers to rapidly adjust to emerging technology and evolving standards is crucial in determining the successful outcome of projects. It is imperative for proficient project managers to recognise the significance of their capacity to predict and respond effectively to these changes, as well as their subsequent effects on ongoing and forthcoming projects, to achieve success in their professional domain. The objective of this study was to examine the effects of the 4IR on the project management discipline. A qualitative technique was employed for the collection and analysis of data. A theoretical framework for project management in the 4IR was developed. The framework identifies (i) what constitutes 4IR projects in terms of characteristics, challenges and success factors, (ii) what skills and competencies are required to deliver these projects, and lastly, (iii) what tools and techniques can be employed to deliver these projects. There is a need for such a framework which offers valuable perspectives and a comprehensive plan for the effective management of 4IR projects, specifically targeting project management professionals.

Keywords

industrial revolutions; conceptual model; characteristics; skills and competencies.

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1. Introduction

A revolution is a change that occurs suddenly; it is drastic in most instances and pervasive (Schwab, 2016). An evolution, on the other hand, is related to the developments that affect a structure over time and it is characterised by continuous and incremental changes in the existing structure (Meyer & Keas, 2011). Within the context of technology, a technological evolution implies a process of enhancement and optimisation of the existing technology rather than the introduction of new frameworks or models (Coccia, 2019), whereas a technology revolution like the Fourth Industrial Revolution (4IR) introduces swift disruptive changes through technologies such as advanced robotics, data analytics and artificial intelligence (AI) that change the ways industries work (Anshari & Hamdan, 2022). The significance and magnitude of advancements associated with the 4IR cannot be disregarded (Li et al., 2017) as they indicate considerable progression and growth in technology and invention, surpassing any previous advancements in human history.

The different Industrial Revolutions have radically influenced the social and economic activities of societies (Easterlin, 2019). The First Industrial Revolution paved the way for the use of the steam engine and mechanisation of products, which in turn enhanced production and the creation of factories (Griffin, 2018). With the Second Industrial Revolution, industry and everyday life were changed and improved by the electrification process. Other notable technological advancements of this era include progress in the internal combustion engine, the integration of electricity into manufacturing and notable breakthroughs in chemical, civil and electrical engineering. The Third Industrial Revolution brought about the digital or information technology age, resulting in an enormous change in the field of information processing and its storage and distribution. Information turned into an important economic product, leading to information economy and knowledge-based industries (Rifkin, 2011). The Fourth Industrial Revolution represents the integration of technologies that blur the boundaries between the physical, digital and biological worlds (Schwab, 2016). These technologies facilitate more effective, accurate and individualised systems (Schwab, 2018). New economic opportunities are created in technology-enabled industries such as technology, health care and financial sectors, resulting in employment in technology-based and skilled positions (Thuemmler & Bai, 2017). Technological developments brought about by the 4IR are expected to result in a significant technological change within the realm of business management, encompassing project management as well (Emejom et al., 2019). However, there are also challenges regarding privacy, security and job displacement resulting from automation (Waidner & Kasper, 2016).

Project management has existed for as long as humans have been on earth (Seymour & Hussein, 2014). Throughout history, several projects were successfully completed despite the difficulties and risks that may have caused the project to fail (Procter & Kozak-Holland, 2019). Most of these projects necessitated a large workforce, big scope, years of work, rigorous planning and flawless execution. Project management in the 1900s was based on the management of construction projects and their successful delivery while mitigating the inevitable risks. The existing literature delineates four significant periods that formed the foundation of project management's advancement: the pre-1958 period, the 1958-1979 period, the 1980-1994 period and the 1995 period (Kwak et al., 2014). The first phase saw the creation of notable milestones, including the Gantt chart, the completion of the Hoover Dam project, the Manhattan project, as well as the Interstate Highway System (Kwak et al., 2014). During the second period, technological advancements emerged and the Program Evaluation and Assessment Technique and Critical Path Technique were also formulated (Seymour & Hussein, 2014). In the third period, personal computers became able to perform multiple tasks simultaneously and therefore software that could be used for handling complex data for projects was developed. With the era of 4IR, there is a greater need once again to develop approaches, tools and techniques to implement and manage 4IR projects effectively, especially in relation to their complex and data-driven nature (Emejom et al., 2019). Project management has played a substantial role in global change since the pre-industrial era. Over the years, projects and project management provided businesses with established techniques and methodologies to achieve specific strategic objectives. Likewise, even in the context of the 4IR, project management is gradually evolving into a strategic process that is increasingly embraced by organisations (Sari et al., 2021).

This study explores the management of 4IR projects, which integrate advanced technologies such as AI, IoT, automation and digital technologies to revolutionise industries and business processes (Lasi et al., 2014; World Economic Forum, 2017). The complexity of these projects, influenced by the integration of 4IR and technology-driven innovations, necessitates an evolution of project management practices and the development of new tools and techniques. The management of 4IR projects varies based on factors such as industry, project scale and organisational context, ranging from extensive transformations in manufacturing to localised technical enhancements in service sectors (Brettel et al., 2017; Lasi et al., 2014). This diversity complicates project management, but the aim of this study is to establish a fundamental framework for managing these projects by identifying essential trends and techniques applicable across various contexts (Pereira & Romero, 2017). The findings highlight general trends in managing projects utilising 4IR technologies, acknowledging that the specific dynamics of individual projects vary based on their unique characteristics (Müller & Voigt, 2018). The 4IR has profoundly transformed project management, requiring significant development in approaches, capabilities and tools (World Economic Forum, 2020). 4IR projects present new challenges and opportunities that differ significantly from conventional project management paradigms. The existing literature lacks a comprehensive understanding of effective project management approaches in the 4IR era. This gap highlights the urgent need for academic research to identify and cultivate the necessary approaches, resources and methods for managing 4IR project complexities. This research enhances academic knowledge and provides valuable insights for practitioners to lead projects effectively in the 4IR. It ensures that project management methodologies align with the requirements of the digital age.

The project management field must undergo further development to adapt to the transformative effects of the 4IR. Project practitioners must have the necessary readiness to navigate these circumstances effectively, as they assume the responsibility of overseeing and executing technology-driven initiatives that seek to enact transformative changes within businesses (Emejom et al., 2019). It is now advised that the existing tools, techniques, skills and competencies are inadequate in addressing the necessary and obligatory evolution required in this particular context. This paper aims to address this deficiency by presenting a conceptual framework for project management in the context of the 4IR. The results and conclusions, derived from a comprehensive assessment of existing literature, provide valuable insights for both project management practitioners and academics. Specifically, these insights aim to enhance the understanding of how the management of projects in the context of the 4IR is influenced by the transformative changes brought about by the 4IR. The aim of the research was to develop a conceptual framework for effectively managing projects that leverage 4IR technologies, denoted as 4IR projects. The following research objectives were identified as key areas to be explored to achieve the study’s main research aim:

- Research objective 1: Re-evaluate how projects are transforming in the era of the 4IR.
- Research objective 2: Identify characteristics of 4IR-enabled projects.
- Research objective 3: Determine 4IR project management tools and techniques.
- Research objective 4: Analyse skills and competencies for 4IR project success.

To investigate and address these research objectives, a systematic literature review (SLR) approach was adopted to examine the impact of the 4IR on project management and present a synthesis of the current literature. SLR is a process known for its rigour and reproducibility in searching, selecting, appraising and synthesising existing research articles to answer a set of research questions (Liao et al., 2018; Siddaway et al., 2019). After a comprehensive comparison of top project management journals, the SLR and analysis were conducted on articles published in the *International Journal of Project Management (IJPM)* between 2011 and 2021; this is a period that marked the inception of the 4IR as a transformative concept (Bahrin et al., 2016; Dopico et al., 2016). This study employed a coding system where the analysis was guided by a coding framework developed in line with the study research objectives. The framework entailed pilot testing, a cycle of modifications and systematic coding of 1,214 articles, and made use of auto coding and code-by-search to code the dataset. The dynamic process facilitated the periodic identification of patterns, trends and emerging themes which led to the formulation of a conceptual framework that illustrates the important technical and soft competencies in managing 4IR projects. This research methodology process ensured that the analysis was transparent, can be easily reproduced by other researchers and provides sufficient comprehension of the effects of the 4IR on the practice of project management.

The remainder of the article is divided into five sections. The literature review provides insights into 4IR projects. The research methodology explains in detail the process that was followed to select the articles as well as the coding process. The third section presents the analysis of the articles based on the codes and themes. A conceptual framework derived from the results is presented in the fourth section. The fifth section concludes the article.

2. Literature review

The rate at which projects are transitioning and evolving by integrating technologies such as AI, robotics, cloud computing, IoT and other related technologies is experiencing significant acceleration. According to Whitmore et al. (2020), the process of project transformation is predominantly observable in large-scale projects conducted in diverse sectors, including construction, manufacturing, agriculture, mining and ICT. They examined two main factors that have had a substantial impact on project management. The factor discussed here pertains to the dramatic advancements in digital technology, which significantly alter the interactive and collaborative environment within which projects are carried out. There has been growing public sentiment toward recognising the urgent importance of prioritising human-centred factors, such as ensuring the safety and well-being of employees (Janse van Rensburg et al., 2019).

4IR projects are oriented around people's psychological needs and pay attention to their human-centred needs (Abbasi & Jaafari, 2018). 4IR projects are centred on design thinking, consumer empathy and iterative designs where there is a focus on the user’s expectations, needs and obstacles. These projects take into account the changing workplace environments by leveraging the current shift of employment and employing flexible work schedules (Whitmore et al., 2020). Abbasi and Jaafari (2018) agree with the notion that numerous conventional projects fail to address fundamental human-centred considerations, such as equality, diversity, inclusivity, mental health and welfare. This deficiency poses a significant obstacle to the successful management of projects in the context of the 4IR.

The embedding of 4IR technologies in projects is increasing (Güngör, 2019). Within the IT sector specifically, projects undertaken seem to be transitioning by integrating technologies such as full automation and robotics, application of AI, as well as the move to cloud-based platforms, making cloud computing the dominant form of 4IR technology used across this industry (Berawi, 2018). This transformation in projects forces project management as a discipline to evolve. This evolution is critical for a thorough understanding of 4IR projects and their major challenges, the skills and competencies, as well as effective tools and techniques required to deliver 4IR projects. Agile as a mindset for managing IT projects has been one principal strategy to respond to the current digitalisation and globalisation models (Emejom et al., 2019; World Economic Forum, 2017).

The future of managing projects in the 4IR is about the necessity to grasp digital competencies (Janse van Rensburg et al., 2019). The 4IR focuses on integrating products, services and multiple technologies that allow ecosystems to work intelligently and autonomously (Santos et al., 2017). In the opinion of Marnewick and Marnewick (2021), essential competencies have changed from manual to digital. The demand for physical talents is currently declining, as the labour market moves towards cognitive, social and digital competencies. As the world progresses further into the 4IR, the need for digitally competent skill sets becomes increasingly crucial (Liu et al., 2024). Furthermore, the level of technological interaction within a team is also another factor to consider, which varies depending on the generations team members were born into (Marnewick & Marnewick, 2020). Regarding project management, project managers of the 4IR are required to administer project management tasks as well as manage the ever-evolving digital transformation. Cakmakci (2019) reiterates that when such a task is properly performed, project management duties supplemented by technology may enhance agile teams, increase team member well-being and support the implementation of better organisational procedures and practices.

3. Research methodology

A comprehensive SLR was undertaken to examine and understand evolving trends at the convergence of the 4IR and project management. The review was done to uncover existing knowledge on how 4IR is reshaping project management, including its approaches, practices, competencies and techniques.

The Scopus database was chosen as an online database to identify the journals from which to review the data. The Scopus online database has many merits specifically necessary for the required datasets of this study. Firstly, it offers an interdisciplinary field coverage feature, which is beneficial for gaining a broader view and definition of the focus journals (IOWA State University Library, 2018). Secondly, Scopus offers the largest abstract and citation database of peer-reviewed literature; this is inclusive of scientific journals. In addition, it provides smart tools that track, examine, analyse and visualise research. From Scopus, a search for the best-reviewed journal rankings was conducted (Elsevier, 2019). The top three journals within the project management area were selected based on Scopus results on a combination of factors including the cites score, percentile, citations, SNIP and SJR findings. These findings are given in Appendix 1. Once the top three journals were identified, the list was exported for further analysis.

Further analysis aimed to search for the highest impact peer-reviewed journal within the project management field. To construct the dataset for the analysis, a comparison of the top three peer-reviewed project management journals was made. This examination and comparison of top project management journals was done to determine which journal rated the best according to the following criteria: (1) Journal impact factor, (2) quartile and (3) Eigenfactor score.

- Journal impact factor (JIF) is a subset of citation analysis that is used to classify or rank journals according to their comparative relevance (Journal Citation Report, 2021). JIFs are based on the notion that journals with a high JIF publish articles that are cited more frequently than journals with a low JIF. The most credible and well-known source on JIFs, according to Martín-Martín et al. (2018), is the Thomson Scientific's Journal Citation Reports (JCR), which is an annual release.
- Quartile is a rank of a journal or manuscript based on the journal's combination rates of impact factor, citations as well as indexing, showing its performance and rank in the year's four quarters (Journal Citation Report, 2021). A high Scopus quartile indicates that the journal is influential in research and that its researchers are highly qualified and experienced in the specific field.
- Eigenfactor score (EFS) is a ratio of the total citations to the overall number of publications (Bergstrom, 2007). The EFS counts and incorporates all citations in journals, including both in the sciences and the social sciences, while excluding self-citations. Both the Eigenfactors and impact factors are often used for evaluating the value and significance of a journal (Haley, 2019). They do not, however, measure the same thing and therefore cannot be used interchangeably.

These three criteria were applied to determine which journal should be used for deriving the dataset. The results are listed in Table 1.

Table 1: Summary of comparison of top three project management journals

Journal	Impact factor	Quartile	Eigenfactor score	Total cites
International Journal of Project Management (IJPM)	7.172	Q1	0.007320	13.640
Project Management Journal (PMJ)	3.570	Q2	0.002030	2.668
International Journal of Managing Projects in Business (IJMPiB)	2.634	Q3	0.001240	1.242

Based on the results of Table 1, the *IJPM* was the peer-reviewed journal selected. The process for the data collection and analysis consisted of the following steps:

1. **Data extraction:** All articles across all volumes of the *IJPM* from 2011 to 2021 were extracted and downloaded. The year 2011 was chosen as the starting point, as it marks the emergence of Industry 4.0 as a concept (Vogel-Heuser & Hess, 2016), initially introduced in Germany to describe changes in automation and IT integration (Ortiz, 2020). This resulted in a dataset of 1 214 journal articles.
2. **Data organisation:** The articles were imported into Atlas.ti version 22, which is qualitative data analysis software, where they were grouped by publication date for systematic review.
3. **Development of coding framework:** A coding framework was developed based on the study's four research objectives. These objectives guided the creation of predefined codes, which were mapped to key concepts aligned with the research constructs. These predefined codes were entered into Atlas.ti for systematic application during the analysis.
4. **Pilot coding and refinement:** To assess the validity of the coding framework, a pilot coding process was applied to a small sample of articles. This step allowed for testing the initial framework and making the necessary improvements to enhance the system's accuracy and consistency.
5. **Systematic coding:** After refining the coding framework, the entire dataset was reviewed systematically. Each article was read in detail, and relevant codes and subcodes were applied to the pertinent text fragments. Atlas.ti's auto-coding, code-by-search and code-by-list features were used to expedite the process, ensuring efficient and comprehensive coding of the dataset.
6. **Dynamic and iterative coding process:** The coding process was dynamic, allowing for adjustments as new insights emerged. As additional patterns and themes were identified, new subcodes were created under the major research objectives. This iterative process ensured that the analysis was flexible and capable of capturing evolving trends in the literature.
7. **Synthesis and organisation of key findings:** Once the qualitative analysis was complete, the coded data were synthesised and organised to extract the key findings. The systematic coding process allowed for comprehensive organisation and identification of important trends, ultimately facilitating the development of a conceptual model for managing 4IR projects.
8. **Establishment of supplementary categories and codes:** To further support the research objectives, supplementary data categories and codes were created. These categories complemented the primary objectives and provided additional context for understanding the relationship between 4IR and project management.

By applying this methodology, the analysis enabled a thorough and structured review of the literature, uncovering emerging patterns and trends. This process was essential for providing insights that directly informed the research objectives and the development of the study's framework. Based on the four research objectives, supplementary data categories and codes that supplement the objectives as per point 3 were established (see Table 2).

From the analysis, 130 codes and subcodes, with 394 corresponding quotations were derived and presented as per Appendix 2 (detailed analysis is too extensive to present in an article, and is therefore available on request). Findings and detailed discussions on the findings are presented and explained in the following sections. For the interpretation of the findings, it is crucial to note that one article reviewed as part of the literature is representative of one project for the findings.

Table 2: Qualitative analysis codes

Research objective	Pre-defined code	Subcodes
Re-evaluate how projects are transforming in the era of the 4IR.	Transformation in terms of increase and change in projects	Project type Project industry Year of publication
Identify characteristics of 4IR-enabled projects.	Change in the nature and form of projects	Project characteristics Project challenges Project success factors Transformation into 4IR evidence Complexities in projects
Determine 4IR project management tools and techniques.	Transformation of project management as a discipline Effective project management tools and techniques	Project management technique Project management tools Communication techniques
Analyse skills and competencies for 4IR project success.	4IR project management transformation in terms of skills and competencies	Project management competencies Project management skills

4. Findings and interpretation

4.1. The transformation of projects in the 4IR era

Throughout the course of the four Industrial Revolutions, there has been a successive introduction of novel projects that predominantly incorporate ideas and technology relevant to the respective period and era (Whitmore et al., 2020). The 4IR has been characterised by significant advancements in technology which have served as the primary catalysts for transformative undertakings. The field of IT has emerged as a fundamental component in the ongoing technological revolution, playing a pivotal role in the overall transformation brought about by the 4IR. Ortiz (2020) posits that the technological advancements driving the 4IR encompass AI, IoT, robots and automation, cloud computing and quantum computing, with IT serving as the facilitating mechanism. The dynamic role of IT as a vital component in emerging technologies has enabled the discipline to transition from a mere facilitator to a key driver of strategic initiatives within organisations (Whitmore et al., 2020).

To determine if projects are transforming through the integration of IT across various industries, an analysis of the coded dataset as per the methodology section was conducted. This analysis was performed by cross-mapping all the project types that were identified against the industries in which they were classified. The objective of this analysis was to ascertain which types of projects have been executed based on the dataset, as well as to identify the industries that undertook these projects. The analysis helped provide an understanding of the rate at which projects are transforming through the integration of new technologies and/or IT across various industries, with IT demonstrating a transformative force in projects related to the 4IR. The findings are illustrated in Fig. 1.

Based on the observations made in Fig. 1, it is evident that the dataset consisted of various articles that studied projects across various industries, with notable representation being articles focusing on construction, manufacturing and IT. The findings further show that the different articles reviewed covered various types of projects across those various industries as per the dataset. From the findings, there was less representation of articles on industries such as energy, finance and agriculture. These findings contribute to the comprehension that projects have been pursued consistently across diverse businesses since 2010. To fulfil research objective 1, a cross-analysis was conducted between the coded industries and project categories.

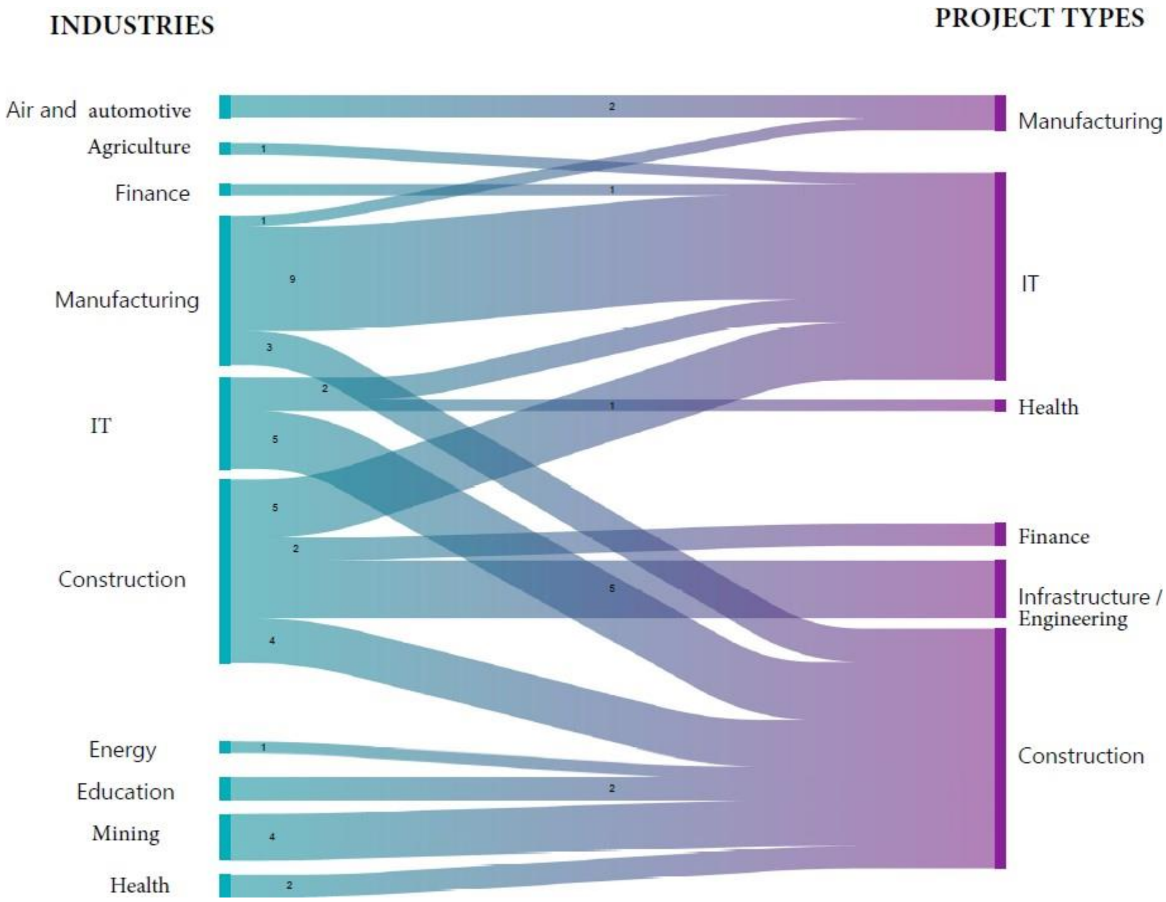

Fig. 1. Industries mapped against project types (2010 – 2021)

The analysis yielded the following observations:

- Most projects implemented were in the manufacturing sector. This observation is rather interesting as it aligns with the existing literature that initial implementation of new technology-driven projects was mostly in the manufacturing sector (Liu & Xu, 2017; Nigappa & Selvakumar, 2016). According to the literature, the integration of IT and new technologies within manufacturing subsequently led to the advancement and evolution of manufacturing projects, fuelling the change and evolution of manufacturing, which was labelled as Industry 4.0 (Cebeci, 2019). Industry 4.0 propelled the integration of these new technologies in other sectors and industries, revolutionising these industries and fuelling the 4IR (Schwab, 2018). From these findings, the significance and impact of IT as a transformer to digitalisation within the manufacturing sector are clear.
- The significant role of IT is also observed in the construction industry. This observation provides an understanding of the growing importance of IT across other sectors. The construction sector has seen significant integration of new technologies in projects and these have been in the form of autonomous construction machinery as well as AI-driven project tools and techniques. Like the manufacturing sector, these transformative undertakings have been radical enough to fuel a new form of construction sector referred to as Construction 4.0 (Bröchner, 2021; Schönbeck et al., 2021). The impact and significance of IT's role in transformation construction projects is immense (Cao et al., 2017).
- Thirdly, the significant representation of projects being undertaken is shown to be by the IT sector itself. These findings are quite expected since for the 4IR to be emerging, transformation within the IT sector itself had to have

taken place. The importance of IT in the transformation of the world, propelling transformations of other sectors, is a crucial finding that validates the growing significance of IT as a strategic driver in organisations (Colin et al., 2015).

Projects in the 4IR era span various industries, with significant representation in construction, manufacturing and IT. Radical technology innovation and the 4IR impact projects differently across industries. Publications emphasise technological innovations and infrastructure enhancement, reflecting industries' pivotal role in embracing and advancing 4IR technologies such as automation and data-centric solutions. However, research underrepresents energy, finance and agriculture, highlighting potential study gaps. The dataset shows consistent project investigation across diverse industries since 2010, illustrating the 4IR's extensive influence on project management and objectives. These findings provide a fundamental understanding of how the 4IR influences project environments across many sectors.

4.2. Characteristics of projects in the era of 4IR

The second objective was to gain an understanding of the traits and characteristics exhibited by projects which have undergone significant alteration because of the extensive incorporation of 4IR technology. This necessitates modifications to the tools, processes and abilities utilised for management, since they include novel qualities that give rise to new success factors and problems. To understand the evolution of certain projects comprehensively, it is necessary to initially grasp the factors that contribute to or serve as catalysts for change in such projects. In this particular instance, the transformative role of IT in projects is examined (Sari et al., 2021). 4IR projects encompass various groundbreaking technologies, including AI, IoT, automation and machine learning. Analysing articles on 4IR project management requires evaluating IT, as it underpins the implementation of advanced technologies key to 4IR. A robust IT environment is essential for effective 4IR project implementation (World Economic Forum, 2019). Analysing IT as a transformative catalyst reveals how technological infrastructure facilitates the transformation and innovation characteristic of 4IR projects. This understanding aids in identifying critical challenges and optimal methods for managing complex, technology-centric requirements and demands in 4IR projects. It also provides insights into the unique features, qualities and success criteria associated with such projects (Hussein, 2019; Ning & Ling, 2015; Pellerin et al., 2014; Tadayon & Andersen, 2021).

The codes and subcodes created under the second research objective were taken into consideration. The quotations from the literature that fell under these various codes and subcodes would help determine if there is indeed transformation of projects. The codes that are part of the findings, as discussed in the methodology section, inclusive of 'project characteristics', 'project challenges', 'project success factors' and 'transformation into 4IR evidence', were then adopted as critical impact factors, and labelled as impact factors 1 to 4, so that all information contained in the quotations, as findings under these codes, was presented accordingly. After the analysis of the dataset and categorisations of quotations under the codes and subcodes as per Appendix 2, the findings are as follows:

- **Impact Factor 1 - IT as a 4IR catalyst in projects:** The expansion of emerging markets, the swift rise of new technology, new environmental policies and shifting consumer expectations contribute to tremendous changes in today's economies, propelling the emergence of a new industrial revolution (Schwab, 2016). Governments and industries have been forced to make efforts to adapt successfully to this transition, and these initiatives have usually taken the form of new projects because of the transition into the "new" world (Whitford et al., 2020). Various industries have responded to the call for technological demands by incorporating new technologies into their processes and projects to increase productivity and efficiency. Table 3 illustrates the findings on 4IR projects regarding the digitalisation of projects.

Table 3: Transformation of projects in 4IR by IT

Industry	4IR techniques & technologies in projects	Compiled from the following articles
IT	Augmented reality Cloud AI	(Costantino et al., 2015), (Rezvani et al., 2018), (C. Wang et al., 2016)
Construction	Construction 4.0 technologies such as building information modelling (BIM) Offsite construction technologies Green and sustainable structures Smart city technologies and development, i.e. robotics	(Chen et al., 2015), (Oraee et al., 2019), (Zhu & Mostafavi, 2017), (Almahmoud et al., 2012)
Manufacturing	Smart manufacturing techniques are addictive manufacturing and robotics Industry 4.0 technologies, i.e. AI	(Stjerne et al., 2019), (Füller et al., 2021)

The findings indicate that the transformation of projects was through the embedding of new technologies such as cloud technologies, AI as well as augmented reality. Furthermore, advanced digital transformation in the form of integrating various technologies that make up smart manufacturing as well as Industry 4.0 technologies is demonstrated in the findings, specifically in the field of manufacturing where IT as a driver is changing and transforming projects. In addition, the same observation can be made in the construction space where 4IR technologies are transforming projects to form new industry concepts such as Construction 4.0. and Industry 4.0 (Ginigaddara et al., 2021; Schönbeck et al., 2021; Stjerne et al., 2019). It is important to further determine what critical success factors, challenges as well as characteristics are present in 4IR projects. Findings on the analysis are discussed the following sections and presented in Table 4.

- **Impact Factor 2 (Critical success factors):** Critical success factors are the components of a project that ensure that all the project's objectives are met (Banihashemi et al., 2017; Totten, 2017). Critical success factors concentrate on what must be accomplished and how it will be accomplished in areas such as cost, quality and customer satisfaction.
- **Impact Factor 3 (Project challenges):** Effective project management requires the effective management of uncertainty and also the ability to deal with a variety of challenges (Pajares et al., 2017). Project challenges are factors that have some likelihood of hindering successful delivery of any project (Pajares et al., 2017). They can originate from a variety of areas and have significant implications for projects (Akhavan-Tabassi et al., 2019). Project planning, information systems, team dynamics, client satisfaction, innovation, communication and quality are examples of such challenges, and they are not unique to a particular industry. More comprehensive efforts are required to identify and address the origins of these challenges (Akhavan-Tabassi et al., 2019). These efforts must consider the project managers' competencies as well as the maturity of the company, including the continuous learning abilities of the project teams.
- **Impact Factor 4 (Project characteristics):** Characteristic refers to a feature or attribute of quality that belongs to a specific entity or object (Pellerin et al., 2014). Project characteristics refer to distinguishing qualities and traits of projects depending on their specific nature and surroundings (Tadayon & Andersen, 2021). There are shared traits recognised about projects that distinguish them from other projects in the corporate context. One of these common features is the notion that projects are temporary endeavours that are unique and have a specific primary goal (Ning & Ling, 2015).

Table 4 illustrates the findings on 4IR critical success factors, challenges as well as characteristics as per the dataset.

Table 4: 4IR critical success factors, challenges and characteristics

Success factors	Compiled from the following articles
▪ A positive relationship between cultural factors such as collectivism, risk tolerance and positive work environment ▪ Effective stakeholder management ▪ Effective IT governance mechanisms ▪ Social alignment that supports and extends on previous work ▪ Effective risk assessment, mitigation, control and management ▪ Resource and project product transparency ▪ Close collaboration ▪ Team orientation ▪ Top management support ▪ Client participation ▪ Create quality indicator requirements and link them to the managers' goals ▪ Clearly defined overall strategic plan ▪ Effective communication ▪ Mechanism for cross-functional coordination ▪ Establishing a culture of cooperation and partnership throughout the life cycle process ▪ Clearly established project specifications and scale ▪ A well-defined project and contractual structure ▪ A capable and skilled project management team, including a principal and senior project manager ▪ Project management standards and procedures ▪ Aligned project team's commitment, cooperation and competence ▪ Effective management of scope, cost, quality and risk, communication in human resource and management ▪ Achieving the project's performance goals	(Gu et al., 2014), (Missonier & Loufrani-Fedida, 2014), (Terlizzi et al., 2016), (Gilchrist et al., 2018), (Neumeier et al., 2018), (Stettina & Hörz, 2015), (de Bakker et al., 2010), (Sirisomboonsuk et al., 2018), (Sun & Zhang, 2011), (Cserháti & Szabó, 2014)
Project challenges	**Compiled from the following articles**
▪ Extremely tight timelines ▪ Teams work on multiple projects at the same time ▪ Some developers also function as project manager ▪ Lack of deep understanding of the various project management methodologies ▪ No procedures in place to ensure good governance ▪ Lack of conformance to the project governance standards ▪ Difficult to get a clear goal for the project ▪ The amount of risk that the company is willing to accept when it comes to new technologies integrated in projects is high ▪ If clients make a special request for specific new technology to be employed, this raises complexity ▪ As the IT sector evolves, project managers are faced with new challenges and are required to take on jobs that have not previously been part of their responsibilities ▪ In comparison to projects with external, visible risk variables, IT projects are more prone to risks as they have internal risk factors	(Einhorn et al., 2019), (Marnewick & Labuschagne, 2011), (Hwang & Ng, 2013), (Jani, 2011)

Project characteristics	Compiled from the following articles
▪ Project success depends on digital intelligence ▪ Project success depends on technical and non-technical expert skills ▪ Projects are complex and ambiguous in nature ▪ Because there is considerable uncertainty, managing risk successfully is always a challenge ▪ Integration and digital competence is fixated and success dependent ▪ Start and finish timeframes are set but usually not achieved ▪ Initial budget and cost definitions are set but usually not achieved ▪ Specific end goal ▪ Integrate some 4IR technology driver to symbolise transformation, mostly cloud computing ▪ Project environment has various stakeholders	(C. Wang et al., 2016), (Sun & Zhang, 2011), (Sanchez et al., 2017), (Kanwal et al., 2017), (Liang et al., 2012), (Caniëls & Bakens, 2012), (Lieftink et al., 2019), (Wang et al., 2017), (Pellerin et al., 2014), (Marnewick & Marnewick, 2021), (Terlizzi et al., 2016)

Certain factors that constitute success factors, challenges and characteristics are not exclusive to 4IR projects, but have been inherited from traditional projects, maintaining relevance throughout different types of projects. It is also clear that projects leveraging innovative technology have unique success factors, challenges and characteristics. This emphasises the importance of a holistic approach to project management, acknowledging the continuity of certain factors across projects while simultaneously addressing the demands of projects driven by new technologies.

- **Success factors:** Knowledge and adequate comprehension of projects' crucial success factors allow individuals leading the project to focus on what is important, and to monitor and direct the project's success (Yu & Kwon, 2011). From the findings, critical success factors for 4IR projects include stakeholder engagement and management, adequate knowledge of project management standards, as well as effective client collaboration and participation. Understanding these success factors is vital, specifically because these kinds of projects are emerging worldwide. A sound understanding of what constitutes critical success factors for 4IR-driven projects would allow project managers and teams still trying to fully conceptualise the nature of these projects to effectively map out strategies towards their successful delivery. In brief, understanding and knowledge of critical success factors are crucial aspects of any project life cycle, as successful delivery and closure of the projects can then be planned for and crafted during the project planning and initiation stages.
- **Project challenges:** In addition, a knowledgeable view of different project challenges for specific kinds of projects is also important for project success. Project teams can address challenges with a knowledgeable view that paves the way for successful delivery of not only current projects, but future projects as well. Some of the notable challenges from the findings include inadequate risk management at the beginning of projects, which, according to the literature, can hinder successful project delivery from as early as the project planning phase (Jani, 2011). Furthermore, challenges such as unclear project deliverables and lack of conformance to IT project governance standards seem to also be some noticeable challenges inherent in these new kinds of projects. Therefore, effective mechanisms to handle such challenges would need to be evaluated and established since the 4IR is still in its emerging stages, and projects leveraging on its technologies are yet to be funded and implemented.
- **Project characteristics:** Common characteristics in projects are factors that make an activity a project as opposed to an ongoing operation within an organisation (Pellerin et al., 2014). The need to understand the characteristics shared by 4IR projects is an immense one, since this equips project management professionals with adequate knowledge of the scope of challenges to expect with such projects. Shared characteristics of these projects include being integration dependent, risky as well as mainly innovation driven; these are just a few examples of characteristics project management professionals can try to study and fully understand to later map out constructive techniques in handling and managing these projects. Adequate understanding of specific project characteristics is crucial not only to facilitate effective, proper management of these projects, but also provide possibilities of determining techniques that work and those that do not in managing these projects. This process would not only facilitate improved competency of project teams, but also pave the way for the project management

discipline to improve and evolve. Understanding the characteristics of 4IR projects is also crucial as it forms part of a better understanding of the successful delivery of these projects.

Regarding the critical success factors of 4IR projects, the study notes that their success is influenced by a confluence of cultural, organisational and managerial factors. Critical success factors encompass cultivating a constructive workplace atmosphere and adopting cultural attributes such as collectivism and risk tolerance. Efficient stakeholder management, client engagement and collaboration are crucial for synchronising project objectives with stakeholder expectations. Proactive risk assessment, resource transparency and robust IT governance safeguard project integrity, while explicit strategic planning, well-delineated project specifications and strong executive backing establish a firm foundation for project execution. Moreover, proficient communication, interdepartmental collaboration and a competent project management team are essential for sustaining alignment and attaining performance objectives, thus guaranteeing the overall success of 4IR initiatives.

Moreover, 4IR projects encounter numerous challenges, such as stringent timelines and the need to manage multiple projects concurrently. Many team members, particularly developers, are required to take on dual roles, such as acting as project managers, which can lead to conflicts in focus and priorities. There is frequently an inadequate comprehension of project management approaches and insufficient protocols for assuring appropriate governance and compliance with project governance requirements. Establishing clear project objectives can be challenging, and a heightened risk tolerance for the incorporation of novel technologies exacerbates the complexity, particularly when clients demand specific technological solutions. The growing IT sector introduces new issues for project managers, necessitating the management of tasks beyond their conventional scope. IT projects are also more prone to internal risks compared to projects with visible external risks, further complicating management and execution.

Lastly, regarding characteristics, 4IR projects are specifically distinguished by their dependence on digital intelligence and a combination of technical and non-technical expertise for successful outcomes. These projects are intrinsically complex and ambiguous, characterised by substantial uncertainty, rendering risk management a formidable challenge. Successful project outcomes rely on integration and digital proficiency, with a predominant focus on technology-driven transformations, especially in cloud computing. Although start and finish timeframes, along with initial budgets, are established, they are often not adhered to. A defined objective directs the project; nevertheless, its attainment is hindered by the dynamic characteristics of 4IR project environments. Moreover, these projects encompass multiple stakeholders, necessitating meticulous administration and coordination.

4.3. 4IR project management tools and techniques

The incorporation of 4IR technologies into current projects and project management tools and techniques is enhancing the development, implementation and management processes of the project life cycle (Emejom et al., 2019). These advanced and innovative technologies are also changing and intensifying the scope and complexity of projects tremendously. These developments add ambiguity to projects and make projects more unpredictable and dynamic (Camci & Kotnour, 2019). Adapting and developing new tools and techniques is crucial, especially as the 4IR is still in its emerging stage (Güngör, 2019). Coding was done to determine which project management tools and techniques have been employed in projects. The findings are presented in Table 5.

Table 5: Project management tools and techniques

Tools & techniques	Compiled from the following articles
▪ Techniques ▪ IT governance mechanisms ▪ Quality assurance ▪ Risk management ▪ Stakeholder management ▪ Fuzzy risk evaluation ▪ Lean thinking ▪ Tools ▪ Network and information modelling ▪ Decision support systems ▪ Social media communication tools ▪ STEEP tool	(Shmueli & Ronen, 2017), (Sudhaman & Thangavel, 2015), (Neumeier et al., 2018), (T. Wang et al., 2016), (Hazır, 2015), (Zhang et al., 2018), (Boateng et al., 2015)

The analysis demonstrates that certain project management tools and practices are universally applicable to both traditional and new projects, maintaining their relevance.

Technology-driven projects consistently adhere to established project management strategies such as IT governance, risk management and lean thinking practices. Given that most of the techniques emphasised in the findings have been present in previous Industrial Revolutions, the next stage of action involves identifying the specific project management environments in which these techniques can be employed. One of the aims of this study was to determine effective techniques that can facilitate the successful execution of IT projects that integrate 4IR technologies. The same sentiments apply to the identified tools. It is imperative to not only recognise these technologies as essential in new projects, but also to substantiate the project management environments in which they would function to establish foundational principles for executing these projects effectively. The research on the impact of this transformation on project management tools and processes is of the utmost importance at present, given the ongoing growth of the 4IR, which is expected to take several years to reach a mature state.

In essence, 4IR projects frequently depend on a combination of project management techniques such as governance, quality and analytical methodologies in conjunction with specific technical tools. Essential techniques encompass IT governance mechanisms that guarantee alignment between project objectives and organisational policies, quality assurance to uphold elevated standards throughout the project life cycle, and risk management, which integrates fuzzy risk evaluation to address ambiguous or swiftly evolving threats. Stakeholder management facilitates good communication and alignment across various parties, whereas lean thinking prioritises efficiency and ongoing enhancement. In terms of tools, network and information modelling and decision support systems assist in the assessment of sophisticated data for informed decision-making, social media communication tools enable real-time collaboration and feedback, and the STEEP (Social, Technological, Economic, Environmental and Political) tool provides a systematic framework for environmental scanning and strategic planning in dynamic 4IR environments.

4.4. Skills and competencies for 4IR project success

The transformation to the 4IR necessitates a focus on innovation, specifically in relation to projects initiated in response to this transformation (Jally et al., 2021). A shift in skills and competencies is required to effectively execute projects driven by innovation (Anshari & Hamdan, 2022). Several scholars have emphasised the importance of future-oriented competencies. Marnewick and Marnewick (2021) believe that the acquisition of new competencies is contingent upon intelligence, with emotional and social intelligence playing a particularly essential role. Digital intelligence is increasingly recognised as vital in the context of humanity's transition into the 4IR (IEEE, 2021; Liu et al., 2024).

The work of project managers on technology-driven projects involves more complex responsibilities beyond the mere planning and tracking of project activities (Doğan & Derici, 2019). The acquisition of digital competencies within a project context entails several key aspects (Marnewick & Marnewick, 2021). These include the cultivation of digital empathy, the establishment of a balanced approach to technology utilisation and the ability to facilitate productive online interactions and conversations. The identification of the project management role as a crucial leadership position necessitates the recruitment of proficient professionals who have a unique skill set and extensive expertise, which cannot be replicated by project management software (Project Management Institute, 2021). Effective communication with stakeholders at every step of the project and proactive thinking are essential attributes for a project manager. According to Zaman et al. (2019), project managers must possess certain essential talents to manage projects effectively that are centred on digital technologies. These skills include the ability to serve as a proficient motivator, a competent leader, an adept organiser and a reliable trust builder.

To have a comprehensive understanding of the skills and competencies that have been utilised in 4IR initiatives since their debut in 2010, additional analysis was conducted on the collected dataset. The findings are presented in Table 6.

Table 6: Project management skills and competencies

Skills & competencies	Compiled from the following articles
▪ Knowledge management ▪ Cost management skills ▪ Supervision and leadership skills ▪ Technical project management expertise ▪ Functional project management expertise ▪ Emotional intelligence ▪ Hard and soft skills competency modelling ▪ Digital intelligence and competency ▪ Innovation ▪ Agility ▪ Creativity ▪ Strategising ▪ Virtual and disperse team management skills ▪ Holistic perspective ▪ Ethics and integrity ▪ Analytical thinking	(Zhang et al., 2022), (Marnewick & Marnewick, 2021), (Reich et al., 2014), (C. Wang et al., 2016), (Zaman et al., 2019), (Chen et al., 2019), (Zhu et al., 2021), (Meng & Boyd, 2017), (Beaume et al., 2010), (Stettina & Hörz, 2015), (Marcella & Rowley, 2015), (Zhang et al., 2018)

To navigate the profound changes brought about by the 4IR effectively, it is imperative to cultivate a new form of intelligence alongside an additional set of competencies (Marnewick & Marnewick, 2021). The specific skills and competencies that should be prioritised, particularly in relation to the domain of project management, remain somewhat unclear. Project managers of 4IR projects have the challenge of managing and adapting to these new projects despite a lack of requisite capabilities and skills (World Economic Forum, 2017). A comprehensive examination of the broader understanding of key skills and competencies required for the effective execution and delivery of 4IR projects is of the utmost importance.

Based on the findings, key competencies include creativity and innovation, agility and emotional intelligence, as well as some sound digital intelligence. These findings align with the conclusions drawn by Marnewick and Marnewick (2021) which suggest that digital intelligence serves as a fundamental component of the necessary skills and abilities that project managers require for managing projects in the context of the 4IR. The significance of soft skills modelling capability in project managers of 4IR projects is emphasised by the results of this study, which align with previous research conducted by Zaman et al. (2019). The competency of soft skills plays a crucial role in the effective management of projects in the context of the 4IR (Azim et al., 2010). This competency enables project practitioners to gain a comprehensive understanding of the project dynamics and social perspectives, including stakeholder management. Moreover, it equips them with the ability to navigate the complexities associated with these factors (Azim et al., 2010). The competencies that have been defined will equip project practitioners with the necessary information to enhance their skills and abilities, enabling them to execute projects related to the 4IR effectively and successfully.

In essence, the findings underscore a combination of technical, managerial and interpersonal competencies crucial for the success of 4IR projects. Expertise in technical and functional domains, encompassing cost management, digital intelligence and analytical reasoning, is essential for navigating the complexities of evolving technologies. Equally significant are soft skills, notably emotional intelligence, creativity and adaptability. These empower leaders to manage virtual or remote teams proficiently while cultivating an inventive and collaborative atmosphere. A comprehensive perspective, integrity and effective knowledge management promote balanced decision-making. These abilities highlight the necessity for a balanced skill set that combines hard and soft talents to attain sustainable success in the 4IR environment.

5. Conceptual framework for managing 4IR projects

The summary findings yielded a conceptual framework for the management of IT projects integrating the 4IR. The conceptual model depicted in Fig. 2 seeks to offer a comprehensive perspective and comprehension of the essential elements required by project practitioners for the efficient management of 4IR projects. The framework comprises four primary components, derived from the study findings: (i) the positioning of 4IR projects in organisations, which, according to the findings, is becoming one of the major strategic drivers in organisations, (ii) attributes of 4IR projects, i.e. traits such as critical success factors, challenges as well as characteristics, (iii) the skills and competencies needed to implement and deliver these projects successfully, and lastly, (iv) the project management tools and techniques employed during the implementation of 4IR projects.

The conceptual model emphasises three essential dimensions vital for the effective implementation and delivery of 4IR projects which are all interconnected in this model for effective implementation and delivery of 4IR projects. The findings reveal that skills and competencies encompass a wide range, including technical proficiency, digital literacy, emotional intelligence and creativity, highlighting the necessity for a comprehensive viewpoint. These abilities emphasise the need for flexible, imaginative and multidisciplinary teams adept at handling the complexities and ambiguities of 4IR initiatives. Furthermore, soft skills, such as stakeholder management, cooperation and governance alignment, are essential for maintaining project coherence and alignment with strategic objectives. The growing reliance on specialised skills and digital technologies illustrates the sophisticated technological environment of 4IR projects, necessitating leaders to cultivate both hard and soft talents within their teams. In addition, the critical success factors constitute the foundation for project success, encompassing leadership, governance, transparency and team participation. Efficient stakeholder management and executive assistance are essential for navigating projects through the intricacies of emerging technology, regulatory requirements and integration challenges. Transparency in resource distribution, client engagement and cohesive governance frameworks guarantee that projects remain flexible and focused on objectives. Moreover, the framework reveals the challenges inherent in 4IR project environments, such as skill deficiencies, ambiguous deliverables and the elevated risk linked to innovative technology. These variables necessitate adaptive leadership and strong frameworks to reduce risks while using the potential offered by technological breakthroughs.

Finally, the model outlines the tools and techniques that underscore the significance of project management tools and techniques inclusive of IT governance, quality assurance and lean approaches in navigating the complexities and dangers associated with 4IR projects. The adoption of tools and techniques, such as social media platforms, information modelling and STEEP analysis, is also highlighted in the findings, which guarantees that projects are anchored in both technological and social frameworks. Risk assessment, team multitasking and the incorporation of new technology are further outlined as they are essential for maintaining resilience and adaptability. The framework adeptly connects the difficulties and potential of 4IR projects by offering a systematic method to synchronise talents, governance and technical resources. This integration is essential for attaining both immediate success and enduring sustainability in the swiftly changing project management environment of the 4IR.

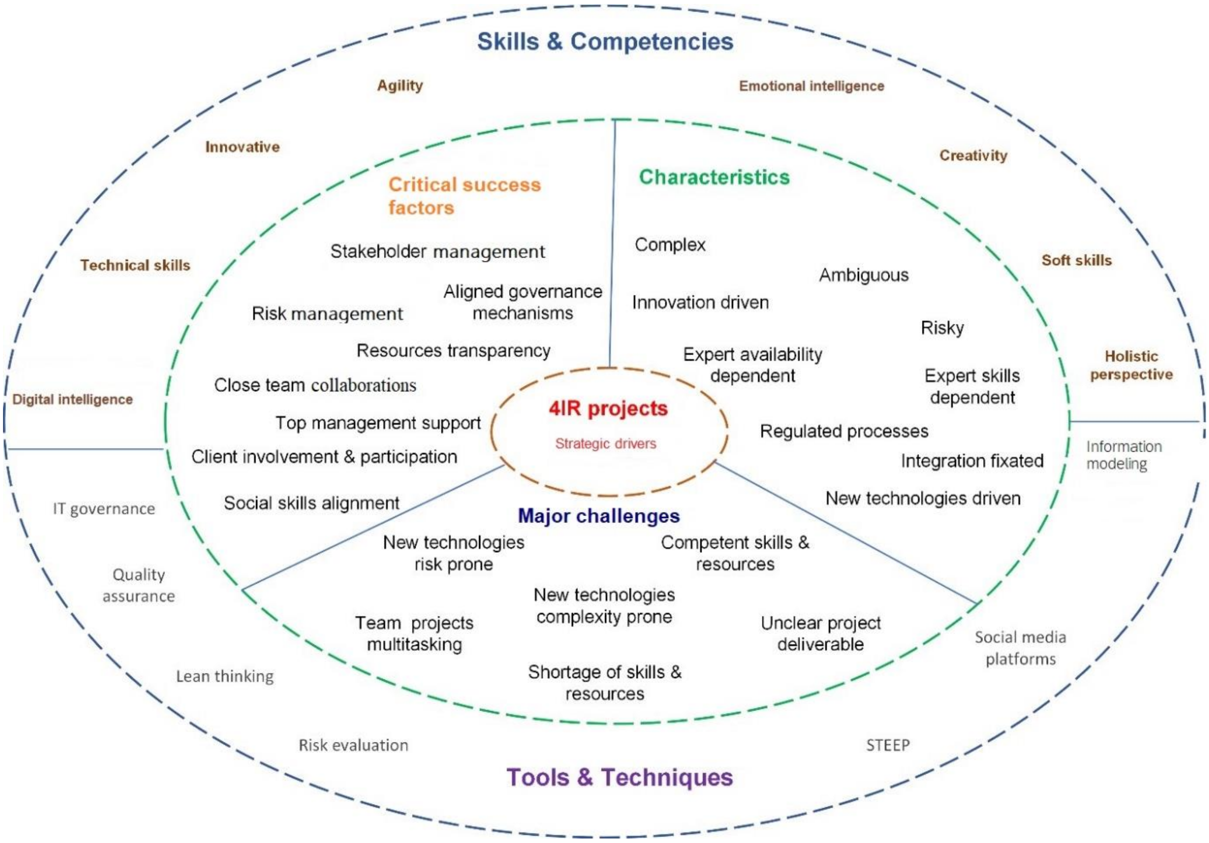

Fig. 2. Conceptual model for 4IR project management

In summary, the transformation into the 4IR is one catalyst that has radicalised the changes and conventions of project management to accommodate the technology transformation (Hwang & Ng, 2013). With the specific focus on 4IR projects, the study found that there are three crucial factors that need consideration to target successful delivery. These are firstly a clear conceptualisation of the value of these types of projects in organisations. From the investigation, it has been confirmed that these types of projects are becoming one form of strategic driver in organisations, which show not only value, but criticality of success for such projects. Secondly, a clear understanding of the nature and attributes of these projects is a significant success contributor as this allows for proper planning and implementation to facilitate successful delivery. Lastly, with comprehensive understanding of the previous factors, the right skills and competencies as well as tools and techniques can be mapped, which directly impacts delivery of the projects. From the findings, it is observed that skills and competencies such as creativity and emotional and digital intelligence are crucial. The conceptual model in Fig. 2 will enable professionals within the project management discipline to not only get a clearer understanding of the nature of these new types of projects, but also be equipped with some of the approaches and techniques that can facilitate successful delivery of these projects.

6. Conclusion

The advent of the Industrial Revolutions has had a profound impact on global society since the 17th century, and their transformative influence is expected to persist in the forthcoming generations. The perpetual progress and evolution of the world are vital for the ongoing existence and survival of humanity. The 4IR is currently in its nascent phase, having commenced in the 2010s, and is poised to fuel significant shifts on a global scale (Schwab, 2016). The 4IR is instigating a profound transformation within business environments. It can be seen as a natural evolution stemming from the concept of Industry 4.0, which prioritises the integration of new technologies across various organisational boundaries to foster a digitalised business environment (L. D. Xu et al., 2018; M. Xu et al., 2018). The implementation and deployment of projects has emerged as a significant strategy adopted by corporations in response to this transformative period (Emejom et al., 2019). Like previous Industrial Revolutions, it is crucial to explore and develop effective methodologies for delivering these projects successfully. This article has made a substantial contribution to this cause by illustrating the rapid transformation of projects into 4IR projects through IT and the transformative integration of new 4IR technologies in projects. Additionally, it has provided a comprehensive understanding of various techniques and approaches that project practitioners can employ to manage these projects efficiently. With the aim of the study being to investigate the impact of 4IR transformation on projects, the investigation conducted based on the study objectives has provided a comprehensive view of the following:

- The advent of the new Industrial Revolution has led to a shift and significant growth in the number of projects being executed. These projects that are leveraging 4IR technologies represent 4IR projects. This assertion is substantiated by the escalating growth in the number of projects executed across various industries which employ the integration of IT and 4IR technology-driven developments in an innovative manner (Lööw et al., 2019; Schönbeck et al., 2021; M. Xu et al., 2018).
- The dawn of the new Industrial Revolution has brought about changes in the features, characteristics, obstacles and success factors associated with projects, making them increasingly complex and challenging to oversee. The assertion is corroborated by Abbasi and Jaafari (2018), who argue that the increasing complexity and modernity of technology have led to greater ambiguity in project outputs and outcomes. Consequently, the field of project management has had to adapt to this shift.
- There is a need to do additional research and develop innovative tools and approaches that may efficiently oversee initiatives related to the 4IR. This observation is substantiated by the empirical evidence indicating that the predominant tools and techniques employed in projects spanning the period from 2011 to 2021 exhibit a notable continuity with those utilised in projects during the Second and Third Industrial Revolutions. While certain tools and techniques play a crucial role in guaranteeing the effective execution of projects, there is a need for new tools and processes that cater specifically to the requirements of projects influenced by advancements in technology.
- Finally, the advent of the 4IR has required project management teams to undergo transformation, develop agility and acquire new skills to maintain their competence. The findings of the study have underscored the significance of creative and agile project competencies across diverse industries. This observation is in line with the Project Management Institute (2018) that a transformation of skills and competencies is necessary for the successful management of projects led by the 4IR.

In conclusion, this study's findings emphasise the importance of a diverse skill set, including technical abilities, emotional intelligence, creativity and digital proficiency, to manage 4IR projects effectively. These findings are in line with those of Ribeiro et al. (2021), who highlight the need for not only technical proficiency but also soft skills such as communication, leadership and stakeholder management. Emotional intelligence is also linked to Agile project management approaches, which are crucial for managing projects in uncertain and rapidly evolving contexts (Ribeiro et al., 2021). Stakeholder management, governance alignment and transparency are essential success determinants and governance structures for 4IR projects. These findings align with research by Müller and Turner (2007) as well as Pinto and Slevin (1987) on a project success framework, and by Sirisomboonsuk et al. (2018) on project governance. Synchronised governance systems promote explicit processes and decision-making frameworks to address regulatory and technological issues specific to 4IR projects.

The model incorporates crucial project management tools and techniques such as information modelling, IT governance and risk assessment, which align with the increasing focus on technology-oriented project management methodologies. Building information modelling (BIM) is a revolutionary tool in building and IT projects, while lean project management principles aim to eradicate waste and improve value delivery. The model further recognises risks and complexities associated with adopting new technologies, emphasising proactive risk management and comprehensive contingency planning. In brief, the model affirms the multifaceted requirements of 4IR project management and highlights the need for project managers to adapt their strategies to the changing environment, integrating both human and technological elements to achieve sustainable project results.

The following research limitations have been identified:

- The study analysed publications from the *International Journal of Project Management (IJPM)*, which may not include significant ideas from other relevant journals.
- The analysis was confined to articles published from 2011 to 2021, which may not reflect the most recent evolving practical issues faced by professionals working within 4IR project environments.
- The coding system was based on predetermined objectives. However, a flexible, dynamic analysis approach that allowed for adjustments through the introduction of new subcodes was adopted to identify any new emerging insights obtained from the literature being reviewed. This iterative process ensured that the analysis was flexible and capable of capturing evolving trends in the literature.
- The study also excluded non-English articles, which may have resulted in overlooking significant contributions from non-English sources, especially considering the global context of the 4IR.

The study opened various avenues for future research. Firstly, extending the range of journals, the timeframe and integrating primary data would assist in a more comprehensive validation of the framework. Cross-cultural perspectives could be investigated to understand the topic across various cultural contexts since 4IR is a world phenomenon.

References

Abbasi, A., & Jaafari, A. (2018). Evolution of project management research and industry-focused innovations. *Journal of Modern Project Management*, *6*(1), 60-69. https://doi.org/10.19255/JMPM01606.

Akhavan-Tabassi, A., Bryde, D., Mustafa Kamal, E., & Dowson, J. (2019). *Challenges for project management in the 21st century*. https://doi.org/10.15405/epms.2019.12.63.

Almahmoud, E. S., Doloi, H. K., & Panuwatwanich, K. (2012). Linking project health to project performance indicators: Multiple case studies of construction projects in saudi arabia. *International Journal of Project Management*, *30*(3), 296-307. https://doi.org/10.1016/j.ijproman.2011.07.001.

Anshari, M., & Hamdan, M. (2022). Understanding knowledge management and upskilling in fourth industrial revolution: Transformational shift and seci model. *VINE Journal of Information and Knowledge Management Systems*, *52*(3), 373-393. https://doi.org/10.1108/VJIKMS-09-2021-0203.

Azim, S., Gale, A., Lawlor-Wright, T., Kirkham, R., Khan, A., & Alam, M. (2010). The importance of soft skills in complex projects. *International Journal of Managing Projects in Business*, *3*(3), 387-401. https://doi.org/10.1108/17538371011056048.

Bahrin, M. A. K., Othman, M. F., Azli, N. H. N., & Talib, M. F. (2016). Industry 4.0: A review on industrial automation and robotic. *Jurnal Teknologi (Sciences & Engineering)*, *78*(6-13). https://doi.org/10.11113/jt.v78.9285.

Banihashemi, S., Hosseini, M. R., Golizadeh, H., & Sankaran, S. (2017). Critical success factors (csfs) for integration of sustainability into construction project management practices in developing countries. *International Journal of Project Management*, *35*(6), 1103-1119. https://doi.org/10.1016/j.ijproman.2017.01.014.

Beaume, R., Maniak, R., & Midler, C. (2010). Crossing innovation and product projects management: A comparative analysis in the automotive industry. *International Journal of Project Management*, *27*(2), 166-174. https://doi.org/10.1016/j.ijproman.2008.09.004.

Berawi, M. A. (2018). The fourth industrial revolution: Managing technology development for competitiveness. *International Journal of Technology*, *9*(1), 291-319. https://doi.org/10.14716/ijtech.v9i1.1504.

Bergstrom, C. (2007). Eigenfactor: Measuring the value and prestige of scholarly journals. *College and Research Libraries News*, *68*, 314-316. https://doi.org/10.5860/crln.68.5.7804.

Boateng, P., Chen, Z., & Ogunlana, S. O. (2015). An analytical network process model for risks prioritisation in megaprojects. *International Journal of Project Management*, *33*(8), 1795-1811. http://dx.doi.org/10.1016/j.ijproman.2015.08.007.

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2017). How virtualization, decentralization and network building change the manufacturing landscape: An industry 4.0 perspective. *FormaMente*, *12*, 47-62. https://research.ebsco.com/linkprocessor/plink?id=3f54a822-0119-39fb-9e8d-73d64a096019

Bröchner, J. (2021). Construction project management fiction: Individual values. *International Journal of Project Management*, *39*(6), 594-604. https://doi.org/10.1016/j.ijproman.2021.04.005.

Cakmakci, M. (2019). Interaction in project management approach within industry 4.0. In *Lecture Notes in Mechanical Engineering* (pp. 176-189): Pleiades Publishing.

Camci, A., & Kotnour, T. (2019). How to manage projects in industry4.0 environment: Aligning management style with complexity. In H. B. Bolat & G. T. Temur (Eds.), *Agile approaches for successfully managing and executing projects in the fourth industrial revolution* (pp. 20-39). IGI Global. https://doi.org/https://doi.org/10.4018/978-1-5225-7865-9.ch002

Caniëls, M. C. J., & Bakens, R. J. J. M. (2012). The effects of project management information systems on decision making in a multi project environment. *International Journal of Project Management*, *30*(2), 162-175. https://doi.org/10.1016/j.ijproman.2011.05.005.

Cao, D., Li, H., Wang, G., & Huang, T. (2017). Identifying and contextualising the motivations for bim implementation in construction projects: An empirical study in china. *International Journal of Project Management*, *35*(4), 658-669. https://doi.org/10.1016/j.ijproman.2016.02.002.

Cebeci, U. (2019). The project management of industry 4.0 strategy for software houses. In H. B. Bolat & G. T. Temur (Eds.), *Agile approaches for successfully managing and executing projects in the fourth industrial revolution* (pp. 228-241). IGI Global. https://doi.org/https://doi.org/10.4018/978-1-5225-7865-9.ch012

Chen, K., Lu, W., Peng, Y., Rowlinson, S., & Huang, G. Q. (2015). Bridging bim and building: From a literature review to an integrated conceptual framework. *International Journal of Project Management*, *33*(6), 1405-1416. http://dx.doi.org/10.1016/j.ijproman.2015.03.006.

Chen, T., Fu, M., Liu, R., Xu, X., Zhou, S., & Liu, B. (2019). How do project management competencies change within the project management career model in large chinese construction companies? *International Journal of Project Management*, *37*(3), 485-500. https://doi.org/10.1016/j.ijproman.2018.12.002.

Coccia, M. (2019). Theories of the evolution of technology based on processes of competitive substitution and multi- mode interaction between technologies. *6*(2), 99-109. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3424108

Colin, M., Galindo, R., & Hernández, O. (2015). Information and communication technology as a key strategy for efficient supply chain management in manufacturing smes. *Procedia Computer Science*, *55*, 833-842. https://doi.org/10.1016/j.procs.2015.07.152.

Costantino, F., Di Gravio, G., & Nonino, F. (2015). Project selection in project portfolio management: An artificial neural network model based on critical success factors. *International Journal of Project Management*, *33*(8), 1744-1754. http://dx.doi.org/10.1016/j.ijproman.2015.07.003.

Cserháti, G., & Szabó, L. (2014). The relationship between success criteria and success factors in organisational event projects. *International Journal of Project Management*, *32*(4), 613-624. http://dx.doi.org/10.1016/j.ijproman.2013.08.008.

de Bakker, K., Boonstra, A., & Wortmann, H. (2010). Does risk management contribute to it project success? A meta-analysis of empirical evidence. *International Journal of Project Management*, *28*(5), 493-503. https://doi.org/10.1016/j.ijproman.2009.07.002.

Doğan, N. Ö., & Derici, S. (2019). Project management and efficiency of the projects in the industry 4.0 era. 188-209. https://doi.org/10.4018/978-1-5225-7865-9.ch010.

Dopico, M., Gomez, A., De la Fuente, D., García, N., Rosillo, R., & Puche, J. (2016). *A vision of industry 4.0 from an artificial intelligence point of view*. Proceedings on the International Conference on Artificial Intelligence (ICAI), Athens, Greece. https://www.proquest.com/conference-papers-proceedings/vision-industry-4-0-artificial-intelligence-point/docview/1806561919/se-2?accountid=13425

Easterlin, R. A. (2019). Three revolutions of the modern era. *Comparative Economic Studies*, *61*(4), 521-530. https://doi.org/10.1057/s41294-019-00098-9.

Einhorn, F., Marnewick, C., & Meredith, J. (2019). Achieving strategic benefits from business it projects: The critical importance of using the business case across the entire project lifetime. *International Journal of Project Management*, *37*(8), 989-1002. https://doi.org/10.1016/j.ijproman.2019.09.001.

Elsevier, B. V. (2019). Scopus factsheet. (February), 2-2. https://www.elsevier.com/__data/assets/pdf_file/0017/114533/Scopus_GlobalResearch_Factsheet2019_FINAL_WEB.pdf

Emejom, A. A., Burgess, C., Pepper, D., & Adkins, J. (2019). Agile approaches for successfully managing and executing projects in the fourth industrial revolution. In H. B. Bolat & G. T. Temur (Eds.), *Agile approaches for successfully managing and executing projects in the fourth industrial revolution* (pp. 1-19). IGI Global. https://doi.org/https://doi.org/10.4018/978-1-5225-7865-9.ch001

Füller, J., Hutter, K., & Kröger, N. (2021). Crowdsourcing as a service – from pilot projects to sustainable innovation routines. *International Journal of Project Management*, *39*(2), 183-195. https://doi.org/10.1016/j.ijproman.2021.01.005.

Gilchrist, A., Burton-Jones, A., & Green, P. (2018). The process of social alignment and misalignment within a complex it project. *International Journal of Project Management*, *36*(6), 845-860. https://doi.org/10.1016/j.ijproman.2018.04.004.

Ginigaddara, B., Perera, S., Feng, Y., & Rahnamayiezekavat, P. (2021). Offsite construction skills evolution: An australian case study. *Construction Innovation*.

Griffin, E. (2018). Diets, hunger and living standards during the british industrial revolution. *Past and Present*, *239*(1), 72-111. https://doi.org/10.1093/pastj/gtx061.

Gu, V. C., Hoffman, J. J., Cao, Q., & Schniederjans, M. J. (2014). The effects of organizational culture and environmental pressures on it project performance: A moderation perspective. *International Journal of Project Management*, *32*(7), 1170-1181. http://dx.doi.org/10.1016/j.ijproman.2013.12.003.

Güngör, D. Ö. (2019). Industry 4.0 technologies used in project management. In H. B. Bolat & G. T. Temur (Eds.), *Agile approaches for successfully managing and executing projects in the fourth industrial revolution* (pp. 40-63). IGI Global. https://doi.org/https://doi.org/10.4018/978-1-5225-7865-9.ch003

Haley, M. R. (2019). An eigenfactor-weighted power mean generalization of the euclidean index. *PLOS ONE*, *14*(2), e0212760. https://doi.org/10.1371/journal.pone.0212760.

Hazır, Ö. (2015). A review of analytical models, approaches and decision support tools in project monitoring and control. *International Journal of Project Management*, *33*(4), 808-815. http://dx.doi.org/10.1016/j.ijproman.2014.09.005.

Hussein, B. (2019). The influence of project characteristics on project success factors. Insights from 21 real life project cases from norway. *Procedia Computer Science*, *164*, 350-357. https://doi.org/10.1016/j.procs.2019.12.193.

Hwang, B.-G., & Ng, W. J. (2013). Project management knowledge and skills for green construction: Overcoming challenges. *International Journal of Project Management*, *31*(2), 272-284. http://dx.doi.org/10.1016/j.ijproman.2012.05.004.

IEEE. (2021). Ieee standard for digital intelligence (dq)–framework for digital literacy, skills, and readiness. In *IEEE Std 3527.1-2020* (pp. 1-47). New York, USA: The Institute of Electrical and Electronics Engineers, Inc.

IOWA State University Library, I. (2018). Scopus vs. Web of science vs. Google scholar. 9-11.

Jally, V., Kulkarni, V. N., Gaitonde, V. N., Satis, G. J., & Kotturshettar, B. B. (2021). A review on project management transformation using industry 4.0.

Jani, A. (2011). Escalation of commitment in troubled it projects: Influence of project risk factors and self-efficacy on the perception of risk and the commitment to a failing project. *International Journal of Project Management*, *29*(7), 934-945. https://doi.org/10.1016/j.ijproman.2010.08.004.

Janse van Rensburg, N., Telukdarie, A., & Dhamija, P. (2019). Society 4.0 applied in africa: Advancing the social impact of technology. *Technology in Society*, *59*, 1-12. https://doi.org/10.1016/j.techsoc.2019.04.001.

Journal Citation Report, J. (2021). *Journal impact factor list 2021*. Clavirate Analytics. https://impactfactorforjournal.com/jcr-2021/

Kanwal, N., Zafar, M. S., & Bashir, S. (2017). The combined effects of managerial control, resource commitment, and top management support on the successful delivery of information systems projects. *International Journal of Project Management*, *35*(8), 1459-1465. https://doi.org/10.1016/j.ijproman.2017.08.007.

Kwak, Y. H., Walewski, J., Sleeper, D., & Sadatsafavi, H. (2014). What can we learn from the hoover dam project that influenced modern project management? *International Journal of Project Management*, *32*(2), 256-264. http://dx.doi.org/10.1016/j.ijproman.2013.04.002.

Lasi, H., Fettke, P., Kemper, H., Feld, T., & Hoffmann, M. (2014). Industry 4.0 [journal article]. *Business & Information Systems Engineering*, *6*(4), 239-242. https://doi.org/10.1007/s12599-014-0334-4.

Li, G., Hou, Y., & Wu, A. (2017). Fourth industrial revolution: Technological drivers, impacts and coping methods. *Chinese Geographical Science*, *27*(4), 626-637. https://doi.org/10.1007/s11769-017-0890-x.

Liang, T.-P., Wu, J. C.-H., Jiang, J. J., & Klein, G. (2012). The impact of value diversity on information system development projects. *International Journal of Project Management*, *30*(6), 731-739. https://doi.org/10.1016/j.ijproman.2011.11.006.

Liao, Y., Loures, E. d. F. R., & Deschamps, F. (2018). Industrial internet of things: A systematic literature review and insights. *IEEE Internet of Things Journal*, *5*(6), 4515-4525. https://doi.org/10.1109/JIOT.2018.2834151.

Lieftink, B., Smits, A., & Lauche, K. (2019). Dual dynamics: Project-based institutional work and subfield differences in the dutch construction industry. *International Journal of Project Management*, *37*(2), 269-282. https://doi.org/10.1016/j.ijproman.2018.03.005.

Liu, Y., & Xu, X. (2017). Industry 4.0 and cloud manufacturing: A comparative analysis. *Journal of Manufacturing Science and Engineering*, *139*(3), 1-8. https://doi.org/10.1115/1.4034667.

Liu, Y., Zeng, N., Papadonikolaki, E., Maritshane, K., & Chan, P. W. (2024). The future of digitalized project practices through data-savvy talent: A digital competence formation perspective. *Project Leadership and Society*, *5*, 1-15. https://doi.org/10.1016/j.plas.2024.100120.

Lööw, J., Abrahamsson, L., & Johansson, J. (2019). Mining 4.0—the impact of new technology from a work place perspective. *Mining, Metallurgy & Exploration*, *36*(4), 701-707. https://doi.org/10.1007/s42461-019-00104-9.

Marcella, M., & Rowley, S. (2015). An exploration of the extent to which project management tools and techniques can be applied across creative industries through a study of their application in the fashion industry in the north east of scotland. *International Journal of Project Management*, *33*(4), 735-746. http://dx.doi.org/10.1016/j.ijproman.2014.12.002.

Marnewick, A. L., & Marnewick, C. (2020). The ability of project managers to implement industry 4.0-related projects. *IEEE Access*, *8*(1), 314-324. https://doi.org/10.1109/ACCESS.2019.2961678.

Marnewick, C., & Labuschagne, L. (2011). An investigation into the governance of information technology projects in south africa. *International Journal of Project Management*, *29*(6), 661-670. https://doi.org/10.1016/j.ijproman.2010.07.004.

Marnewick, C., & Marnewick, A. L. (2021). Digital intelligence: A must-have for project managers. *Project Leadership and Society*, *2*, 1-12. https://doi.org/10.1016/j.plas.2021.100026.

Martín-Martín, A., Orduña-Malea, E., Thelwall, M., Delgado-López-Cózar, E., Orduna-Malea, E., Thelwall, M., Delgado-López-Cózar, E., & Delgado López-Cózar, E. (2018). Scopus: A systematic comparison of citations in 252 subject categories. *Journal of Informetrics*, *12*(4), 1160-1177. https://doi.org/10.1016/J.JOI.2018.09.002.

Meng, X., & Boyd, P. (2017). The role of the project manager in relationship management. *International Journal of Project Management*, *35*(5), 717-728. https://doi.org/10.1016/j.ijproman.2017.03.001.

Meyer, S., & Keas, M. (2011). The meanings of evolution. In J. A. Campbell & M. S.C. (Eds.), *Darwinism, design, and public education*. Michigan State University Press. http://arn.org/docs/meyer/sm_meaningsofevolution.pdf

Missonier, S., & Loufrani-Fedida, S. (2014). Stakeholder analysis and engagement in projects: From stakeholder relational perspective to stakeholder relational ontology. *International Journal of Project Management*, *32*(7), 1108-1122. http://dx.doi.org/10.1016/j.ijproman.2014.02.010.

Müller, J. M., & Voigt, K.-I. (2018). The impact of industry 4.0 on supply chains in engineer-to-order industries - an exploratory case study. *IFAC-PapersOnLine*, *51*(11), 122-127. https://doi.org/10.1016/j.ifacol.2018.08.245.

Müller, R., & Turner, R. (2007). The influence of project managers on project success criteria and project success by type of project. *European Management Journal*, *25*(4), 298-309. https://doi.org/10.1016/j.emj.2007.06.003.

Neumeier, A., Radszuwill, S., & Garizy, T. Z. (2018). Modeling project criticality in it project portfolios. *International Journal of Project Management*, *36*(6), 833-844. https://doi.org/10.1016/j.ijproman.2018.04.005.

Nigappa, K., & Selvakumar, J. (2016). Industry 4.0: A cost and energy efficient micro plc for smart manufacturing. *Indian Journal of Science and Technology*, *9*(44), 1-6. https://doi.org/10.17485/ijst/2016/v9i44/125304.

Ning, Y., & Ling, F. Y. Y. (2015). The effects of project characteristics on adopting relational transaction strategies. *International Journal of Project Management*, *33*(5), 998-1007. http://dx.doi.org/10.1016/j.ijproman.2014.12.006.

Oraee, M., Hosseini, M. R., Edwards, D. J., Li, H., Papadonikolaki, E., & Cao, D. (2019). Collaboration barriers in bim-based construction networks: A conceptual model. *International Journal of Project Management*, *37*(6), 839-854. https://doi.org/10.1016/j.ijproman.2019.05.004.

Ortiz, J. H. (Ed.). (2020). *Industry 4.0: Current status and future trends*. InTechOpen. https://doi.org/http://dx.doi.org/10.5772/intechopen.86000.

Pajares, J., Poza, D., & Villafa, F. (2017). Project management methodologies in the fourth technological revolution. 121-144. https://doi.org/10.1007/978-3-319-55889-9.

Pellerin, R., Perrier, N., Guillot, X., & Léger, P.-M. (2014). Project characteristics, project management software utilization and project performance: An impact analysis based on real project data. *International Journal of Information Systems and Project Management*, *1*. https://doi.org/10.12821/ijispm010301.

Pereira, A. C., & Romero, F. (2017). A review of the meanings and the implications of the industry 4.0 concept. *Procedia Manufacturing*, *13*, 1206-1214. https://doi.org/10.1016/j.promfg.2017.09.032.

Pinto, J. K., & Slevin, D. P. (1987). Critical factors in successful project implementation. *IEEE Transactions on Engineering Management*, *EM-34*(1), 22-27. https://doi.org/10.1109/TEM.1987.6498856.

Procter, C., & Kozak-Holland, M. (2019). The giza pyramid: Learning from this megaproject. *Journal of Management History*, *25*(3), 364-383. https://doi.org/10.1108/JMH-11-2018-0061.

Project Management Institute. (2018). *The project manager of the future: Developing digital-age project management skills to thrive in disruptive times* (Pulse of the Profession, Issue. P. M. Institute. https://www.pmi.org/learning/thought-leadership/pulse/the-project-manager-of-the-future

Project Management Institute. (2021). *Top 10 most influential projects by industry*. I. Project Management Institute. https://www.pmi.org/most-influential-projects-2021/top-10-by-industry/technology

Reich, B. H., Gemino, A., & Sauer, C. (2014). How knowledge management impacts performance in projects: An empirical study. *International Journal of Project Management*, *32*(4), 590-602. http://dx.doi.org/10.1016/j.ijproman.2013.09.004.

Rezvani, A., Khosravi, P., & Ashkanasy, N. M. (2018). Examining the interdependencies among emotional intelligence, trust, and performance in infrastructure projects: A multilevel study. *International Journal of Project Management*, *36*(8), 1034-1046. https://doi.org/10.1016/j.ijproman.2018.08.002.

Ribeiro, A., Amaral, A., & Barros, T. (2021). Project manager competencies in the context of the industry 4.0. *Procedia Computer Science*, *181*, 803-810. https://doi.org/10.1016/j.procs.2021.01.233.

Rifkin, J. (2011). *The third industrial revolution: How lateral power is transforming energy, the economy, and the world*. Palgrave Macmillan.

Sanchez, O. P., Terlizzi, M. A., & de Moraes, H. R. d. O. C. (2017). Cost and time project management success factors for information systems development projects. *International Journal of Project Management*, *35*(8), 1608-1626. https://doi.org/10.1016/j.ijproman.2017.09.007.

Santos, M. Y., Oliveira e Sá, J., Andrade, C., Vale Lima, F., Costa, E., Costa, C., Martinho, B., & Galvão, J. (2017). A big data system supporting bosch braga industry 4.0 strategy. *International Journal of Information Management*, *37*(6), 750-760. https://doi.org/10.1016/j.ijinfomgt.2017.07.012.

Sari, I. U., Cafer, E., & Ak, U. (2021). Feasibility analysis of industry 4.0 projects and an application in automotive maintenance systems. In I. R. M. Association (Ed.), *Research anthology on cross-industry challenges of industry 4.0* (pp. 755-771). IGI Global. https://doi.org/https://doi.org/10.4018/978-1-7998-8548-1.ch038

Schönbeck, P., Löfsjögård, M., & Ansell, A. (2021). Collaboration and knowledge exchange possibilities between industry and construction 4.0 research. *Procedia Computer Science*, *192*, 129-137. https://doi.org/10.1016/j.procs.2021.08.014.

Schwab, K. (2016). The fourth industrial revolution: What it means and how to respond. *World Economic Forum*.

Schwab, K. (2018). The fourth industrial revolution (industry 4.0) a social innovation perspective. *Tạp chí Nghiên cứu dân tộc*, *7*(23), 12-21. https://doi.org/10.25073/0866-773x/97.

Seymour, T., & Hussein, S. (2014). The history of project management. *International Journal of Management & Information Systems (IJMIS)*, *18*(4), 233-240. https://doi.org/10.19030/ijmis.v18i4.8820.

Shmueli, O., & Ronen, B. (2017). Excessive software development: Practices and penalties. *International Journal of Project Management*, *35*(1), 13-27. http://dx.doi.org/10.1016/j.ijproman.2016.10.002.

Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to do a systematic review: A best practice guide for conducting and reporting narrative reviews, meta-analyses, and meta-syntheses. *Annual Review of Psychology*, *70*, 747-770. https://doi.org/10.1146/annurev-psych-010418-102803.

Sirisomboonsuk, P., Gu, V. C., Cao, R. Q., & Burns, J. R. (2018). Relationships between project governance and information technology governance and their impact on project performance. *International Journal of Project Management*, *36*(2), 287-300. https://doi.org/10.1016/j.ijproman.2017.10.003.

Stettina, C. J., & Hörz, J. (2015). Agile portfolio management: An empirical perspective on the practice in use. *International Journal of Project Management*, *33*(1), 140-152. http://dx.doi.org/10.1016/j.ijproman.2014.03.008.

Stjerne, I. S., Söderlund, J., & Minbaeva, D. (2019). Crossing times: Temporal boundary-spanning practices in interorganizational projects. *International Journal of Project Management*, *37*(2), 347-365. https://doi.org/10.1016/j.ijproman.2018.09.004.

Sudhaman, P., & Thangavel, C. (2015). Efficiency analysis of erp projects—software quality perspective. *International Journal of Project Management*, *33*(4), 961-970. http://dx.doi.org/10.1016/j.ijproman.2014.10.011.

Sun, J., & Zhang, P. (2011). Owner organization design for mega industrial construction projects. *International Journal of Project Management*, *29*(7), 828-833. https://doi.org/10.1016/j.ijproman.2011.04.005.

Tadayon, A., & Andersen, B. (2021). Characteristics of a project that are suitable for a relational pdm. *Procedia Computer Science*, *181*, 1089-1096. https://doi.org/10.1016/j.procs.2021.01.305.

Terlizzi, M. A., Meirelles, F. d. S., & de Moraes, H. R. O. C. (2016). Barriers to the use of an it project management methodology in a large financial institution. *International Journal of Project Management*, *34*(3), 467-479. http://dx.doi.org/10.1016/j.ijproman.2015.12.005.

Thuemmler, C., & Bai, C. (2017). Health 4.0: Application of industry 4.0 design principles in future asthma management. In C. Thuemmler & C. Bai (Eds.), *Health 4.0: How virtualization and big data are revolutionizing healthcare* (pp. 23-37). Springer International Publishing. https://doi.org/https://doi.org/10.1007/978-3-319-47617-9_2

Totten, J. (2017). *Critical success factors for agile project management in non-software related product development teams* [Doctoral, Western Michigan University]. Kalamazoo, Michigan, United States. https://scholarworks.wmich.edu/cgi/viewcontent.cgi?article=4210&context=dissertations

Vogel-Heuser, B., & Hess, D. (2016). Guest editorial industry 4.0–prerequisites and visions. *IEEE Transactions on Automation Science and Engineering*, *13*(2), 411-413. https://doi.org/10.1109/TASE.2016.2523639.

Waidner, M., & Kasper, M. (2016, 14-18 March 2016). Security in industrie 4.0 - challenges and solutions for the fourth industrial revolution. 2016 Design, Automation & Test in Europe Conference & Exhibition (DATE), Dresden, Germany.

Wang, C., Wood, L. C., Abdul-Rahman, H., & Lee, Y. T. (2016). When traditional information technology project managers encounter the cloud: Opportunities and dilemmas in the transition to cloud services. *International Journal of Project Management*, *34*(3), 371-388. http://dx.doi.org/10.1016/j.ijproman.2015.11.006.

Wang, L., Kunc, M., & Bai, S.-j. (2017). Realizing value from project implementation under uncertainty: An exploratory study using system dynamics. *International Journal of Project Management*, *35*(3), 341-352. http://dx.doi.org/10.1016/j.ijproman.2017.01.009.

Wang, T., Wang, S., Zhang, L., Huang, Z., & Li, Y. (2016). A major infrastructure risk-assessment framework: Application to a cross-sea route project in china. *International Journal of Project Management*, *34*(7), 1403-1415. http://dx.doi.org/10.1016/j.ijproman.2015.12.006.

Whitford, A. B., Yates, J., Burchfield, A., Anastasopoulos, J. L., & Anderson, D. M. (2020). The adoption of robotics by government agencies: Evidence from crime labs [https://doi.org/10.1111/puar.13301]. *Public Administration Review*, *80*(6), 976-988. https://doi.org/10.1111/puar.13301.

Whitmore, D., Papadonikolaki, E., Krystallis, I., & Locatelli, G. (2020). Are megaprojects ready for the 4th industrial revolution? *Proceedings of the Institution of Civil Engineers - Management, Procurement and Law*, *174*, 1-9. https://doi.org/10.1680/jmapl.20.00002.

World Economic Forum. (2017). *Realizing human potential in the fourth industrial revolution*. World Economic Forum. http://www3.weforum.org/docs/WEF_EGW_Whitepaper.pdf

World Economic Forum. (2019). *Fourth industrial revolution: Beacons of technology and innovation in manufacturing*. World Economic Forum. https://www3.weforum.org/docs/WEF_4IR_Beacons_of_Technology_and_Innovation_in_Manufacturing_report_2019.pdf

World Economic Forum. (2020). *Jobs of tomorrow: Mapping opportunity in the new economy*. World Economic Forum. https://www.weforum.org/reports/jobs-of-tomorrow-mapping-opportunity-in-the-new-economy

Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: State of the art and future trends. *International Journal of Production Research*, *56*(8), 2941-2962. https://doi.org/10.1080/00207543.2018.1444806.

Xu, M., David, J. M., & Kim, S. H. (2018). The fourth industrial revolution: Opportunities and challenges. *International Journal of Financial Research*, *9*(2), 90-95. https://doi.org/10.5430/ijfr.v9n2p90.

Yu, J.-H., & Kwon, H.-R. (2011). Critical success factors for urban regeneration projects in korea. *International Journal of Project Management*, *29*(7), 889-899. https://doi.org/10.1016/j.ijproman.2010.09.001.

Zaman, U., Jabbar, Z., Nawaz, S., & Abbas, M. (2019). Understanding the soft side of software projects: An empirical study on the interactive effects of social skills and political skills on complexity – performance relationship. *International Journal of Project Management*, *37*(3), 444-460. https://doi.org/10.1016/j.ijproman.2019.01.015.

Zhang, Y., Sun, J., Yang, Z., & Wang, Y. (2018). Mobile social media in inter-organizational projects: Aligning tool, task and team for virtual collaboration effectiveness. *International Journal of Project Management*, *36*(8), 1096-1108. https://doi.org/10.1016/j.ijproman.2018.09.003.

Zhang, Z., Min, M., Cai, X., & Qiu, H. (2022). Mitigating the negative performance effect of project complexity through an informal mechanism: The conditional mediating role of knowledge hiding. *International Journal of Project Management*, *40*(3), 192-204. https://doi.org/10.1016/j.ijproman.2022.01.002.

Zhu, F., Wang, X., Wang, L., & Yu, M. (2021). Project manager's emotional intelligence and project performance: The mediating role of project commitment. *International Journal of Project Management*, *39*(7), 788-798. https://doi.org/10.1016/j.ijproman.2021.08.002.

Zhu, J., & Mostafavi, A. (2017). Discovering complexity and emergent properties in project systems: A new approach to understanding project performance. *International Journal of Project Management*, *35*(1), 1-12. http://dx.doi.org/10.1016/j.ijproman.2016.10.004.

Appendix 1. Journal comparison

Source title	CiteScore	Highest percentile	2020-23 citations	2020-23 documents	% cited	SNIP	SJR	Publisher
International Journal of Project Management	12.3	92.0% 32/443 Business and International Management	3119	253	87	2.549	2.039	Elsevier
Project Management Journal	9.3	87.0% 57/443 Business and International Management	1370	148	89	1.959	1.327	SAGE
International Journal of Managing Projects in Business	7	79.0% 92/443 Business and International Management	1647	235	85	1.394	0.757	Emerald Publishing
Journal of Project Management (Canada)	3.7	78.0% 108/511 Communication	302	82	71	0.845	N/A	Growing Science
International Journal of Information Systems and Project Management	6.3	75.0% 33/131 Management Information Systems	406	64	81	1.307	0.59	UMinho Editora

Appendix 2. Codes and subcodes

Codes	Subcodes
• Project challenges	• Project management specific • Manufacturing • Construction projects • IT projects
• Communication techniques	• Construction teams
• Complexities in projects	• Construction projects
• Environmental issues	
• Evolution of industries to 4IR	• Manufacturing • Construction • IT
• Evolution of projects to 4IR – benefits & challenges	• Cloud
• Project management competencies in construction	• Environmental, safety, health management • Understanding of project management processes • Stakeholder management • Creativity • Conflict management • Knowledge & skill intensive personnel • Competency management • Effective change management • Hard skills important • Virtual disperse teams • Change management
• Project management competencies in IT	• Technical and functional management skill • Risk management • Knowledge management
• Project management competencies in manufacturing	• Effective stakeholder engagement • Cost management
• Project management development stages	• Closure • Initiation • Acquisition • Planning • Development • Training
○ Project management explanations	○ Construction
• Project management skill	• Software development specialist • Required in construction • Technical management skill • Functional management skill • Soft skills • Technical & hard skills
• Project management technique	• Stakeholder analysis • Conflict management

Codes	Subcodes
	• Risk management: construction • Process stages • Fuzzy logic • Risk management: IT • SDLC construction • Project structures • Risk management • Lean production systems • Analytical Network Process (ANP) • Effective communication and collaborations • Quality assurance • Task analysis • Network planning • Team fragmentation
• Project management tool	• Ontology evaluation • Remote real-time monitoring system • Critical path • STEEP • Collaborative networks • Diagramming technique tool • Electronic procurement system • Building information modelling • Project management software • Last planner system
○ Progression stats in projects	○ Construction – China
• Project characteristics	• Construction • Oil and gas industry • IT projects • Air & automotive • Health projects
○ Project deliverable	○ Construction
• Project industry	• Health • Energy • Education • Oil and gas industry • Infrastructure • Air and automotive • IT • Mining • Construction • Agriculture • Manufacturing • Finance industry
• Project success factors	• Construction

Codes	Subcodes
	• Manufacturing • All projects • IT • Oil & gas sector
• Project type	• Energy • IT • Construction • Manufacturing • Infrastructure • Health
• Year	• 2010 • 2011 • 2012 • 2013 • 2014 • 2015 • 2016 • 2017 • 2018 • 2019 • 2020 • 2021

Biographical notes

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RESEARCH ARTICLE

Sources of project tool misalignment in multistakeholder projects

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Abstract
Inter-organizational collaboration is recognized as one of the key success factors for complex project delivery. Simultaneously, tools and technologies play a growing role in project management and operations, especially as project work is increasingly being conducted in hybrid and remote settings. These tools play a critical role in achieving productive collaboration, and when properly selected, implemented, and aligned, they offer opportunities for increased project productivity. However, the selection of correct tools can be tricky, and at worst, tools can end up hampering project operations. This study empirically identifies key project tool-related challenges and clarifies the role of tools in relation to stakeholder collaboration. The results emphasize two-dimensional alignment for the selection and implementation of tools: by aligning with both project objectives and the teams executing the project, tools are better set to fulfill their role as a link that supports project organization toward its goals and fosters productive inter-organizational collaboration.

Keywords
project stakeholder collaboration; project tools; collaborative tools.

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1. Introduction

Productive inter-organizational collaboration is critical for the success of complex projects (Rönndahl et al., 2025; Tampio et al., 2022). As inter-organizational projects gather many stakeholders to plan and execute, these stakeholders must work effectively together to achieve project success (Ahola, 2018; Saukko et al., 2020). Project research and practice have developed numerous pathways, delivery models, mechanisms, methods, and tools to foster more effective collaboration within project organizations. Efficiently achieving productive collaboration, however, remains a difficult and complex task (Nikulina et al., 2022; Nwajei et al., 2022).

Simultaneously, project tools have become an integral part of project management and play increasingly important roles in achieving productive inter-organizational project operations (Jitpaiboon et al., 2019; Tereso et al., 2019) particularly amidst increasing virtual teams (Swart et al., 2022). Tools typically consist of approaches, methods, and technological solutions that help project actors communicate and collaborate more effectively, monitor project progress, identify bottlenecks, and so on. Tools, however, are developing quickly and are available in abundance (Tampio & Haapasalo, 2024). This, combined with the temporary and nonrecurring nature of projects, makes planning, implementing, and utilizing tools in the inter-organizational project context a challenging process.

Project management research has typically placed greater emphasis on tools as techniques and methods to manage projects and inter-organizational collaboration, while devoting less scrutiny to technological tools (e.g., systems, applications, and software) and their role in the collaboration phenomenon. This may be due to management techniques and approaches having a considerably longer lifetime, whereas tools develop, get replaced, and become outdated in a shorter time span. However, technological advancements in tools offer significant opportunities to increase performance in project-based industries and should not be overlooked. Additionally, the key principles behind technological tools can withstand the test of time.

Project tools and methods are used to operationalize the project's strategy and collaboration (Nwajei et al., 2022). However, there is a trend of expanding the project tool kit beyond a reasonable size, overcomplicating daily operations, and introducing friction to collaboration (Jitpaiboon et al., 2019; Nwajei et al., 2022). Moreover, collaboration can be costly and require substantial effort to achieve (Eriksson, 2015; Walker et al., 2017). Limiting the size of this project tool kit can streamline the process of collaboration, enhance value creation, reduce unnecessary complexity, and maintain focus on key project objectives (Jitpaiboon et al., 2019; Nwajei et al., 2022; Tampio et al., 2022). For example, Tampio and Haapasalo (2024) described the utilization of Smartsheet and Last Planner System (LPS) tools in complex hospital construction project and reported a positive outcome due to a limited few but well-integrated tools that facilitated better results through increased usability and stakeholder commitment.

Considering the above, this study explores the role technological tools play in achieving productive inter-organizational collaboration and how this role is accomplished in inter-organizational project settings. We scope and define technological tools as software, systems, and platforms projects select and implement to support operations and collaboration, in contrast to other tools that are better characterized as managerial methods. Clarifying and understanding this role fosters selecting tools that fit a given project and effectively translate toward increased project productivity. We aim to define the core purpose of project tools in relation to inter-organizational collaboration and investigate the key characteristics and attributes to look for in the planning and selection of project tools that not only avoid hindering collaboration but also actively foster it in inter-organizational project contexts. Thus, the study contributes to the research on achieving inter-organizational collaboration and offers practical implications on evaluation and selection of tools that are aligned with and benefit the project and its objectives. To support these research objectives, we formed the following research questions:

RQ1: What are the key challenges of technological tools in inter-organizational projects?

RQ2: What is the role of these tools in enabling inter-organizational collaboration?

The rest of the paper is organized as follows. First, we cover background literature on project stakeholder collaboration and the role of project tools in enabling and facilitating inter-organizational collaboration. Then, we describe the research method and process used in this study. Next, in the results section, we present the challenges associated with project tools in relation to both objectives (purpose of tools) and people (use of tools). Thereafter, based on the covered literature and our empirical findings, we discuss the roles tools have in inter-organizational collaboration, conceptualize a tool alignment matrix, and explain the key principles in selecting project tools that initiate and enable productive and goal-oriented collaboration. Finally, we discuss the contributions and practical implications and conclude with a discussion of limitations and upcoming research opportunities.

2. Theoretical background

2.1. Inter-organizational collaboration

Large and complex projects are predominantly carried out in inter-organizational arrangements, as the capabilities required to plan, design, and construct span across organizational boundaries (Ahola, 2018). Inter-organizational projects form a group of diversely skilled organizations and individuals that work together on a complex task over a limited time (Van Marrewijk, 2018). These stakeholders, such as owners, contractors, and suppliers, form and work in networks of relationships (Ali & Haapasalo, 2023; Liu et al., 2021; Rowley, 1997) and engage in interdependent activities to achieve the project objectives together (Saukko et al., 2020). These interdependencies force project stakeholders to work collectively to complete various project tasks (Aapaoja et al., 2013; Heugens et al., 2002; Rankinen et al., 2022).

Productive stakeholder collaboration has become one of the key determinants for inter-organizational project delivery success (Bond-Barnard et al., 2018; Caniëls et al., 2019; Castañer & Oliveira, 2020). Complex projects, such as large infrastructure construction, have long suffered from problems of low productivity, cost overruns, and schedule delays (Baiden et al., 2006). Elevated inter-organizational collaboration is highlighted as a remedy to these persistent problems (Nikulina et al., 2022; Suprapto et al., 2015; Walker & Lloyd-Walker, 2016) and has been shown to lead to positive project outcomes (Bond-Barnard et al., 2018).

The central premise behind inter-organizational collaboration is to unify the entire project organization toward common goals (Hietajärvi et al., 2017; Olsson et al., 2024), foster less opportunistic behavior (Nwajei et al., 2022), and jointly create more value than what the stakeholders can individually (McGahan, 2021; Savage et al., 2010). Collaboration results in trust, motivation to pursue the best outcomes for the project, effective use of the project organization's capabilities, and the ability to make sound decisions, enabling a successful and value-creating project (Tampio & Haapasalo, 2024; Wawak, 2024). Especially in complex projects characterized by uncertainty, technical depth, and the novelty of the desired output, the involvement of numerous stakeholders and their expertise in designing and delivering the project is essential (Romero-Torres, 2020; Van Marrewijk et al., 2008). However, due to the temporary nature of the project, participating stakeholders may lack prior experience working with each other, have insufficient time to develop mutual trust, and use varying operating methods and practices. As a result, achieving productive inter-organizational collaboration is a difficulty (Schein, 2017; Xu et al., 2021).

In literature, there exists no unified and widely agreed-upon definition for what inter-organizational project collaboration is or consists of (Ali & Haapasalo, 2023; Engebø et al., 2020). Rather, it is often seen as an ideal state where joint value creation is maximized by synergizing the competencies of participating stakeholders who work reciprocally toward shared objectives (Hietajärvi et al., 2017; McGahan, 2021; Nwajei et al., 2022). In contrast, traditional project deliveries are built upon bilateral contracts between the project owners and suppliers. How this state of productive collaboration is achieved remains an elusive challenge, and practitioners and researchers have varying views and approaches.

2.2. From cooperation to collaboration

Obscurity and confusion remain regarding inter-organizational collaboration and its related terminology (Ali & Haapasalo, 2023; Pauna et al., 2021). Mattessich and Johnson (2018) describe collaboration as a dynamic and mutually beneficial relationship between two or more stakeholders to achieve common goals. Ali and Haapasalo (2023) depicted four hierarchical levels in stakeholder relationships: cooperation, coordination, control, and collaboration. They conceptualized cooperation as a beginning for alignment of interests while collaboration—the highest level of inter-organizational engagement—as a dynamic process of active engagement and a high degree of mutual understanding. Similarly, this study recognizes collaboration as a desirable organizational capability of a project organization that synergizes stakeholders' capabilities and aligns their interests toward best-for-the-project. Evidently, collaboration is a variable that can be improved through managerial means and methods; in some projects, stakeholders collaborate more extensively than in others.

Collaborative project delivery models and approaches that seek elevated levels of collaboration have emerged as a response to the underperformance and have increased in popularity, especially in complex construction projects such as large infrastructure developments (Engebø et al., 2020; Lahdenperä, 2012). Typically, in large projects, increased levels of collaboration have been pursued and implemented through relational project delivery arrangements to foster and manage inter-organizational collaboration (Pauna et al., 2021). These collaborative arrangements, or delivery models, take a more inclusive approach to involving multiple parties in the project (Bygballe & Swärd, 2019) compared to traditional project deliveries, which are based on dyadic ties and bilateral contracts between the owner and suppliers (Lavikka et al., 2015). These delivery models (e.g., alliancing, partnering, and integrated project delivery) share many fundamental features (Lahdenperä, 2012). They are based on relational contracting (Nwajei, 2021), aim to align individual interests with shared project goals (Hietajärvi et al., 2017), emphasize the early involvement of stakeholders to design and plan the project together (Aapaoja et al., 2013), and use multi-party agreements (Lahdenperä, 2012).

While collaboration is extensively highlighted in collaborative project delivery models, it is not strictly limited to these methods (Nikulina et al., 2022). In all projects, stakeholders collaborate to some extent, and any project could benefit from increased collaboration provided that the value gained outweighs the cost and time invested. Besides formal contractual means, collaboration can be fostered through integrative processes and practices applicable to all projects (Hong et al., 2010; Schein, 2017).

2.3. The relationship between project tools and collaboration

Project tools can be recognized as an extension to a project's strategy, translating it into actionable tasks that support and enable the project's objectives (Nwajei et al., 2022). As such, these tools should not be chosen based on their features alone but how well they support the specific goals and needs of a project (Zhang et al., 2018). This alignment between the tools and core project objectives ensures that tools are not only functional but also relevant, directly contributing to the project's success: the ultimate objective of these tools should not be merely their use but to support the achievement of project goals. Besides this tool-objective fit, tools and technologies must be well-suited to the project organization's people and processes to act as extensions that support individuals in executing project tasks more efficiently and productively (Behn & Silvius, 2025; Morgan & Liker, 2020).

However, choosing the correct tools alone is not sufficient to achieve effective collaboration and tool use. Successful tool implementation requires careful planning, training, follow-up, and leadership (Moore, 2007; Nwajei et al., 2022). Therefore, tools should not be viewed as standalone solutions but as part of a broader system that, together with people and processes, contributes to the formation of collaborative project environment. The relationship between tools and collaboration is bidirectional; tools provide the means to facilitate collaboration, but their success depends on how well they are integrated into the larger project environment.

3. Methodology

3.1. Research method

In this study, we adopted an exploratory approach following inductive logic and employed a cross-sectional qualitative research design (Spector, 2019; Thomas, 2006). Inductive reasoning involves uncovering patterns, themes, and relationships from specific observations, suiting our aim of identifying the key project tool-related challenges and exploring the relationship between tools and inter-organizational collaboration. The cross-sectional research design is a feasible method for exploratory and descriptive research (Maier et al., 2023), as it concerns identifying unknown patterns and relationships (Spector, 2019), as opposed to quantitatively testing them.

The empirical data were gathered through interviews with project-based business professionals. From the interviews, we sought to identify the key challenges related to project tools and inter-organizational collaboration, particularly those arising from the increased use of tools and virtual participation. The interviews followed a semi-structured design (McIntosh & Morse, 2015). The identified challenges were initially grouped into generic categories and then further into two main categories: those related to the purpose of tools and those related to their use. The analysis identified 11 challenges in the first category and 28 challenges in the second, representing key project tool-related challenge areas. From these identified challenges, we further conceptualized the interdependencies between the challenge categories.

3.2. Data collection

This research employed semi-structured interviews as a primary method for collecting empirical data. To reach data saturation (Francis et al., 2010), 23 interviews in total were conducted with project practitioners from various project-based industries. Interviewees were purposively sampled (Palinkas et al., 2015) based on their expertise in distinct project-based industries and project types to gain a broad range of information and insights about the tool-related challenges and the role of tools in inter-organizational collaboration. In addition to representing different industries, the respondents held multiple stakeholder roles in inter-organizational projects, such as client, consultant, advisor, contractor, and various managerial positions.

The interviews (Table 1) were conducted via Microsoft Teams and lasted approximately sixty minutes each. The interviews were recorded and then transcribed to allow for thorough and reliable analysis. We utilized an open-ended interview structure to allow respondents to freely discuss and describe their experiences and insights on the matter at hand. During the interview sessions we aimed to foster an informal and conversational atmosphere to allow for detailed and rich discussion on the topics covered and to overcome potential interviewee bias (Adeoye-Olatunde & Olenik, 2021).

Table 1. Interviewed respondents

No.	Respondent's role	Industry	Organization and project context	Duration
1	Head of development	Construction	Large construction company operating in both residential and non-residential sectors	43 min
2	Director, consulting expert	Information technology	Large multinational IT consulting company	50 min
3	Chief operating officer	Industrial engineering	Consulting company with primary focus on large-scale industrial engineering projects	36 min
4	Planning manager	Healthcare	Large on-going hospital construction project that has adopted alliance delivery model	52 min
5	Area director	Industrial engineering	Consulting company with primary focus on large-scale industrial engineering projects	54 min

No.	Respondent's role	Industry	Organization and project context	Duration
6	Head of project management	Industrial engineering	Large mining industry company	46 min
7	Construction manager	Construction	Construction engineering and consulting company	47 min
8	Head of industrial solutions	Information technology	Software engineering and innovation company that develops custom solutions for industrial clients	52 min
9	Chief business officer	Information technology	Software engineering and innovation company that develops custom solutions for industrial clients	49 min
10	Project manager	Construction	Large construction company operating in both residential and non-residential sectors	52 min
11	Professor	Research	Department of civil engineering of a university, industrialized construction	50 min
12	Project manager	Construction	Large construction engineering and consulting company	74 min
13	Construction manager	Industrial engineering	Consulting company with primary focus on large-scale civil and industrial engineering projects	48 min
14	Construction engineer	Healthcare	Large on-going hospital construction project that has adopted alliance delivery model	53 min
15	Senior consultant	Information technology	Large multinational IT consulting company	44 min
16	Project lead	Engineering consultancy	Architecture, engineering, and consultancy company	49 min
17	Regional manager	Engineering consultancy	Civil and industrial engineering consultancy company	44 min
18	Technical director	Construction	Large construction company operating in both residential and non-residential sectors	60 min
19	Department manager	Industrial engineering	Engineering consultancy company with a focus on construction, energy, and environmental engineering	46 min
20	Professor	Research	Military research and teaching unit of a university, complex procurement projects	48 min
21	Leadership team member	Information technology	Telecommunications company with an ongoing smart campus construction project	48 min
22	Business area director	Retail corporation	Large store group that constructs and operates retail stores	39 min
23	Development director	Information technology	Video game development company	41 min

3.3. Data analysis

The data were analyzed using a qualitative content analysis method (Elo & Kyngäs, 2008). We chose content analysis to inductively derive patterns from interview data (Lindgren et al., 2020), as we sought to identify key challenge areas of project tools by grouping empirical findings into common categories. The content analysis followed an inductive approach with open coding, allowing categories to emerge directly from the data (Elo & Kyngäs, 2008).

The analysis began with reviewing the interview recordings and transcripts to re-familiarize us with the gathered data. From the transcripts, all challenges and issues related directly and indirectly to project tools, including their selection, implementation, and use were coded into descriptions of the challenges. At this stage, identical and near-similar codes were aggregated, resulting in 39 tool-related challenges. Next, the challenges were grouped into higher-order categories, resulting in nine categories named using content-specific words. In the final step, two common factors emerged from the identified challenges that were used to split the challenges into two main categories: the challenges related to the purpose of tools and the challenges related to their use.

During the analysis, as we coded the challenges and grouped them into second-order categories, it became evident that the identified categories are highly interdependent. For this reason, we conceptualized the connections and interdependencies between the challenges to provide a comprehensive view of the investigated phenomenon of tool-related challenges.

4. Results

The project-tool category focuses on the purpose of tools; their alignment with the project and its direction, forming a more strategic basis for tool selection. The people-tool category focuses on the use of tools; the challenges related to usage and utilization of tools, focusing on a more operational perspective. The challenges are listed in Tables 2 and 3 and their implications described in the following subsections.

Table 2. Identified project-tool related challenges

Key challenges	Categories	Relation
Tools are often misaligned with project objectives	Tool misalignment	Project-tool related (purpose of tools)
Tools alienate the focus from project goals to tools themselves		
Goals, objectives, and key practices need to be planned, defined and agreed upon first, and tools implemented on top		
Some tools do not provide any significant value to project at hand		
Lack of clarity on why a certain tool is needed or used		
Project tools do not synergize well and structured unsystematically	Tool totality	
Structure of tools and systems as an entirety should be planned and agreed upon early in the project		
Tools require a degree of governance and ownership		
Inter-organizational context challenges tool integration, both technically but also organizationally		
More tools selected than what would suffice	Haphazard selection	
Tools often have uncertain value provided and costs incurred		

Table 3. Identified people-tool related challenges

Key challenges	Categories	Relation
Number of tools in a single project unnecessarily large	Prevalence of tools	People-tool related (use of tools)
Number of tools make operations unnecessarily complicated		
Increased number of tools require extensive training		
Understanding and managing many tools gets complicated		
Tools often have a wide array of functions that remain underutilized		
Number of tools for a given project difficult to balance		
Over involvement with tools can become burdening		
Achieving high utilization of tools requires training	Thorough implementation	
Once tools implemented, utilization can remain insignificant		

Key challenges	Categories	Relation
Tools are often haphazardly implemented		
Lack of facilitation and leadership for collaborative tools		
Fragmented communication channels scatter information	Fragmented information flow	
Scattered information hinders operations		
Too much unnecessary data and information		
Achieving commitment to use selected tools is difficult	Commitment to tools	
Collaborative tools require commitment to participation		
Initial trust a prerequisite for virtual collaboration		
All feasible stakeholders should be involved with collaborative tools		
Commitment to selected tools diminish over time		
Motivation to virtual collaboration requires as project progresses		
Agreed upon communication and tool use practices need to be upheld and require documentation	Common rules and practices	
Virtual communication challenges mutual understanding and increases potential for misunderstandings		
High threshold to use tools curtails utilization	User experience	
Tools are often difficult to use with inferior user experience		
Virtual spaces diminish the richness of collaboration		
Collaborative tools often unintuitive to use		
Tools lack accessibility, e.g.., from mobile devices		
Tool's flexibility and usability key to achieve high utilization		

4.1. Challenges and implications of project-tool relationship

The first three challenge categories revolve around the project-tool relationship. These describe the fit between the tools and the project. In other words, these categories consider how well the tools support the project and its objectives, along with the challenges related to this support. Project-tool-related challenges consider the strategic nature of planning the project's set of tools, while the people-tool category considers more operational challenges faced during the use of tools. Tools are selected and implemented to support the project and its purpose: the project's requirements and objectives dictate which types of tools are needed and provide value to the project. However, achieving this project-tool fit can become challenging for various reasons in inter-organizational projects.

4.1.1. Tool misalignment

Tool misalignment relates to how well individual tools and the overall toolset fit the specific project needs. A certain tool may have a significantly better strategic fit and benefits in one project while being obsolete and unnecessary in another. Despite this, projects often suffer from using tools that provide little value to their core needs and functions. Project tools should align with key project objectives and tasks and directly support their achievement. This requires defining and clarifying what the project seeks and simultaneously understanding the purpose for which the potential tools exist for.

The project's strategy, goals, and requirements dictate what kinds of tools have merit in a specific project. The project objectives should define the selection of tools—not the other way around, where tools are selected and then adjusted to align with the requirements. One interviewee summed up this view:

> "Tools and technologies are not the goal, but the means to achieve the goals."

4.1.2. Tool totality

Tool totality relates to how well the tools of a project act as an operable and productive whole. While a project's technological systems, tools, and platforms have their individual purposes, they also together form a "totality." This concept of totality emphasizes that tools are inevitably interconnected and should be considered and planned as a complementary whole, in addition to their individual specifications and fit. Failing to consider tool totality may create various inefficiencies in project operations. The interviewees especially noted frequent overlaps in project tools' functionalities. For example, certain types of documentation are conducted in separate tools when a single one would suffice. Or how a new tool may be implemented for a specific function, even though an existing tool or platform already has this functionality but is not utilized. Alternatively, a new collaborative tool is introduced to foster collaborative capabilities, but a substitute tool is already in place but underutilized. Such issues are emphasized in an inter-organizational context, as stated by an interviewee:

> "When you have constructors, designers, client organization, and operators, and everyone has their own tools and systems... ...it works, but it leads to overlapping work."

The structure of tools and systems as a totality should be planned and agreed upon early on. Neglecting tool totality may lead to a situation where tools fail to enhance operations and collaboration as intended, becoming a source of friction and burden instead.

4.1.3. Haphazard selection

Haphazard selection refers to the eager selection of project tools without thoroughly considering whether a particular tool is truly necessary or provides significant value to the project. This exacerbates issues related to misalignment and tool totality. Respondents identified several causes for hasty tool selection. The potential of existing project tools may go unrecognized and underutilized, leading to the introduction of new tools even when similar or substituting functionalities already exist within current tools. Additionally, positive experiences from prior projects might suggest that a tool will be useful, but its benefit to the present project may be uncertain. While overlapping challenges are particularly problematic in inter-organizational environments, they are not exclusive to such contexts, as one interviewee noted:

> "At worst, there are overlapping tools even in a single organizational entity."

Moreover, the overall costs versus benefits may not be fully considered. Beyond direct costs, new tools require time and effort for implementation and training of project stakeholders. Due to these additional costs and the resources needed to properly utilize a new tool, only tools that provide significant value or are directly required should be selected.

4.2. Challenges and implications of people-tool relationship

The latter six challenge categories focus on the project-tool relationship. Whereas the project-tool fit describes a more strategic alignment with the tools and goals, the people-people relationship considers a more operational perspective. It consists of challenge areas that individually and collectively affect the usability of tools in daily project operations.

4.2.1. Prevalence of tools

Prevalence of tools relates to the number of tools implemented in a project and used by the project participants. There are numerous tools available for various project needs and functions, increasingly being developed and implemented in project-based practice. As the number of these tools increases beyond a certain threshold, they begin to challenge project operations, as perceived by a respondent:

> "Today there are so many tools that it is beginning to hamper the work itself."

Having fewer tools has positive consequences in other domains of challenges. Managing and understanding the tool totality becomes easier and makes successful implementation more straightforward and less costly. Tools are more likely to be well-utilized, and usability improves as the set of tools remains limited and easier to grasp. On the other hand, a certain number of tools are required to satisfy the project's needs and requirements. Balancing the advantages of additional functions and tools with the disadvantages related to the prevalence of tools remains a challenging yet critical task.

4.2.2. Thorough implementation

Thorough implementation concerns the challenges and measures necessary to successfully implement a tool. Selecting suitable and well-aligned tools is not sufficient; tools only deliver significant productivity benefits and other sources of value when they are properly and thoroughly implemented and utilized.

The variability and number of stakeholders involved make thorough implementation more challenging yet simultaneously emphasize its importance. Without proper implementation, tools may be perceived difficult to use, remain underutilized, and fail to achieve the purpose for which they were selected. The following separate statements from two respondents underscore the importance of implementation in realizing tool benefits:

> "Technology is not the issue and has not been for a long time. The issue is the use of technology and humans using it."

> "Tools are only as good as the users are at using them."

4.2.3. Fragmented information flow

Fragmented information flow refers to the scattering of information in a project environment. Information and data are crucial project resources needed for planning, development, operations, and informed decision-making. Information flow is a key factor for productivity in inter-organizational projects, but information needs to be reliable and easily accessible, as remarked by an interviewee:

> "Data is only as good as it is correct, information is only as good as it is available."

Achieving this state requires taking multiple factors into consideration. Communication channels and practices, both formal and informal, should be jointly planned and agreed upon with key stakeholders to ensure that the practices are committed to and followed. Interviewees noted that communication is often well structured and begins as intended, but as the project progresses, slippages occur, and information begins to silo into smaller circles, challenging its accessibility. Interviewees also noted that an abundance of information and data can become burdensome if not properly structured.

4.2.4. Commitment to tools

Commitment to tools refers to the level of commitment required by participants to stay motivated and consistently use the selected tools as the project progresses. Tools must be consistently used to provide the benefits for which they were selected and implemented.

Commitment is the sum of many parts. To some extent, commitment can be built through agreements and contracts, but interviewees saw such enforcement as short-lived. Rather, they emphasized building real commitment through team cohesion and internalizing the reason the tools were set up in the first place. This requires leadership, proper training, and having an unambiguous set of selected tools. Furthermore, all stakeholders required to use certain tools should be involved to grasp the benefits, while stakeholders who are not needed should be excluded to maintain efficiency. This was summarized by one interviewee:

> "Tools and systems integrate eventually. The challenge lies in achieving a lasting commitment to use and keep using the tools and systems."

4.2.5. Common rules and practices

Common rules and practices relate to the interpersonal nature of inter-organizational projects. As these projects gather participants across inter-organizational boundaries, establishing common ground becomes crucial for joint collaborations. Respondents highlighted that it is key to mutually agree upon tools and tool usage with stakeholders during the early project stages and to ensure that these agreements hold as the project progresses.

> "Tools alone don't suffice. They require structures, standards, and unified practices to get properly utilized."

4.2.6. User experience

User experience relates to the challenges encountered during the daily use and usability of project tools. Interviewees highlighted how project tools are often difficult and burdensome to use. Such challenges are further accentuated when the number of tools used in daily project operations is high, and when there has been inadequate training for tool usage. Usability was also recognized as a motivating factor for the recurring use of tools across the project. Interviewees noted that project participants are more willing to utilize tools that they find easy to use and intuitive, emphasizing user experience as a key factor for higher utilization.

The role of usability is especially important in more complex tools, such as those requiring virtual and real-time collaboration with other participants. Tools, both individually and as a set, should feel intuitive to use to ease deployment and utilization. The relationship between user experience and utilization is well summarized by one interviewee:

> "When considering virtual tools or software, if they are difficult to use, then not everyone can and will use them."

4.3. Interdependencies between the challenges

The identified nine key challenge categories are highly interrelated and have distinct interdependencies (Figure 1). Challenges in one category often give rise to further issues in other categories. However, not all challenges stem from preceding challenges; they arise from various causes. While no challenge category can be completely eliminated by addressing the preceding category (e.g., having a limited number of tools does not eliminate the challenge of thorough implementation), disregarding a group of challenges can escalate subsequent challenges. Conceptualizing and understanding these interdependencies in a project can highlight areas that have the highest impact on the successful implementation and utilization of tools.

Notably, individual challenges in the project-tool category seem to lead to issues in the people-tool category. This correlation is reasonable, as the former involves planning and forming project tools that occur before their utilization. For this reason, proper planning and evaluation is emphasized.

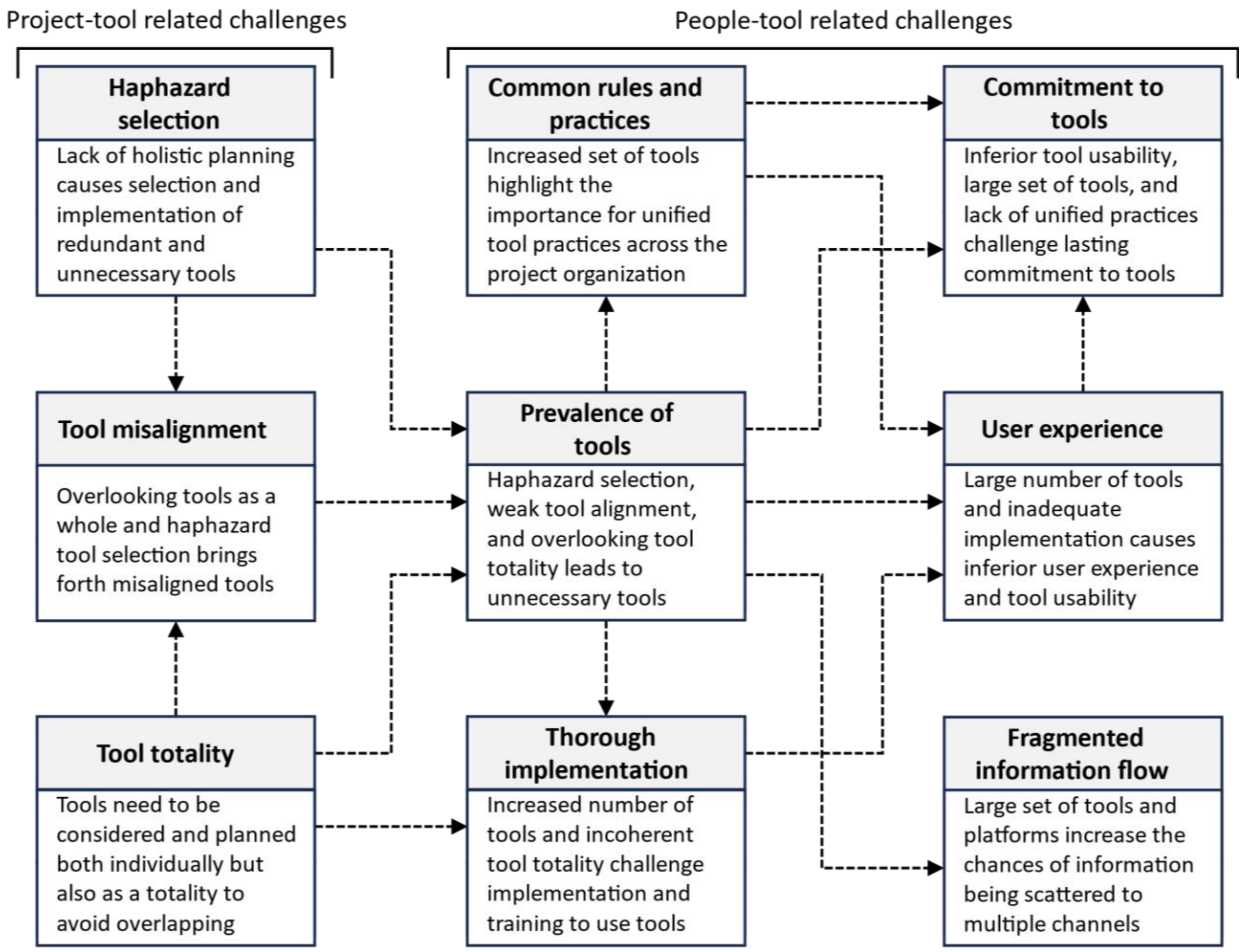

Fig. 1. Conceptualized interdependencies of identified tool-related challenges

5. Discussion

An abundance of technological tools aimed at enhancing project management and operations is readily available, constantly evolving, and are likely to keep increasingly accelerated by the advancements in artificial intelligence. However, despite technological advancements, tools have often failed to translate into successes in project performance (Mir & Pinnington, 2014). They are frequently difficult and costly to implement (Nikulina et al., 2022), and without careful attention, they may end up burdening inter-organizational project operations (Nwajei et al., 2022). Project context is what makes this challenging, as tools are selected in the early stages but have long-lasting consequences across latter stages.

Technological tools are implemented to provide the infrastructure for project work and collaboration, but their effectiveness is heavily influenced by the organizational environment in which they are deployed (Behn & Silvius, 2025). Because technological aspects are highly interconnected with organizational characteristics, technological problems often manifest as organizational challenges, and vice versa. Based on our findings, these technological tool-related failures predominantly arise from organizational mishaps.

Typically, enhanced collaboration is pursued in complex projects to cope with uncertainty and achieve more value jointly (Engebø et al., 2020; McGahan, 2021). Project tools can have both direct and indirect roles in enabling inter-organizational collaboration (Tampio & Haapasalo, 2024). Tools with a direct role are specifically designed and implemented to facilitate collaboration. These can include, for example, project management software, communication platforms, and document-sharing systems, which provide structures and environment for stakeholders to coordinate efforts, share information, and manage tasks efficiently.

On the other hand, tools with an indirect role contribute to collaboration more subtly, but their impact can be just as important if not greater. For instance, a well-integrated data management system can streamline information flow, reducing misunderstandings and fostering trust among team members, thus stimulating collaboration within a project organization. After all, lasting collaborative culture within the group is built through positive and shared experiences (Schein, 2017). Consequently, all tools can have a similar indirect role by creating the necessary conditions for a productive and cohesive work environment (Tampio & Haapasalo, 2024). However, our results find that this indirect role gets easily overlooked and can have a significant negative impact on collaboration when tools are not carefully selected and properly implemented to a specific project environment. To foster productivity and limit negative impact, tools need to be purposeful and adequately usable. That is, aligned with the project's objectives and their users.

The results of this study highlight two distinct relationships that must be aligned to ensure that tools contribute to productive and value-driven collaboration (Figure 2). The first, project-tool alignment, refers to the fit of a tool to support the specific requirements of a project. It emphasizes that tools should be selected and adapted to meet the project's requirements. Based on the empirical data, this ultimate purpose of tools—to support project's primary objectives—can get lost, which shifts the focus from the project to tools.

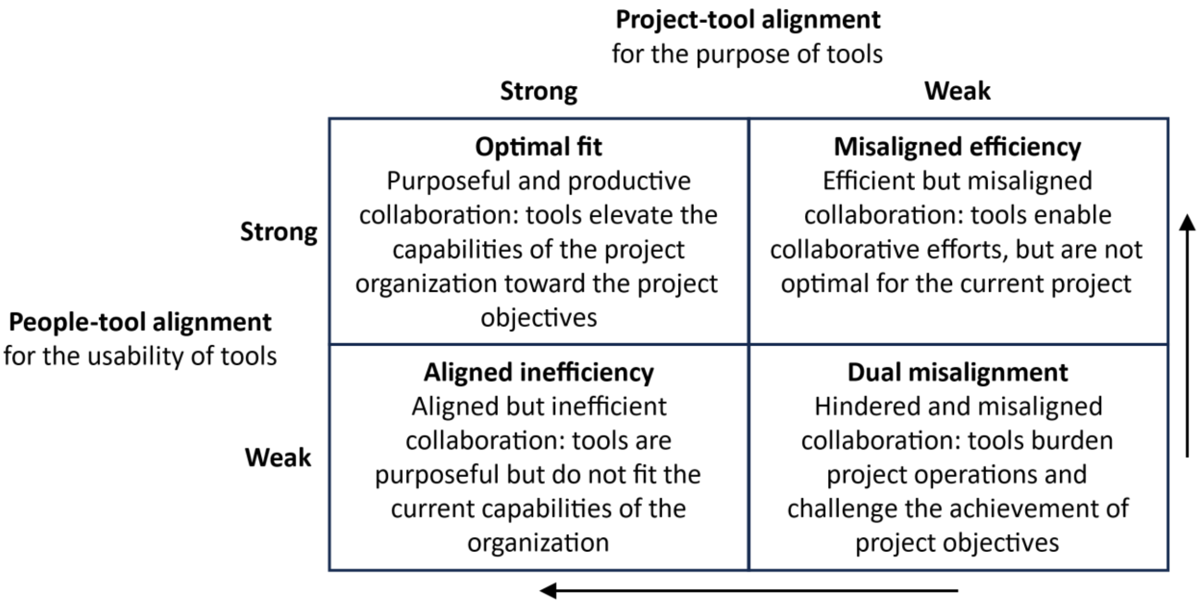

Fig. 2. Project tool alignment across project-tool and people-tool relationships

The second, people-tool alignment, concerns the operability of tools by the project team and other stakeholders. Even the most strategically aligned tools are futile if the team cannot use them effectively. Tools must fit to the organization to prove effective (Liker & Morgan, 2006; Zhang et al., 2018). Focusing solely on the strategic alignment between the tools and project objectives overlooking their usability can lead to inferior utilization in practice. The other way around, collaborative efforts may not produce the outcomes desired. Together both alignments ensure that tools are not only strategically aligned with project goals but are also operationally feasible, enabling the project team to utilize them effectively.

Project-tool alignment should be prioritized foremost in tool selection. If a tool does not directly contribute to the project and its objectives, there is little to do to strengthen the alignment. People-tool alignment and the usability of tools, however, can be improved more easily. Thorough implementation, additional training, and further development are all opportunities to improve the people-tool fit. Process-people-technology logic (Morgan & Liker, 2020), where tools and technologies empower people working on the processes toward defined objectives, is concealed within the two alignments: together they aim to ensure that the technological tools effectively link and support people executing the project toward defined project outcomes.

5.1. Theoretical contributions and practical implications

The study contributes to the discussion on inter-organizational collaboration phenomenon by examining the role of project tools play in it. In the context of collaboration literature, technological tools have been overshadowed by delivery models and organizational methods and often recognized simply as integration mechanisms to elevate team effectiveness. However, this study highlights the dualism of direct and indirect implications (Tampio & Haapaasalo, 2024) technological tools have on the collaborative environment, opening avenues for expansion particularly in the realm of these indirect, secondary effects that can have significant collaboration and operations hindering ramifications. Moreover, the proposed alignment matrix offers a novel conceptualization emphasizing the interplay between organizational and technological factors of collaboration phenomenon (Nwajei et al., 2022).

While collaboration is a well-established concept in relational delivery models such as alliancing, partnering, and integrated project deliveries, its importance and applicability extends to all types of projects. Regardless of the delivery model, stakeholders must collaborate to certain extent, and all projects stand to benefit from increased collaboration—provided that the value gained outweighs the costs involved. Through aligned and intuitive tools, project management can foster natural collaboration that benefits stakeholder cooperation. The right tools can significantly enhance stakeholders' collaborative capabilities, that in turn, can translate into better project outcomes. However, as technological tools provide the necessary infrastructure for collaboration, carelessly selected and implemented tools can instead become a significant burden on stakeholders working on the project. Project-tool and people-tool alignments work as a simple yet profound heuristic to aid in selection of tools that fit to the specific project environment. Tools must first be aligned to support project objectives but also suitable to the specific project organization.

Moreover, tools should be considered as a fundamental component of collaboration. Our results argue that all tools have an indirect yet meaningful impact on collaboration in the project environment. A data management system, for example, can significantly streamline transparent information flow or hamper it, affecting stakeholder collaboration. The analysis of challenges particularly emphasizes the impact that too many tools can have on collaboration. Project operations should not be complicated any more by tools that do not serve a definitive purpose. Quality of tools should be prioritized over quantity to strive toward lean and effective tool sets that support project goals. A streamlined set of well-chosen tools is more likely to be used effectively, leading to higher levels of commitment and long-term utilization across different stages of the project. Usability is a critical factor in the lasting success of collaboration tools. The ease with which stakeholders can use a tool affects not only their willingness to adopt it but also their ability to collaborate effectively throughout the project. This usability is determined by both the attributes of individual tools and how well they function together as a cohesive system. When tools are simple, intuitive, and well-executed, they foster a collaborative environment that is both efficient and sustainable.

5.2. Limitations and future research

This research has two main limitations. First, due to the nature of cross-sectional research design and the lack of longitudinal analysis (Maier et al., 2023), the interdependencies between the challenges lack validation for causality. However, as the interdependencies were depicted to showcase the interconnected nature of tool challenges, rather than systematically analyze the causalities, this is not a major limitation, and further validation is left for future studies.

The second limitation considers the type of data collected. Interviews as a data collection method are subject to bias. However, we sought to limit interview bias by fostering an informal and conversational atmosphere during the interviews, through use of a semi-structured interview design to not steer respondents in certain directions, and by collecting data from broad range of project-based industries.

During this research we came across a few emergent and interesting research opportunities. Firstly, further analysis of the causalities between key tool challenges could benefit prioritization and ranking of most impactful areas. With limited time and other resources during the project, focus on the most impactful elements is key towards efficiency. Second, the relation between technological challenges and organizational issues provides avenues for further theorization. The two are closely intervened, but on a more theoretical level were merely scratched in this study. And third, further exploration of the two alignments proposed offers multiple opportunities. These could include validation and further conceptualizations, for example identifying key attributes that engender higher levels of alignment across both dimensions.

6. Conclusion

This study set out to explore the role technological project tools have in inter-organizational collaboration. The study identified nine key project-tool related challenges based on empirical data collected. The study found that technological tools can have significant direct and indirect roles in establishing and promoting collaboration and productive project work through by their direct and indirect implications. Particularly the indirect implications can easily get overlooked and have significant negative effects hindering project operations. Misalignment of tools was depicted as the main cause for challenges, and a tool alignment matrix, that aims to ensure tool alignment with project objectives and people executing the project, was conceptualized.

References

Aapaoja, A., Herrala, M., Pekuri, A., & Haapasalo, H. (2013). The characteristics of and cornerstones for creating integrated teams. International Journal of Managing Projects in Business, 6(4), 695–713. https://doi.org/10.1108/IJMPB-09-2012-0056

Adeoye-Olatunde, O. A., & Olenik, N. L. (2021). Research and scholarly methods: Semi-structured interviews. Journal of the American College of Clinical Pharmacy, 4(10), 1358–1367. https://doi.org/10.1002/jac5.1441

Ahola, T. (2018). So alike yet so different: A typology of interorganisational projects. International Journal of Project Management, 36(8), 1007–1018. https://doi.org/10.1016/j.ijproman.2018.07.005

Ali, F., & Haapasalo, H. (2023). Development levels of stakeholder relationships in collaborative projects: Challenges and preconditions. International Journal of Managing Projects in Business, 16(8), 58–76. https://doi.org/10.1108/IJMPB-03-2022-0066

Baiden, B. K., Price, A. D., & Dainty, A. R. (2006). The extent of team integration within construction projects. International Journal of Project Management, 24(1), 13–23. https://doi.org/10.1016/j.ijproman.2005.05.001

Behn, M., & Silvius, G. (2025). Measuring and predicting teamwork quality in virtual project teams. International Journal of Information Systems and Project Management, 13(1), 1–24. https://doi.org/10.12821/ijispm130104

Bond-Barnard, T. J., Fletcher, L., & Steyn, H. (2018). Linking trust and collaboration in project teams to project management success. International Journal of Managing Projects in Business, 11(2), 432–457. https://doi.org/10.1108/IJMPB-06-2017-0068

Bygballe, L.E., & Swärd, A. (2019). Collaborative project delivery models and the role of routines in institutionalizing partnering. Project Management Journal, 50(2), 161–176. https://doi.org/10.1177/8756972818820213

Caniëls, M. C., Chiocchio, F., & van Loon, N. P. (2019). Collaboration in project teams: The role of mastery and performance climates. International Journal of Project Management, 37(1), 1–13. https://doi.org/10.1016/j.ijproman.2018.09.006

Castañer, X., & Oliveira, N. (2020). Collaboration, coordination, and cooperation among organizations: Establishing the distinctive meanings of these terms through a systematic literature review. Journal of Management, 46(6), 965–1001. https://doi.org/10.1177/0149206320901565

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. Journal of Advanced Nursing, 62(1), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

Engebø, A., Lædre, O., Young, B., Larssen, P. F., Lohne, J., & Klakegg, O. J. (2020). Collaborative project delivery methods: A scoping review. Journal of Civil Engineering and Management, 26(3), 278–303. https://doi.org/10.3846/jcem.2020.12186

Eriksson, P. E. (2015). Partnering in engineering projects: Four dimensions of supply chain integration. Journal of Purchasing and Supply Management, 21(1), 38–50. https://doi.org/10.1016/j.pursup.2014.08.003

Francis, J. J., Johnston, M., Robertson, C., Glidewell, L., Entwistle, V., Eccles, M. P., & Grimshaw, J. M. (2010). What is an adequate sample size? Operationalising data saturation for theory-based interview studies. Psychology and Health, 25(10), 1229–1245. https://doi.org/10.1080/08870440903194015

Heugens, P. P., Van Den Bosch, F. A., & Van Riel, C. B. (2002). Stakeholder integration: Building mutually enforcing relationships. Business & Society, 41(1), 36–60. https://doi.org/10.1177/000765030204100104

Hietajärvi, A. M., Aaltonen, K., & Haapasalo, H. (2017). Managing integration in infrastructure alliance projects: Dynamics of integration mechanisms. International Journal of Managing Projects in Business, 10(1), 5–31. https://doi.org/10.1108/IJMPB-02-2016-0009

Hong, Y., Chan, D. W., Chan, A. P., & Yeung, J. F. (2012). Critical analysis of partnering research trend in construction journals. Journal of Management in Engineering, 28(2), 82–95. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000084

Jitpaiboon, T., Smith, S. M., & Gu, Q. (2019). Critical success factors affecting project performance: An analysis of tools, practices, and managerial support. Project Management Journal, 50(3), 271–287. https://doi.org/10.1177/8756972819833545

Lahdenperä, P. (2012). Making sense of the multi-party contractual arrangements of project partnering, project alliancing and integrated project delivery. Construction Management and Economics, 30(1), 57–79. https://doi.org/10.1080/01446193.2011.648947

Lavikka, R. H., Smeds, R., & Jaatinen, M. (2015). Coordinating collaboration in contractually different complex construction projects. Supply Chain Management, 20(2), 205–217. https://doi.org/10.1108/SCM-10-2014-0331

Liker, J. K., & Morgan, J. M. (2006). The Toyota way in services: The case of lean product development. Academy of Management Perspectives, 20(2), 5–20. https://doi.org/10.5465/amp.2006.20591002

Lindgren, B. M., Lundman, B., & Graneheim, U. H. (2020). Abstraction and interpretation during the qualitative content analysis process. International Journal of Nursing Studies, 108, 103632. https://doi.org/10.1016/j.ijnurstu.2020.103632

Liu, L., Zhao, M., Fu, L., & Cao, J. (2021). Unraveling local relationship patterns in project networks: A network motif approach. International Journal of Project Management, 39(5), 437–448. https://doi.org/10.1016/j.ijproman.2021.02.004

Maier, C., Thatcher, J. B., Grover, V., & Dwivedi, Y. K. (2023). Cross-sectional research: A critical perspective, use cases, and recommendations for IS research. International Journal of Information Management, 70, 102625. https://doi.org/10.1016/j.ijinfomgt.2023.102625

Mattessich, P. W., & Johnson, K. M. (2018). Collaboration: What makes it work. Fieldstone Alliance.

McGahan, A. M. (2021). Integrating insights from the resource-based view of the firm into the new stakeholder theory. Journal of Management, 47(7), 1734–1756. https://doi.org/10.1177/0149206320987282

McIntosh, M. J., & Morse, J. M. (2015). Situating and constructing diversity in semi-structured interviews. Global Qualitative Nursing Research, 2. https://doi.org/10.1177/2333393615597674

Mir, F. A., & Pinnington, A. H. (2014). Exploring the value of project management: Linking project management performance and project success. International Journal of Project Management, 32(2), 202–217. https://doi.org/10.1016/j.ijproman.2013.05.012

Moore, R. (2007). Selecting the right manufacturing improvement tools: What tool? When? Elsevier.

Morgan, J., & Liker, J. K. (2020). The Toyota product development system: Integrating people, process, and technology. Productivity press.

Nikulina, A., Volker, L., & Bosch-Rekveldt, M. (2022). The interplay of formal integrative mechanisms and relational norms in project collaboration. International Journal of Project Management, 40(7), 798–812. https://doi.org/10.1016/j.ijproman.2022.08.006

Nwajei, U. O. K. (2021). How relational contract theory influence management strategies and project outcomes: A systematic literature review. Construction Management and Economics, 39(5), 432–457. https://doi.org/10.1080/01446193.2021.1913285

Nwajei, U. O. K., Bølviken, T., & Hellström, M. M. (2022). Overcoming the principal-agent problem: The need for alignment of tools and methods in collaborative project delivery. International Journal of Project Management, 40(7), 750–762. https://doi.org/10.1016/j.ijproman.2022.08.003

Olsson, T., Artto, K., Hauhia, A., & Kivinen, S. (2024). When project outcomes matter: Organizational integration in managing long-term target benefits. International Journal of Project Management, 42(8), 102648. https://doi.org/10.1016/j.ijproman.2024.102648

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. Administration and Policy in Mental Health and Mental Health Services Research, 42, 533–544. https://doi.org/10.1007/s10488-013-0528-y

Pauna, T., Lampela, H., Aaltonen, K., & Kujala, J. (2021). Challenges for implementing collaborative practices in industrial engineering projects. Project Leadership and Society, 2, 100029. https://doi.org/10.1016/j.plas.2021.100029

Rankinen, J. A., Lakkala, S., Haapasalo, H., & Hirvonen-Kantola, S. (2022). Stakeholder management in PED projects: Challenges and management model. International Journal of Sustainable Energy Planning and Management, 34, 91–106. https://doi.org/10.54337/ijsepm.6979

Romero-Torres, A. (2020). Asymmetry of stakeholders' perceptions as an obstacle for collaboration in inter-organizational projects: The case of medicine traceability projects. International Journal of Managing Projects in Business, 13(3), 467–482. https://doi.org/10.1108/IJMPB-10-2018-0230

Rowley, T. J. (1997). Moving beyond dyadic ties: A network theory of stakeholder influences. Academy of Management Review, 22(4), 887–910. http://doi.org/10.5465/amr.1997.9711022107

Rönndahl, C., Bosch-Sijtsema, P., Rempling, R., & Karlsson, M. (2025). Making Sense of Collaboration in Major Infrastructure Construction Projects. Project Leadership and Society, 100178. https://doi.org/10.1016/j.plas.2025.100178

Saukko, L., Aaltonen, K., & Haapasalo, H. (2020). Inter-organizational collaboration challenges and preconditions in industrial engineering projects. International Journal of Managing Projects in Business, 13(5), 999–1023. https://doi.org/10.1108/IJMPB-10-2019-0250

Savage, G. T., Bunn, M. D., Gray, B., Xiao, Q., Wang, S., Wilson, E. J., & Williams, E. S. (2010). Stakeholder collaboration: Implications for stakeholder theory and practice. Journal of Business Ethics, 96, 21–26. https://doi.org/10.1007/s10551-011-0939-1

Schein, E. H. (2017). Organizational Culture and Leadership. John Wiley & Sons.

Spector, P. E. (2019). Do not cross me: Optimizing the use of cross-sectional designs. Journal of Business and Psychology, 34(2), 125–137. https://doi.org/10.1007/s10869-018-09613-8

Suprapto, M., Bakker, H. L., Mooi, H. G., & Moree, W. (2015). Sorting out the essence of owner–contractor collaboration in capital project delivery. International Journal of Project Management, 33(3), 664–683. https://doi.org/10.1016/j.ijproman.2014.05.001

Swart, K., Bond-Barnard, T., & Chugh, R. (2022). Challenges and critical success factors of digital communication, collaboration and knowledge sharing in project management virtual teams: a review. International Journal of Information Systems and Project Management, 10(4), 84–103. https://doi.org/10.12821/ijispm100404

Tampio, K. P., & Haapasalo, H. (2024). Organising methods enabling integration for value creation in complex projects. Construction Innovation, 24(7), 21–43. https://doi.org/10.1108/CI-11-2021-0223

Tampio, K.-P., Haapasalo, H., & Farooq, A. (2022). Stakeholder analysis and landscape in a hospital project – elements and implications for value creation. International Journal of Managing Projects in Business, 15(8), 48–76. https://doi.org/10.1108/IJMPB-07-2021-0179

Tereso, A., Ribeiro, P., Fernandes, G., Loureiro, I., & Ferreira, M. (2019). Project management practices in private organizations. Project Management Journal, 50(1), 6–22. https://doi.org/10.1177/8756972818810966

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. American Journal of Evaluation, 27(2), 237–246. https://doi.org/10.1177/1098214005283748

Van Marrewijk, A. (2018). Digging for change: Change and resistance in interorganizational projects in the utilities sector. Project Management Journal, 49(3), 34–45. https://doi.org/10.1177/8756972818770590

Van Marrewijk, A., Clegg, S. R., Pitsis, T. S., & Veenswijk, M. (2008). Managing public–private megaprojects: Paradoxes, complexity, and project design. International Journal of Project Management, 26(6), 591–600. https://doi.org/10.1016/j.ijproman.2007.09.007

Walker, D. H., Davis, P. R., & Stevenson, A. (2017). Coping with uncertainty and ambiguity through team collaboration in infrastructure projects. International Journal of Project Management, 35(2), 180–190. https://doi.org/10.1016/j.ijproman.2016.11.001

Walker, D. H., & Lloyd-Walker, B. M. (2016). Understanding the motivation and context for alliancing in the Australian construction industry. International Journal of Managing Projects in Business, 9(1), 74–93. https://doi.org/10.1108/IJMPB-07-2015-0065

Wawak, S. (2024). Enhancing project quality through effective team management. International Journal of Information Systems and Project Management, 12(2), 50–67. https://doi.org/10.12821/ijispm120203

Xu, J., Smyth, H., & Zerjav, V. (2021). Towards the dynamics of trust in the relationship between project-based firms and suppliers. International Journal of Project Management, 39(1), 32–44. https://doi.org/10.1016/j.ijproman.2020.09.005

Zhang, Y., Sun, J., Yang, Z., & Wang, Y. (2018). Mobile social media in inter-organizational projects: Aligning tool, task and team for virtual collaboration effectiveness. International Journal of Project Management, 36(8), 1096–1108. https://doi.org/10.1016/j.ijproman.2018.09.003

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RESEARCH ARTICLE

A decision support process for the selection of sustainable public ICT project investments

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Abstract
The allocation of limited public resources to public investments necessitates selecting projects with the highest social and economic value, along with the greatest likelihood of success. However, the literature lacks well-defined criteria to measure the alignment of such projects with national policies, social benefits, and institutional capabilities. This paper aims to fill this gap by presenting a process methodology and a set of criteria for evaluating and prioritizing public sector information and communication technologies (ICT) projects. A project selection process is defined with a comprehensive criteria set, and it was tested on 11 carefully selected information and communication technology projects. A process has been defined consisting of prerequisite elimination, criteria weighting, project scoring, and verification. Both AHP and TOPSIS methods were utilized. The study also attempts to measure social benefits with respect to Türkiye's national priorities, through more tangible sub-criteria. To the best of our available knowledge, the study provides the most comprehensive set of criteria for selecting ICT investment projects in the public sector. The findings reveal that projects aligned with national priorities and providing high social benefits were ranked highest. The fact that project criteria provide feedback from a broad perspective shows that information systems can also support project maturation, along with project selection.

Keywords
public investment projects; decision support systems; project selection; project success; multi-criteria decision-making.

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1. Introduction

A key responsibility of the public sector is to enhance citizens' welfare by allocating limited national resources to areas that maximize social benefits while minimizing risks. This is a challenging task that has led to numerous qualitative and quantitative studies (PSB, 2020c, p. 1). The public sector tries to fulfill its mission through different tools such as investments, taxation, regulation, auditing, and incentives. Among these, public investment stands out as a significant specialized instrument. Among public investment projects, information and communication technologies (ICT) projects offer high added value and have a multiplier effect on other sectors. Due to limited resources for public investments, institutions must select ICT projects that maximize value while minimizing budget requirements.

In national-scale projects, a wide variety of criteria exist, such as the conformity of the project with national objectives, its social benefits, the capabilities of the executing organization, and its financial feasibility. Often, a choice has to be made between conflicting criteria. Human intelligence has difficulty in considering many parameters at the same time. Therefore, systematic methodologies are needed to assist decision-makers (Druzdzel & Flynn, 2002, p. 8). In the literature review, no comprehensive and inclusive set of criteria specific to the public sector was identified. This study aims to address this gap in the literature.

A systematic, evidence-based approach to project selection is important for three reasons. It increases the objectivity of the project evaluation process, helps public institutions gain a better understanding of how their proposed projects are assessed, strengthens the overall institutionalization of the project evaluation process. Thus, subjectivity in project evaluations will be reduced, new staff will adapt more easily, and it will become possible to create detailed datasets on projects for future use.

In 2024, the Turkish Government allocated 30.6 Billion Turkish Liras (TL), equivalent to approximately 956 million USD, for ICT investments (PSB, 2023b), representing 3.1% of the 1 Trillion TL total public investment budget. Even minor improvements in the project selection process could lead to substantial benefits. Given that methodology developed for ICT sector can potentially be applied to other sectors as well, the study has a significant potential for financial impact.

In Türkiye, Presidency Office of Strategy and Budget (PSB) is responsible for overseeing the approval process of public investments. Each year, between August and September, public institutions submit the projects they plan to implement in the following year to the PSB. This study focuses on establishing criteria for prioritizing IT projects proposed to PSB in Türkiye. Among multi-criteria decision making methods (MCDM), the Analytic Hierarchy Process (AHP) method is used to form criteria weights. 11 sample projects have been chosen as sample. Experts made pairwise comparisons and scored projects according to criteria. TOPSIS method is used to rank the projects. But simply scoring categories of criteria and creating a static final ranking would not suffice for the evaluation of the social impact, organizational adequacy, etc. Hence, a decision support model (DSM) and a decision support system (DSS) is provided to experts, allowing them to dynamically activate-deactivate various criteria groups and observe changes in project rankings.

The main structure of the study is as follows. The second section provides information on public investment projects and their evaluation processes in Türkiye, which is essential for understanding the general framework in which the study is applied. The third section presents a literature review. The methodology used in the study is explained in the fourth section. The fifth section covers the application according to the methodology. The study concludes with a discussion and summary of the results.

2. Background

The public sector holds a significant position in a country's economy due to its substantial financial power (Rosen, 2005; Şeker, 2019, p. 19). According to the OECD, infrastructure investments that provide benefits for more than one year are classified as public investments (OECD, 2014). As part of public expenditures, investments have a longer-term impact on the national economy compared to other types of spending. Public investment is viewed as a policy tool to ensure economic growth, innovation and prosperity (OECD, 2016, p. 12). It is one of the most important tools governments use to implement economic and social policies (Çetin, 2019, pp. 6–7) and is a key factor in increasing gross national product (Masten & Grdović Gnip, 2019, p. 1179). Public sector investments differ from private sector investments in terms of considerations related to social benefits.

Public investments are executed as projects. According to the Project Management Institute (PMI), a project, in general terms, is a set of activities with a certain budget, predetermined start and end dates, and defined operations and processes in order to create a product, service or benefit (PMI, 2009). The European Commission defines a project as a set of activities aimed at achieving clearly defined objectives within a certain period and with a certain budget (European Commission, 2014).

Budgets are allocated for the implementation of projects. In situations where a limited budget must be allocated to a large number of projects, it is important to select the projects with the highest added value. Unlike the private sector, which generally focuses on a few objectives, many goals coexist in the public sector (Şeker, 2019, p. 64). These may include the quality of service provided to citizens, support for disadvantaged groups, and strategic benefits, among others.

The approach to assessing social benefits in public investment projects has evolved over time. Project analysis in public investments began to gain prominence globally during the 1960-1970 period. However, in the 1970s, development aspects beyond economic growth, such as income distribution, became important. It was also recognized during this time that improving income distribution was a challenging task (DPT, 2001, pp. 4–5). This shift marked a significant milestone in project evaluation. In this period, both social and economic dimensions began to be considered. Social benefit is multifaceted, and the target audience can be any segment of society. Therefore, the criteria's adequacy is crucial for effective project evaluation. Social benefits are also directly related to the structure and priorities of a nation.

ICT investments hold a special place within public investments. In addition to being a sector that contributes to the economy, the ICT sector also creates a leverage effect on other sectors. Since the early 2000s, organizations have regarded ICT investments as important tools for enhancing efficiency and effectiveness (Gunasekaran et al., 2001).

To date, the project selection literature has developed and diversified across a broad spectrum. One possible reason for this that the issue of project selection arises in every aspect of life. Another reason could be that different sectors and conditions require different methods. Two main areas stand out in the literature on project selection: some studies focus on pairwise comparisons of projects, while others deal with the overall portfolio management. While both areas are important, this study focuses on project comparisons, a prerequisite for effective portfolio management.

3. Literature review

In the 1960s, Türkiye entered what is known as the "planned period". In this period, development plans became central to the national development goals. Public investments also began to be addressed within this broader framework (PSB, 2020b). The preparation of national plans and the approval processes for public investments are both coordinated by the PSB. Basic principles and guidelines for the selection and prioritization of projects have been established by the PSB (PSB, 2020a). Principles regarding public ICT investments are also prepared and updated annually by the PSB. The principles provide information on which projects will be prioritized in the ICT sector (PSB, 2022). However, the list of priorities and conditions is not concrete enough to be converted into objective criteria that can be consistently followed by each expert at the PSB and considered by institutions preparing project proposals. Therefore, although the existing policies and principles are instructive, they currently do not provide a systematic methodology.

In addition to Türkiye, many other countries have faced challenges in evaluating public sector projects, particularly balancing financial constraints with social benefits. For example, in Trinidad and Tobago, Benjamin (1985) applied goal programming to select energy sector projects, emphasizing the importance of minimizing risks while maximizing long-term social benefits. Similarly, in the European Union, the OECD (2016) developed a framework for public infrastructure investments, which integrates sustainability and social impact considerations into project evaluations. These examples illustrate the global relevance of MCDM methods for addressing the complex nature of public investments.

Methods for prioritizing projects are divided into financial and non-financial methods (Gray & Larson, 2018). While financial analysis is also important in public sector projects, the main determinant remains social benefit. Hence, there is a need for an analysis that covers, but goes beyond, financial cost-benefit analysis. It is also important to note that many public services have no alternatives (non-rivalry) and, in most cases, beneficiaries cannot be identified (non-excludability) (McNutt, 1999). These characteristics also make a pure financial analysis inadequate.

Mathematical models are also widely used within the project selection literature. However, these methods require both complex implementation processes and robust datasets (C.-T. Chen & Cheng, 2009). Although ICT projects share many similarities with projects in other sectors, they also have their distinctive features. It has been observed that technical factors alone are not sufficient for ICT success today and that behavioral, political, and other institutional factors have become more critical for organizations (Ragowsky et al., 1996).

Project prioritization involves multiple criteria and factors. A ‘criterion’ refers to any principle or standard used in evaluation, while a ‘factor’ refers to any situation, condition or influence that contributes to an outcome (Lim & Mohamed, 1999). While “criteria” are emphasized in the evaluation of projects, “factors” that affect outcomes are considered in predicting the success of projects. Since there is an evaluation of the projects within the scope of the research, the selection of criteria becomes crucial.

Since project selection problems are inherently multi-criteria and conflicting criteria often co-exist, MCDM methods are extensively used in this field. In multi-criteria selection problems, a solution that ideally satisfies all criteria is usually not possible (Ishizaka & Nemery, 2013, pp. 1–2). Therefore, the focus is on solutions that closely approximate the ideal. To date, many MCDM methods have been developed and new methods continue to be introduced (Wallenius et al., 2008). While there are examples of using a single selection method, it is also common to combine multiple methods.

Souza et al. (2021) conducted a study that focused on R&D projects. In their study, they examined the frequency of use of MCDM methods that have been used since 1970. They found that the most commonly used single method is AHP and its variations, followed by ANP and real option analysis (ROA). It was also revealed that in studies where more than one method was used together, AHP and data envelopment analysis (DEA), as well as TOPSIS and DEMATEL, were often combined. In the literature, AHP and TOPSIS methods have been applied together in various scenarios for project selection. These include the utilization of fuzzy AHP and TOPSIS methods for project selection in general (Han et al., 2019), the application of fuzzy AHP and fuzzy TOPSIS methods together in the selection of construction projects (Taylan et al., 2014), general-purpose project selection (Mahmoodzadeh et al., 2007), utilizing fuzzy AHP and fuzzy TOPSIS methods for risk prioritization and selection of contractor participation in public-private partnership projects using a case study (Jokar et al., 2020), using AHP and TOPSIS for selecting eligible economy actors for call for grants (Chrit et al., 2022), and project selection for oil fields (Amiri, 2010). In these examples, AHP is generally used to determine criteria weights, while TOPSIS is used to rank alternatives. Triantaphyllou et al. (1994) note risk of inconsistency and calculation complexity in fuzzy methods, especially those utilizing large criteria sets. Although fuzzy methods are utilized to tackle uncertainty, this is not the case in public investment projects in Türkiye, because uncertainty in planning phase results in project rejection and subsequent maturation by the proposing institution. In addition to clarifying the methods used in project selection, it is also necessary to determine the set of criteria to be used. The first step of the literature review in this context is undoubtedly the identification of the criteria currently used in the selection of public ICT investment projects in Türkiye.

The hierarchical criteria structure of AHP makes issues more understandable. Inconsistency ratio aspect of the method increases trust and objectivity (Saaty, 1980). On the other hand, as in all pairwise comparison methods, utilizing methods such as AHP involve partial subjectivity (Dong et al., 2010). TOPSIS is easy and flexible to implement (Hwang & Yoon, 1981). Chen (2010) states that both methods assume independence of criteria, which is hard to achieve, especially in large criteria sets, but combining them balances such disadvantages to some extent. Similarly, Sharma et al. (2020) found that combining these two methods yielded better results instead of using only AHP, and increased trust.

According to the Investment Program Preparation Guide prepared by PSB (PSB, 2023a), public investment projects, regardless of sector, must align with key national policy documents and institutional strategic plans, include adequate social benefit analysis, be completed within a reasonable timeframe, and support private sector investments. In addition to the general criteria, PSB also defines specific criteria for the ICT sector (PSB, 2022). Some of these criteria relate to technology dependency. These include preventing contractor or technology dependency, reducing foreign dependency by using domestic capabilities, and avoiding product or platform dependency. In addition, it should centrally address the need for information system infrastructure, ensure interoperability and data sharing, effectively utilize human resources, and consider the total cost of ownership. Some of these criteria are critical for successful completion of any project. Therefore, they can also be considered prerequisites for the project evaluation process.

In addition to the criteria taken into account in the current processes in Türkiye, it is also important to consider the criteria of organizations such as the OECD, IMF, and World Bank. Including the approaches of these organizations is crucial due to joint projects and Türkiye’s participation in international agreements. The OECD Development Support Committee developed a project evaluation approach in 1991, which included the criteria of relevance, effectiveness, impact, and sustainability. This categorization is still widely used by many international organizations, particularly the European Union (Çelik, 2010, pp. 51–55). While the International Monetary Fund (IMF) considers the cost-benefit ratio as the primary parameter for selecting public investment projects, it also emphasizes the efficiency of investments (IMF, 2015). Although these criteria are comprehensive, they are often very difficult to measure and quantify. Recently, the focus of international organizations in project selection has shifted towards portfolio management and, more broadly, toward the management of the entire public investment process. In this context, the World Bank's Public Investment Management Reference Guide (Kim et al., 2020) and the IMF's Public Investment Management Assessment (PIMA) framework (IMF, 2022) are two complementary references that provide a framework for the integrity of the public investment process and its integration with national policies. OECD specifically highlights data access and transparency in public policy and public investment (OECD, 2019).

Another important source for determining the criteria set is the existing body of literature. Although the existing literature is extensive, we focused on studies that are relevant from a public sector perspective. Chu et al. (1996) proposed a DSS for project portfolio selection. To prioritize projects, they used criteria such as project cost, implementation time, and probability of project success. In their study, experts scored the likelihood of success. Henriksen and Traynor (1999, p. 164) developed a set of criteria for project prioritization, including factors such as alignment with the duties and objectives of the organization, feasibility of technical requirements, the potential to achieve project goals with available resources, and the economic impact of the project if successful. Sowlati, Paradi, and Suld (2005, p. 1283) proposed a project prioritization approach for information systems projects by using a variety of criteria. These included the reduction of organizational expenditures, the reduction of man/months needed to complete tasks, social benefits that cannot be measured concretely, short project completion times, and the project’s contribution to the efficiency of organizational processes. They also considered financial and personnel resources as cost factors.

In the project portfolio literature, understanding the differences between the public and private sectors is crucial. Tregear and Jenkins (2007) examined the key differences these sectors in the construction of project portfolios. They found that public projects are driven by citizen demand, public accountability, political sensitivity, alignment with the overall public ecosystem (such as other ongoing projects), supporting national or institutional standardization, and promoting cultural improvement.

Costantino et al. (2015) proposed an approach to estimate the cumulative predicted success of a project portfolio by using the critical success factors of projects through neural networks. Although project success factors alone are not sufficient for project prioritization, they can be considered complementary elements. They used criteria such as the suitability of the project mission, top management support, consultation with affected parties, personnel capabilities, and the ability to handle unexpected risks. The use of artificial neural networks is only possible when sufficient structural data from previous years is available.

Huang et al. (2008) prioritized publicly funded technology development projects in Taiwan by combining a fuzzy AHP approach with an exact decision matrix approach. The categories they used include technology competitiveness, technology compatibility, economic benefit, social benefit, the quality of the technical plan, and adequacy of resources. Project risk was also analyzed as a separate criterion group, which included technical risk, development risk, and commercial risk.

In Trinidad and Tobago, a small Caribbean country, the goal programming method was applied to select public projects in the energy sector (Benjamin, 1985). Four of the identified priorities also apply to ICT projects: minimizing the number of active projects, promoting long-term economic development, increasing employment, and reducing investment risks.

In their study on the risks of software projects, Keil et al. (1998) identified 11 risk factors. From these, four basic risk categories were identified. These are senior management and end-user support, scope and requirements (project planning), project management success and team competence, and the management of unexpected environmental risks. The first two categories are considered the most critical because they are elements that project managers cannot manage.

Kim and Chang (2013) proposed a methodology for national R&D projects, using criteria such as relevance to government objectives, clarity of project objectives, employment potential, relevance of the technical plan, technical flexibility, domestic substitution potential, and income generation potential.

Karasakal and Aker (2017) combined data envelopment analysis and AHP for R&D projects. The criteria weights were calculated using AHP and added to the model as a regional constraint. Their criteria included the technology used in the project, the appropriateness of the project design, the adequacy of resources and technical team, top management support, and employment generation potential.

Albert Hirschman, one of the founders of development economics, was the first to attempt to make project appraisal a standard practice in the field of development through his work on World Bank projects in the 1960s. Hirschman viewed the influence of politics on project acceptance as inevitable (Hirschman, 2015). Similarly, Turnpenny et al. (2009) examined the political influence on the project selection process and emphasized its importance. Chopra (2015) emphasized the role of political ownership in the implementation of India's social policies.

The selection of criteria in a DSM for project selection is critical. However, the design of the DSS remains the primary factor in enabling experts to benefit from the system. In this context, it is important to incorporate insights from the literature into the methodology. Ghasemzadeh and Archer (2000) argue that a DSS should offer users flexibility in both the choice of methodology and the sequencing of projects. Since "supporting" the user is a key feature of a DSS, a general ranking of projects, as well as specialized rankings according to different categories would support the user, making the methodology adopted in this study a good example of a DSS.

Andersen questioned project planning as an approach (Andersen, 1996) and, along with colleagues, proposed a phased planning approach (Andersen et al., 2009). The observability of immature projects in the design of a DSM allows for multiple stages of maturation rather than a single acceptance-rejection process. The methodology proposed in this study aligns with this approach. Adopting a phased process rather than a single acceptance-rejection method better supports organizations.

4. Method

The literature review has shown that project selection is a well-researched field and that MCDM methods are commonly employed. Multiple methods are frequently combined in various phases of project selection. The studies indicate that project prioritization is typically based on a limited number of criteria. It is observed that there are few studies targeting a holistic analysis based on cost-benefit at the national level. This study aims to address the literature gap and the potential for selection of public sector ICT projects.

In the prioritization of projects, some criteria may influence the order of priority of a project, while others may be sufficient for the acceptance or rejection of a project by themselves. For example, a project that is not legally feasible and is unlikely to become feasible in the future will not be implemented even if all other conditions are optimally met. An example of this would be a project falling under the mandate of one public institution while another public institution wants to implement.

Social benefits play a critical role in the evaluation of public ICT projects. Social benefit is directly influenced by trends such as sustainability, resilience, changes in employment regimes, and digital transformation. However it is not possible to quantitatively measure to what extent a project aligns with these trends. Hence, in this study, we developed sub-criteria aimed at quantifying these benefits in a more tangible manner. These sub-criteria were derived from an extensive literature review and expert consultations, focusing on factors such as accessibility improvements, social inclusiveness, and the overall enhancement of public welfare. Each sub-criterion was carefully designed to capture a distinct aspect of social impact that contributes to the broader success of the project.

The selection of social impact sub-criteria was guided by both theoretical and practical considerations. Drawing on models and frameworks from prior public sector evaluations (Henriksen & Traynor, 1999; IMF, 2022; Keil et al., 1998; Kim et al., 2020; OECD, 2016, 2019), we identified key factors such as the number of beneficiaries, enhancements to national security, and employment opportunities. These sub-criteria were selected for their ability to measure tangible outcomes that directly affect citizens. Türkiye's national goals for short and long term also played a key role in the selection of such criteria. Global trends such as cybersecurity and resilience, sustainability, governance-focused public administration, digital transformation were addressed. Since these trends are relatively abstract and not quantifiable, we adopted an approach to identify causes and accelerators of such trends. For example, we preferred using access to information as a catalyst for transparency and the commitment of key stakeholders as an indicator of governance-based public administration.

PSB has the responsibility of approving public investments and executes this duty through a sectoral structure. One of the sectoral departments is the ICT department, consisting of a department head and eight experts. ICT investment projects are evaluated by these experts at PSB. For ICT projects incorporating elements from other sectors (e.g., agriculture, education), consultative support is obtained. Evaluating national projects requires a unique set of expertise, in fields including, but not limited to political, legal, economic, technical, and strategic. The required expertise is not theoretical but requires extensive on-the-job training. Because of the need for multi-disciplinary expertise, this study strongly depended on the expertise within PSB, along with a literature review.

Out of eight experts, one has a PhD, five have a master's degree, the remaining two have a bachelor's degree. Three of them have more than 20 years of experience, other three have between 10 and 20 years of experience, and the remaining two have less than 10 years of experience. They graduated from a variety of fields, including public administration, business administration, engineering, and economics. Additionally, apart from the general knowledge of project evaluation that everyone gains, each expert has specialized in a sub-field of ICT over time. Differences in specialization and fields of graduation formed a learning environment that is open to negotiation and learning from each other. On the other hand, a lack of a common methodology hinders experts from reflecting their experience across all areas of project evaluation. The need for a systematic approach has initiated this study.

After the initial literature review was conducted, a total of 43 criteria were identified, some of which were mentioned above. The remaining steps of this study were put into practice by PSB experts as group work. According to these experts, four of the criteria were deemed so critical that initiating the project without meeting them would pose a serious risk. Since scoring was not an option for these criteria, they were removed from the project prioritization criteria list and added to the pre-qualification criteria group. These preconditions are listed in Table 1. Projects that do not pass the pre-qualification stage are not taken into consideration.

The remaining 37 criteria from the pre-qualification criteria were grouped into five categories and those with similar qualities were combined. As a result of the merging, 20 criteria were identified. The list of criteria and their descriptions were reviewed by eight PSB experts and their feedback was collected. With the help of the experts, both the number of criteria and the criteria groupings were revised. During these discussions, seven additional criteria were noted and three criteria were deemed less important than the others. At the end of the study, 30 criteria were established, including six pre-qualification criteria and 24 comparison criteria (Table 1, Table 2). In the selection and grouping of the criteria, aspects such as their singular importance, their alignment with the related criteria group, and ensuring coherence were considered so that, when met, the group's objective would also be achieved. In addition to these, recently submitted project proposals were evaluated in terms of any possible need for additional criteria. Both AHP and TOPSIS methods require that criteria do not influence each other. Special effort was made to distinguish the criteria from each other to minimize their influence. Criteria explanations helped in defining the boundaries.

Table 1. Pre-qualification criteria

Criteria	Source
Project is compliant with the responsibility of the organization and the public sector in general	(Huang et al., 2008; IMF, 2022; J.-H. Kim et al., 2020; Y. Kim & Chang, 2013; PSB, 2023a)
Required legal base is available and project is not in conflict with main legal framework	(PSB, 2023a)
Project is not a duplicate of or very similar to another existing project	(PSB, 2023a)
Sufficient prior analysis of the project has been carried out	(Karasakal & Aker, 2017; Keil et al., 1998; Y. Kim & Chang, 2013; PSB, 2023a)
Financial predictability is ensured	(IMF, 2022; J.-H. Kim et al., 2020; PSB, 2022)
Proper analysis and fulfilment of stakeholder requirements were fulfilled	(Keil et al., 1998; PSB, 2022)

Table 2. Project prioritization criteria

Criteria	Explanation and Source
Alignment with national and sectoral policies and political support (NPS)	
Alignment with key national policies	The project serves policies and strategies on a national scale and covering all sectors, especially the National Development Plan (IMF, 2020, 2022; J.-H. Kim et al., 2020; PSB, 2023a)
Alignment with organizational strategic plan	The project serves the realization of the objectives and actions written in the organization's own strategic plan (Henriksen & Traynor, 1999; PSB, 2023a)
Alignment with a sector-specific strategy	The project serves the realization of the objectives and actions written in national strategies specific to a particular field such as cyber security, e-government, smart cities, etc. (PSB, 2023a)
Level of political ownership	The project is subject to political oversight, is closely followed politically, and is one of the commitments made to citizens (Deepta Chopra, 2015; Hirschman, 2015; Schneider et al., 2022; Turnpenny et al., 2009)
Critical multiplier effects (CME)	
Being a common infrastructure	The project outputs are reusable in many areas, the project eliminates the need for a large number of various investments, the project plays an enabling role for private sector investments in the implementation area, the project contributes to standardization in a specific area (PSB, 2022)
Contribution to national security	Replacing the foreign-origin solution that currently poses a risk to cyber security with a national alternative, enhancing cyber security (Expert Opinion)
Creation of new business and employment opportunities	The project will increase citizens' ICT literacy and create awareness and know-how in a field where employment is currently insufficient. People employed in the project are not in this scope (Benjamin, 1985; Karasakal & Aker, 2017; Y. Kim & Chang, 2013)
Access to information and transparency	Increased added value resulting from the integration of different data sources, the project's potential to increase the objectivity and usability of public data, enabling transparency in public service delivery. (OECD, 2019; PSB, 2022)
Production of domestic technologies	The project includes elements that will enable the use of domestic technologies and the development of domestic products and solutions. (Y. Kim & Chang, 2013; PSB, 2022)
Prevention of corruption	Eliminating the lack of control caused by the fragmentation of public information systems and preventing corruption by cross-checking data from different sources (IMF, 2022; J.-H. Kim et al., 2020; OECD, 2014, 2016)
Other project benefits (OPB)	
Number of beneficiaries and magnitude of benefit	Number of stakeholder organizations and/or citizens directly benefited by the project (Expert Opinion)
Use of domestic technologies	The project includes elements that will enable the use of domestic technologies and the development of domestic products and solutions (Y. Kim & Chang, 2013; PSB, 2022)
More efficient use of personnel and resources	Cost efficiency through transition to lower-cost licensing types, introduction of new cost-effective technologies, integration of services, becoming more sustainable with a reduced workforce (Karasakal & Aker, 2017; Y. Kim & Chang, 2013; PSB, 2022)

Criteria	Explanation and Source
Increasing public revenues and preventing waste	Short-term financial recovery of the initial investment cost, collection of taxes that are currently uncollected, creation or better delivery of a value-added public service that is subject to a fee (Benjamin, 1985; Henriksen & Traynor, 1999; IMF, 2022; J.-H. Kim et al., 2020; Y. Kim & Chang, 2013)
Reduced technology or contractor dependency	Reducing technology dependency by using standard equipment, using widespread technologies, increasing interoperability; reducing contractor dependency by ensuring preserving institutional know-how, changing infrastructure to open systems (PSB, 2022)
Financial adequacy and sustainability (FAS)	
Ease of implementation and maintenance	The project can be realized in a short time and the small-scale budget is sufficient to cover both initial investment cost and maintenance expenses (Benjamin, 1985; Henriksen & Traynor, 1999; PSB, 2023a)
Project cost	Total ownership cost of the project, including, but not limited to energy costs, workforce costs, recurring cost. (Henriksen & Traynor, 1999; Karasakal & Aker, 2017; PSB, 2022)
Cost to stakeholders	Direct cost to stakeholders, such as any licensing or equipment to be able to participate in the project, or integration work to be carried out (PSB, 2022)
Direct cost to citizens	The cost to citizens when they need to pay for the service, or purchase any equipment to use the service (PSB, 2022)
Competence of the executing organization (CEO)	
Commitment of top management and key stakeholders	Positioning the project as a top priority for the top management of the organization, making necessary interventions at points where the project may be blocked (Costantino et al., 2015; Karasakal & Aker, 2017; Keil et al., 1998)
Appropriateness of technology choice	The selected technical architecture is sustainable, has the flexibility to allow for easy expansion when necessary, and has a technical design that ensures a low level of contractor dependency (Henriksen & Traynor, 1999; IMF, 2020; Y. Kim & Chang, 2013)
Competence of the technical team	Both the technical competence and project management skills of the team responsible for executing the project are sufficient to successfully implement and maintain it effectively (Costantino et al., 2015; Karasakal & Aker, 2017; Keil et al., 1998)
Past project experience	The organization is able to achieve a certain level of success in each project by institutionalizing project management processes, has qualified technical and project management teams (Keil et al., 1998)
Manageability of project risks	Risk factors such as uncertainty from R&D activities, risk from changes in technology, risks from changes in needs can be reduced to manageable levels (Benjamin, 1985; Chu et al., 1996; Costantino et al., 2015; IMF, 2020; Keil et al., 1998)

4.1. AHP

AHP method was first proposed as a framework by Saaty in 1977 (Saaty, 1977) and systematized in 1980 (Saaty, 1980). In AHP, the criteria are first organized in a hierarchical structure. Then, the criteria in each level of the hierarchy are subjected to pairwise comparison among themselves. Since AHP values subjective information, i.e. comparisons are largely based on personal experience. As a result of the comparisons, a superiority matrix is formed, which contains the relative superiority of the criteria (Yadav & Jayswal, 2013, pp. 775–776).

Miller found that the human brain can process an average of seven components of short-term memory, which can vary by ±2 depending on the individual (Miller, 1956). Therefore, the number of criteria to be included in the pairwise comparison should not exceed these thresholds. Another important consideration in the use of the method is that a criterion with a large number of sub-criteria has a higher weight than one with a smaller number of sub-criteria (Stillwell et al., 1987; Weber et al., 1988). To avoid this situation, the number of criteria in the criteria group at any level should not be fewer than four. These considerations were taken into account when determining the criteria.

Since the AHP method was used to determine the criteria weights within the scope of the study, the relevant part of the AHP method for determining the criteria weights was analyzed. In addition to this, a consistency index calculation was also made. The following formulas were used to calculate the consistency ratio. In the first formula, λ_{max} is the maximum value in the matrix and n represents the number of elements in the matrix (Eq. 1).

$$Consistency\ Index = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

The consistency index is divided by the random index series (Eq. 2), a constant coefficient that varies based on the number of elements, to calculate the consistency ratio.

$$Consistency\ Ratio = \frac{Consistency\ Index}{Random\ Index\ Series\ [n]} \quad (2)$$

If the consistency ratio resulting from the calculation is less than 0.1, it is concluded that the matrix, and therefore the judgments of the decision makers, are consistent.

4.2. TOPSIS

TOPSIS (Technique For Order Preference By Similarity To An Ideal Solution) is an MCDM method. It was created by Hwang and Yoon (1981) and further developed by Chen and Hwang (1992). In the TOPSIS method, the convergence rate of alternative options to the ideal state is calculated. The solution that is closest to the positive ideal solution point and farthest from the negative ideal solution point is considered to be the most ideal solution (Demireli, 2010, p. 104). First, a matrix is created from the alternatives and the criteria against which these alternatives will be compared. The criteria weights obtained from the AHP method are used to determine the summation effect of each criterion. In the second stage, the matrix is subjected to a normalization process. During normalization, each criterion is divided by the square root of the sum of the squares of all criteria. For negative criteria, the result is subtracted from 1.

$$Z_{ij} = \frac{y_{ij}}{\sqrt{\sum_{i=1}^{n} \left(y_{ij}\right)^2}} \qquad i = 1....n;\ j = 1....k \quad (3)$$

$$Z_{ij\ (negative)} = 1 - \frac{y_{ij}}{\sqrt{\sum_{i=1}^{n} \left(y_{ij}\right)^2}} \qquad i = 1....n;\ j = 1....k \quad (4)$$

In the third stage, the elements of the decision matrix normalized in the second stage are weighted. Weighting was performed by multiplying the elements with the criteria weights previously determined by AHP (Eq. 5).

$$X_{ij} = w_i \cdot Z_{ij} \qquad i = 1 \dots . n; j = 1 \dots . k \quad (5)$$

In the next step, m^* and m^- ideal sequences are created by determining the maximum and minimum values in each column of the normalized matrix. Then, the distance to the most ideal point is calculated by the following formula (Eq. 6).

$$S_i^* = \sqrt{\sum_{j=1}^{k} \left(X_{ij} - X_j^*\right)} \qquad i = 1 \dots . n \tag{6}$$

Similarly, the distance to the most negative state is calculated using the following formula (Eq. 7).

$$S_i^- = \sqrt{\sum_{j=1}^{k} \left(X_{ij} - X_j^-\right)} \qquad i = 1 \dots . n \tag{7}$$

4.3. Application steps of methods

The methods used in the research complement each other. The criteria weights determined by AHP were used in TOPSIS to rank projects. Application steps of both methods are shown in Fig.1. The first two steps shown in the figure belong to the AHP method. In these steps, criteria are established and their weights are determined. The remaining steps belong to the TOPSIS method, where project scores were determined using the decision matrices and the final project ranking was obtained.

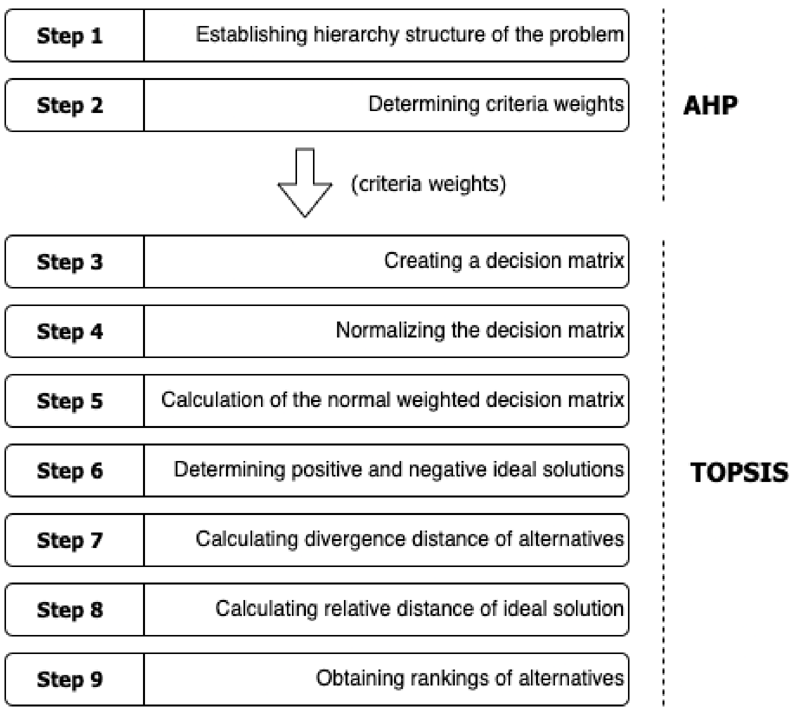

Fig. 1. Application steps for AHP and TOPSIS

5. Results

A process has been defined for weighting the criteria shown in Table 2 and validating them with sample projects. In the previous sections, the problem was defined, and the criteria were identified. The steps of weighting the criteria, selecting the sample projects, scoring the projects and verifying the system scores were conducted using DSS interfaces. Fig.2 shows all the steps of the methodology implementation, including problem definition and criteria setting. The process diagram detailing how the steps will be implemented is shown in Fig.3.

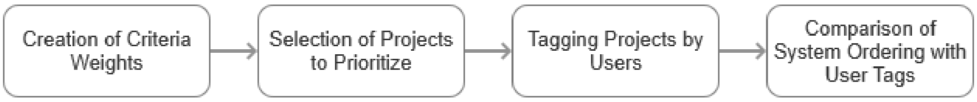

Fig. 2. Application Steps of Recommended Methodology

Since DSS interfaces were extensively used, testing these interfaces was also an important step. For testing, a sample problem was first solved in Excel, then it was checked whether the same results could be obtained from the DSS.

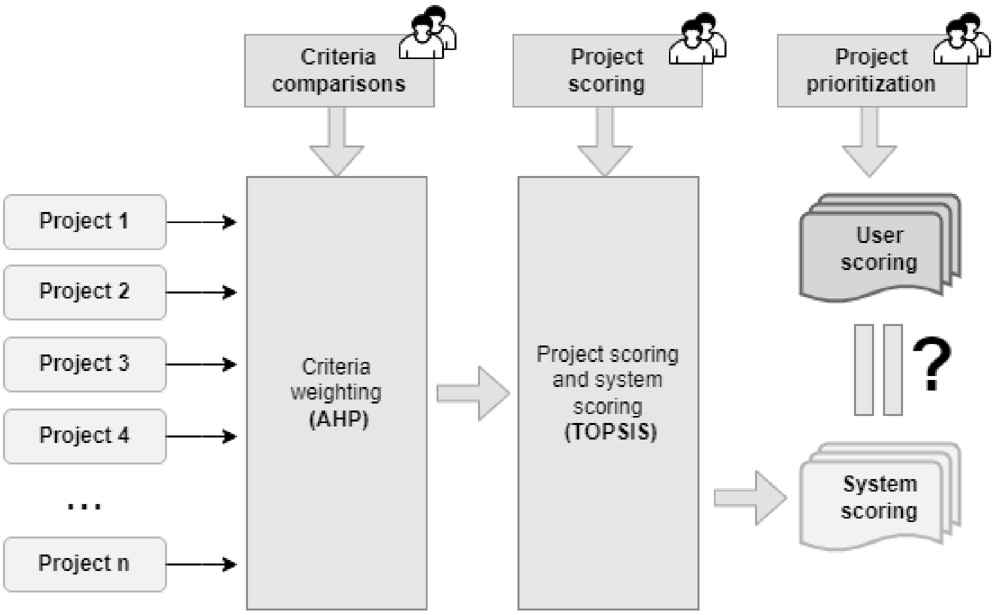

Fig. 3. Stages Carried Out in the Methodology

5.1. Creation of criteria weights

DSS used in this study has the capability of accepting criteria as a hierarchical group and offering pairwise comparison scoring. The experts initially reviewed the criteria individually. In determining the weights of the criteria in Table 2, the expert group decided on the criteria weights during a group discussion session. The group work helped reduce potential subjectivities to an acceptable level. DSS performed the final calculation using the AHP method. Since each expert has distinctive expertise in specific areas of ICT, experts shared their views on the criteria involved, which helped create a learning environment. Organizational culture based on mutual negotiation helped avoid certain experts' opinions carrying more weight than they should. Experts were previously exchanging ideas on projects, this time, exchanging ideas on project selection criteria were also added value. AHP consistency ratios, calculated dynamically by the DSS, are given in Table 3. The criteria weights obtained are presented in Table 4. Both local and global weights are given. Some criteria are negative and are indicated with a "(-)" sign in Table 4.

Table 3. AHP consistency ratios

	Main	NPS	CME	OPB	NEX	FAS	CEO
Ratio	0.012	0.014	0.021	0.070	0.009	0.062	0.006

Table 4. Calculated Criteria Weights

Criteria	Local Weights (%)	Weights (%)
NPS. Alignment with national policies and political support		**20.5**
Alignment with key national policies	52.1	10.7
Alignment with organizational strategic plan	5.3	1.1
Alignment with a sector-specific strategy	12.7	2.6
Level of political ownership	29.9	6.1
CME. Critical multiplier effects		**35.5**
Being a common infrastructure	30.0	10.7
Contribution to national security	20.0	7.1
Creation of new business and employment opportunities	5.0	1.8
Access to information and transparency	6.2	2.1
Production of domestic technologies	19.4	6.9
Prevention of corruption	19.4	6.9
OPB. Other project benefits		**10.0**
Number of beneficiaries and magnitude of benefit	13.0	1.3
Use of domestic technologies	20.6	2.0
More efficient use of personnel and resources	9.6	1.0
Increasing public revenues and preventing waste	24.3	2.4
Reduced technology or contractor dependency	32.5	3.2
FAS. Financial adequacy and sustainability		**5.3**
Ease of implementation and maintenance	16.1	0.9
(-) Project cost	13.7	0.7
(-) Cost to stakeholders	35.1	1.9

Criteria	Local Weights (%)	Weights (%)
(-) Direct cost to citizens	35.1	1.9
CEO. Competence of the executing organization		**28.7**
Commitment of top management and key stakeholders	14.8	4.2
Appropriateness of technology choice	14.8	4.2
Competence of the technical team	38.2	10.9
Past project experience	16.1	4.7
Manageability of project risks	16.1	4.7

5.2. Selection of projects to prioritize

Every year, PSB publishes Public Information and Communication Technologies Investments Report. The report presents the complete list of ICT projects approved for inclusion in the Government Investment Program for the relevant year. 335 ICT projects were included in the 2023 Public ICT Investments Report. The total investment volume of these projects was approximately 21.2 billion TL. More than half of the total budget was allocated to maintenance-related expenses (PSB, 2023b).

A subset of these projects must be selected for the study, requiring a clear rationale for sample selection. Some projects included in the investment program have a specific characteristic that are well-known to PSB experts. For example, a project is obviously meant to increase national security. Another project is of critical importance for the development of national information infrastructure. The criteria set can be more effectively tested with projects whose features are clearly observed. The DSS must be capable of identifying the relevant features for each project. Therefore, projects that stand out in certain aspects were selected for the accuracy test of the system. Among the selected projects, 11 projects with distinctive characteristics and best known by experts were used as a sample within the scope of the research (Table 5). Full names of the projects were not written for confidentiality reasons, and the project budgets were slightly changed.

A different method was employed in the calculation of project cost factors. This method is more appropriate than the Likert scale, as it allows for the estimation of project costs in numerical terms. We used the cost factors listed in Table 5, i.e. project budget, maintenance cost and direct costs to stakeholders. Direct cost to stakeholders refers to the amount that each stakeholder needs to pay for the project to be fully implemented. For instance, while a data center project for an institution does not require stakeholder costs, a nation-wide open source software project requires each stakeholder to convert its software base to open source to ensure full implementation. The maintenance cost was calculated for a period of five years, which is common in IT related estimations. The total cost was calculated using the formula: “Cost x (maintenance cost x 5) + cost to stakeholders”. Normalization of this cost was then performed, where the project with the highest cost was assigned a value of 1, producing the project cost factor.

Projects 10 and 11 were eliminated during the pre-selection phase. Project 10 was eliminated due to a change in legislation, which took duty away from the institution responsible for the project. Project 11 was eliminated because it lacked a legal basis. For effective use, hints were used to guide users across screens.

Table 5. Project List for Testing the Methodology

No	Project	Budget	Maintenance Cost	Stakeholders' Direct Cost	Total Cost	Coef.
1	A core infrastructure for national security	6	0	5	11	0.0122
2	A data collection and standardization project	300	0	0	300	0.3333
3	A central records management system	50	5	10	85	0.0944
4	A core infrastructure for geographical datasets	36	6	20	86	0.0956
5	A nation-wide open source software project	51	10	30	131	0.1456
6	An integrated platform for security software solutions	17	0	0	17	0.0189
7	A disaster recovery system of an institution	3	1	0	8	0.0089
8	An institutional open source software transformation	2	0	0	2	0.0022
9	A data center of an institution	80	8	0	120	0.1333
10	A project for traffic data standardization	135	0	0	135	0.1500
11	National central data center	600	60	0	900	1.0000

5.3. Tagging projects by users

Experts scored the projects using the DSS interfaces as a group. Group work was also preferred in this stage because detailed information about the projects was not available to each expert, and the exchange of ideas among experts would allow for more objective scoring. For each project, a score was given based on the criteria determined in the previous stage. A 5-level Likert scale (very low, low, normal, high, very high) was used in scoring alternatives. However, as there were cases where some projects had no impact on certain criteria, the option “No impact” was added to the options. An example to this situation is that projects that have no revenue-generating aspect should not be scored on criteria about revenue generation.

On the scoring screens, the imprint and summary information of the projects are also presented. The scores entered by the users into the system, based on the agreed results of the group work, were converted into project rankings using the TOPSIS method. The DSS interfaces were used for scoring and methodical calculations.

5.4. Comparison of system ordering with user tags

A ranking was obtained with the TOPSIS method by means of criteria weights and project scores calculated in the previous phase. The DSS screen was designed to allow dynamically enabling/disabling one or more criteria groups. When a criteria group was deactivated, the weights of the remaining groups were proportionally increased on-the-fly so that their totals add up to 100%. Ajax technology was specifically used for this interface to display results on the screen in real time. Thus, it was possible to determine in which criteria groups the projects stood out. Differences between group's ranking and system ranking were analyzed. Each criteria group was designed to reflect a different aspect of the projects. This approach aligned with the goal of viewing the projects through different and meaningful lenses. Whether the system rankings captured specific project strengths was tested. Table 6 shows scores for each criteria category. Scores were weighted according to group weights, and then normalized. The final total score for each project was calculated (Table 6).

We followed a different method for calculating project cost factors. Since we have some numbers to estimate project costs, numerical values were deemed more appropriate than a likert scale. We used cost factors listed in Table 5, namely project budget, maintenance cost and stakeholders' direct costs. Maintenance cost was calculated for a duration of five years, which is common in ICT-related estimations. Project with the greatest total cost had a cost factor of 1.000, and other projects were scored accordingly.

Table 6. TOPSIS results by category and Total

Project	Total		NPS		CME		OPB		FAS		CEO	
	Scr.	#	Scr.	#	Scr.	#	Scr.	#	Scr.	#	Scr.	#
P1. A core infrastructure for national security	50.6	3	85.1	3	47.6	4	39.6	4	99.6	1	55.6	6
P2. A data collection and standardization project	46.7	5	44.1	7	47.4	5	27.2	7	0.0	9	62.7	4
P3. A central records management system	49.3	4	85.1	3	49.8	3	20.0	8	36.9	4	33.4	9
P4. A core infrastructure for geographical datasets	40.6	6	100	1	35.6	6	32.6	6	59.7	3	36.8	8
P5. A nation-wide open source software project	58.4	2	95.5	2	55.1	2	59.7	3	78.6	2	58.0	5
P6. An integrated platform for security software solutions	63.8	1	71.7	5	62.7	1	69.0	2	25.4	7	88.0	1
P7. A disaster recovery system of an institution	14.9	9	2.2	8	8.9	9	12.8	9	27.1	6	42.6	7
P8. An institutional open source software transformation	34.0	7	53.0	6	17.1	7	71.9	1	28.8	5	87.6	2
P9. A data center of an institution	25.2	8	2.2	8	16.9	8	37.4	5	20.6	8	67.4	3

As can be seen in Table 6, in addition to a cumulative scoring and ranking, scoring and ranking for each criteria category are also presented. This approach provides more detailed clues about project strengths and risks. It was chosen because the evaluation process is a living process. The needs of public institutions are ongoing, and it is assumed that the proposed projects are relevant to these needs. Therefore, the rejection of projects should not be considered a definitive rejection, but rather as giving institutions time to rework their projects. With the proposed set of criteria, the shortcomings in both the institutional capacities of the institutions and their projects can be seen more objectively. However, it is still recommended that the set of criteria be refined before it is presented to the applicant public institutions.

6. Findings, discussion and recommendations

Table 6 presents important findings on different aspects of the projects. Discussing these findings provides insights into how closely the criteria used in the study and the scoring process align with real-life situations. A project that the criterion set ranks high in a certain category should also be ranked high in the same category by the experts, and a project receiving a low score in a category should similarly be considered inadequate in the same category by the experts.

Projects 6 and 1 aims to enhance national cybersecurity infrastructure. Project 6 does this by creating a framework for private sector, while project 1 aims to build a government-wide secure communication medium. Risks are low for these projects, since institutions responsible for cybersecurity have high technical capabilities. Top management support is also higher for these projects. The high ranking of projects related to national security aligns with the opinions of PSB experts in this field.

Projects 3 and 4 were ranked roughly lower. They are relatively costly, and both have some disadvantages; Project 3 offers a clear benefit, but not as critical as other projects having national scope. However, its low risks make it a good alternative. Although project 4 provides greater benefits, it also involves greater risks in terms of critical stakeholder support and technical competence.

It is noteworthy to examine project 5; although it ranked 5th in organizational competence, it ranked 2nd in the overall ranking. The objectives of this project, which aims to introduce open source software to all public institutions, are clear and important. Open source software has a direct impact on both human resources capacity and national security by preventing dependence on foreign software. Therefore, it also raises the ranking for national substitution. Hence, the high risk associated with organizational competence could not lower the ranking of this project. However, the main conclusion to be drawn here is not the ranking information itself. The methodology proposed in the study provides insight into which aspects of the projects need to be improved. For this project, further steps should be taken to improve organizational competence.

Public policy documents are assumed to emphasize the most value-added public investment projects. However, this may not always be the case. It is interesting to observe the differences in ranking between national policies and critical multiplier effects of public investment projects. Alignment with national policies and critical multiplier effects are ranked almost equally across all projects, except for projects 4 and 6. Project 4 scored highest in the alignment with national policies category and lowest in the critical multiplier effect. The project has a high level of political ownership. It has clear benefits on a national scale, but scored low compared to other critical projects on the list. The opposite is true for project 6. Although the critical multiplier effect of the project is very high, it lags in terms of alignment with national policies and political ownership. This characteristic of the proposed methodology is noteworthy as it creates a feedback loop from public investment projects to national policy cycle.

Projects 7, 8, and 9 are not national, but organization-wide projects. It is understandable that such projects score lower than those of national scale, due to their narrower benefit scope. The methodology used should be able to distinguish national scale projects from organization-wide projects in rankings. The highest-scoring organization-wide project has a score of 34.0, while the lowest scoring national scale project is 40.6. The score differences are more pronounced in the critical multiplier effect category. The blurring of the differences in the overall category is due to the fact that the scoring takes into account a wide range of factors. The proposed methodology is not designed as a simple ranking system. The user can focus on each set of criteria and evaluate projects from different perspectives.

Scores (especially those in the institutional capability group) should not be considered final. With insights and feedback on the main risk factors, organizations can improve their projects for better scoring. Thus, our methodology not only provides hints about project rankings, but also helps organizations identify the critical aspects of their projects and the areas that urgently need improvement. An obvious example in our project sample is project 5. Although it aims to address a national need, the lack of organizational competence prevents it from doing so. Once this issue is recognized and quantitatively documented, the institution will be easily guided and motivated to mitigate this risk factor.

Overall, the expert group was satisfied with the criteria, criteria weights and the resulting project rankings. Although both criteria and their weights are subject to change, it was beneficial for experts to observe the projects through different lenses. The project selection process, driven by concrete data and enhanced feedback, met the experts' expectations for the DSS design. The criteria set could be further developed and customized for specific types of projects. For instance, there may be differences between software projects and information system infrastructure projects. While maintaining common criteria, specialized criteria can be applied for different types of projects. The current version of the methodology provides a solid foundation for further improvements.

Similar frameworks have been successfully adapted to different sectors such as transportation (Henriksen & Traynor, 1999) and healthcare (de Souza et al., 2021), demonstrating that the proposed decision support system can meet the needs of various public project environments in other countries as well. This study aligns well with previous studies due to its extensive literature review for criteria. It also improves upon previous work by offering two key advantages. One advantage is that literature review revealed a lack of comprehensive set of hierarchical criteria. This study should be viewed as a first step toward addressing this important gap. Another significant benefit is that the criteria, process, and complementary DSS interface help project evaluation become a living process. This approach has not received significant attention in the literature.

In terms of using DSS, Ghasemzadeh and Archer's (2000) emphasis on the flexibility of methodology choice and sequencing of projects was partly covered by this study. Flexibility of project sequencing with respect to different criteria combinations was found useful by PSB experts. In terms of the flexibility of methodology, including other methods for criteria weighting, scoring, and ranking, and allowing users to choose the methodology is recommended as a development in the DSS. The proposal of Andersen et al. (2009) on a phased planning approach for projects is considered to be fully achieved by this methodology.

Caution should be exercised with the cumulative scores resulting from the weightings and project scores, as both the weighting of criteria and the scoring of projects are inherently subjective. The aim is not to fully eliminate subjectivity, but to provide a method that minimizes it as much as possible. Therefore, it would be more appropriate to consider projects with particularly close scores as having equivalent scores. Conversely, obvious score differences should indeed be considered indicating a meaningful difference.

While we believe we have reduced it to an acceptable level, a certain degree of subjectivity still exists within the criteria groups. Especially in the field of project selection, addressing subjectivity is not easy. Nevertheless, two types of measures were taken. On the one hand, experts were made aware of the remaining subjectivity. On the other hand, coloring was used in DSS interface to display three main categories (green, yellow and red). This approach helped projects to be viewed as a part of broader group, instead of a single ranking order.

Another limitation of the study was the size of the expert group. Since the necessary competencies were only available within the PSB, the study could not be extended to a broader group of experts. Hence, there are certainly areas within the criteria that are open to improvement. It is also important to note that measuring social benefits is directly related to the structure and priorities of the relevant country. The criteria were specifically designed for use by the Turkish Government. In Particular, criteria regarding social benefit naturally reflect Türkiye's political priorities. Needless to say, it is possible to revise the criteria to align with the priorities of other countries.

Eleven projects selected for the sample were few in number, but they clearly stood out in certain aspects. After the methodology is implemented, it is recommended to revise the criteria set and weightings, as new projects are evaluated. The study was conducted specifically for public ICT investment projects, but the methodology has a significant potential for all investment projects. With minor criteria revisions, the methodology can also be adapted for cross-sector comparisons.

One of the key challenges in public ICT investments is ensuring that the benefits of these projects extend well beyond the initial implementation phase. The proposed criteria can be adapted to evaluate the long-term sustainability and social impacts of ICT projects. By incorporating metrics that assess the continued relevance, effectiveness, and efficiency of these projects, decision-makers can ensure that investments provide ongoing value. This long-term impact assessment can include factors such as the scalability of the project, its adaptability to technological advancements, and the persistence of social and economic benefits over time.

While the proposed framework was designed for public ICT projects in Türkiye, its underlying principles can be adapted for use in other sectors and/or countries. The MCDM approach and the criteria used in the AHP and TOPSIS methods can be customized to fit different economic, social, and political contexts. For example, sectors such as healthcare, infrastructure, or education, which also require strategic prioritization of public investments, may benefit from the adaptability of this framework. Furthermore, by adjusting criteria weights to account for different national policies or sector-specific challenges, the framework could serve as a valuable tool for project selection in various environments and for making cross-sector effectiveness comparisons.

DSS was used to support experts in the PSB. A more effective approach may be to make it available for use by the project-owning organizations. In this way, the goal of improving projects according to national objectives will be more easily achieved. After four or five years of application, enough data sets will be obtained. This will create the potential to utilize numerical analysis, data mining, and artificial intelligence methods.

7. Conclusion

Public investments play a fundamental role in public policies. Therefore, the effectiveness of public investments is of critical importance for channeling public policies toward more appropriate areas. It is a well-known fact that public resources are limited. National social welfare strongly depends on how these limited resources are utilized.

In this study, a methodology was developed for evaluation and continuous improvement of public ICT projects, using the AHP and TOPSIS methods. It was observed that the methodology provides adequate objectivity and effectiveness in selecting, prioritizing, and improving projects. The criteria set developed within the scope of the study was shown to be aligned with expert opinions.

The basic philosophy of a DSS is that information systems support the decision-making processes. Hence, the main approach in this study was to help decision makers gain detailed insights into various aspects of projects. A dynamic interface supports experts from this perspective.

Projects involving national security, development of domestic technologies and those addressing a national need are given more prominence and recognition by the methodology. In cases where these projects have significant risks, methodology also gives crucial feedback, enabling the responsible institution to further refine the project to mitigate risks.

The criteria set provides a systematic approach to measure social benefit. However, accurately identifying the criteria for measuring social benefit, assigning the correct weights to them and objectively scoring projects according to these criteria can reduce the margin of error. The methodology proposed in the study was tested on 11 projects. In the future, testing it on a larger sample may enhance both the criteria set and the scoring mechanics.

In conclusion, this research contributes to both the academic and practical realms by providing a robust framework for the evaluation of public ICT projects. Its broader implications include improved resource allocation, more transparent decision-making, and enhanced project success rates in various sectors. By fostering a systematic approach to project evaluation, the framework offers governments and organizations a pathway to maximize the social and economic value of their investments, ultimately leading to more impactful and sustainable public projects.

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References

Amiri, M. P. (2010). Project selection for oil-fields development by using the AHP and fuzzy TOPSIS methods. *Expert Systems with Applications*, *37*(9), 6218–6224. https://doi.org/10.1016/j.eswa.2010.02.103

Andersen, E. S. (1996). Warning: Activity planning is hazardous to your project's health! *International Journal of Project Management*, *14*(2), 89–94. https://doi.org/10.1016/0263-7863(95)00056-9

Andersen, E. S., Grude, K. V., & Haug, T. (2009). *Goal directed project management: Effective techniques and strategies*. Kogan Page Publishers.

Benjamin, C. O. (1985). A Linear Goal-Programming Model for Public-Sector Project Selection. *Journal of the Operational Research Society*, 36(1), 13–23. https://doi.org/10.1057/jors.1985.3

Çelik, Ş G. (2010). *Monitoring and Evaluation of Public Investments: Recommendations for Turkey* [Master's Thesis, In Turkish]. Department of Finance, Institute of Social Sciences, Hacettepe University.

Çetin, V. R. (2019). *Evaluation of the Economic Impact of Public Transport Infrastructure Investment Expenditures and Alternative Financing Methods: A Computable General Equilibrium Analysis for Turkey* [Doctoral Dissertation, In Turkish]. Department of Finance, Institute of Social Sciences, Ankara University.

Chen, C.-T., & Cheng, H.-L. (2009). A comprehensive model for selecting information system project under fuzzy environment. *International Journal of Project Management*, *27*(4), 389–399. https://doi.org/10.1016/j.ijproman.2008.04.001

Chen, S.-J., & Hwang, C.-L. (1992). *Fuzzy Multiple Attribute Decision Making: Methods and Applications*. Springer Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-46768-4

Chen, T. (2010). Integration of AHP and TOPSIS in Decision Making for Collaborative Systems. *Expert Systems with Applications*, *37*(12), 8082–8088. https://doi.org/10.1016/j.eswa.2010.05.017

Chrit, S., Azmani, A., & Azmani, M. (2022). Combining AHP and Topsis to Select Eligible Social and Solidarity Economy Actors for a Call for Grants. *International Journal of Advanced Computer Science and Applications*. https://doi.org/10.14569/IJACSA.2022.0131148

Chu, P.-Y. V., Hsu, Y.-L., & Fehling, M. (1996). A decision support system for project portfolio selection. *Computers in Industry*, *32*(2), 141–149. https://doi.org/10.1016/S0166-3615(96)00067-X

Costantino, F., Di Gravio, G., & Nonino, F. (2015). Project selection in project portfolio management: An artificial neural network model based on critical success factors. *International Journal of Project Management*, *33*(8), 1744–1754. https://doi.org/10.1016/j.ijproman.2015.07.003

de Souza, D. G., dos Santos, E. A., Soma, N. Y., & da Silva, C. E. (2021). MCDM-Based R&D Project Selection: A Systematic Literature Review. *Sustainability*, *13*(21), 1-34. https://doi.org/10.3390/su132111626

Deepta Chopra. (2015). *Political commitment in India's social policy implementation: Shaping the performance of MGNREGA* (Working Paper No. 50; ESID Working Papers). Effective States and Inclusive Development (ESID).

Demireli, E. (2010). TOPSIS Multi-Criteria Decision-Making System: An Application on Public Banks in Turkey [In Turkish]. *Journal of Entrepreneurship and Development*, 5(1), 101–112.

Dong, Y., Liu, Y., Zhang, G., & Yao, T. (2010). Research on the analytic hierarchy process in decision making for selecting. *Management Science Letters*, *2*(5), 849–858. https://doi.org/10.5267/j.msl.2010.0067

State Planning Organization (DPT). (2001). *Eighth Five-Year Development Plan, Specialization Commission Report on Social Services and Assistance* [Specialization Commission Report, in Turkish]. State Planning Organization.

Druzdzel, M. J., & Flynn, R. R. (2002). Decision Support Systems. In A. Kent (Ed.), *Encyclopedia of Library and Information Science* (Second Edition, p. 10). Marcel Dekker.

European Commission. (2014). *Guide to Cost-Benefit Analysis of Investment Projects: Economic Appraisal Tool for Cohesion Policy 2014-2020*. European Commission, Directorate-General for Regional and Urban Policy.

Ghasemzadeh, F., & Archer, N. P. (2000). Project portfolio selection through decision support. *Decision Support Systems*, *29*(1), 73–88. https://doi.org/10.1016/S0167-9236(00)00065-8

Gray, C. F., & Larson, E. W. (2018). *Project management: The managerial process* (Seventh edition). McGraw-Hill Education.

Gunasekaran, A., Love, P. E. D., Rahimi, F., & Miele, R. (2001). A model for investment justification in information technology projects. *International Journal of Information Management*, *21*(5), 349–364. https://doi.org/10.1016/S0268-4012(01)00024-X

Han, B., Zhang, X.-X., & Yi, Y. (2019). Multi-criteria project selection using fuzzy preference relations based AHP and TOPSIS. *2019 Chinese Control and Decision Conference (CCDC)*, 3809–3816. https://doi.org/10.1109/CCDC.2019.8833175

Henriksen, A., & Traynor, A. (1999). A practical R&D project-selection scoring tool. *IEEE Transactions On Engineering Management*, *46*, 158–170. https://doi.org/10.1109/17.759144

Hirschman, A. O. (2015). *Development Projects Observed*. Brookings Institution Press.

Huang, C.-C., Chu, P.-Y., & Chiang, Y.-H. (2008). A fuzzy AHP application in government-sponsored R&D project selection. *A Special Issue Dedicated to the 2008 Beijing Olympic Games*, *36*(6), 1038–1052. https://doi.org/10.1016/j.omega.2006.05.003

Hwang, C.-L., & Yoon, K. (1981). *Multiple Attribute Decision Making: Methods and Applications A State-of-the-Art Survey*. Springer Berlin Heidelberg.

IMF. (2015). *Making Public Investment More Efficient* [Staff Report]. International Monetary Fund.

IMF. (2020). *Well Spent: How Strong Infrastructure Governance Can End Waste in Public Investment*. International Monetary Fund.

IMF. (2022). *PIMA Handbook: Public Investment Management Assessment*. International Monetary Fund.

Ishizaka, A., & Nemery, P. (2013). *Multi-criteria decision analysis: Methods and software*. Wiley.

Jokar, E., Nejad, A., & Lork, A. (2020). Risk prioritization and selection of contractor participating in Public-Private Partnership (PPP) infrastructure project using Hybrid Fuzzy AHP and Fuzzy TOPSIS (Case Study: Saveh-Salafchegan Freeway Project). *Journal of Construction Engineering, Management & Innovation*, *3*(1), 1–16.

Karasakal, E., & Aker, P. (2017). A multicriteria sorting approach based on data envelopment analysis for R&D project selection problem. *Omega*, *73*(C), 79–92. https://doi.org/10.1016/j.omega.2016.12.006

Keil, M., Cule, P. E., Lyytinen, K., & Schmidt, R. C. (1998). A Framework for Identifying Software Project Risks. *Commun. ACM*, *41*(11), 76–83. https://doi.org/10.1145/287831.287843

Kim, J.-H., Fallov, J. A., & Groom, S. (2020). *Public Investment Management Reference Guide*. World Bank Group. https://doi.org/10.1596/978-1-4648-1529-4

Kim, Y., & Chang, H. (2013). A Study on Project Selection Framework for Future ICT Technologies. In *Wireless Personel Communications*. 73(4), 1591–1600. https://doi.org/10.1007/s11277-013-1268-8

Lim, C. S., & Mohamed, M. Z. (1999). Criteria of project success: An exploratory re-examination. *International Journal of Project Management*, *17*(4), 243–248. https://doi.org/10.1016/S0263-7863(98)00040-4

Mahmoodzadeh, S., Shahrabi, J., Pariazar, M., & Zaeri, M.S. (2007). Project selection by using fuzzy AHP and TOPSIS technique. *World Academy of Science, Engineering and Technology*, 1.

Masten, I., & GrdovićGnip, A. (2019). Macroeconomic effects of public investment in South-East Europe. *Journal of Policy Modeling*, 41(6), 1179-1194. https://doi.org/10.1016/j.jpolmod.2019.05.005

McNutt, P. (1999). Public goods and club goods. *Encyclopedia of Law and Economics*, 927–951.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, *63*(2), 81–97.

OECD. (2014). *Recommendation of the Council on Effective Public Investment Across Levels of Government*. Organization for Economic Co-operation and Development (OECD). https://www.oecd.org/regional/regional-policy/Principles-Public-Investment.pdf

OECD. (2016). *Integrity Framework for Public Investment* (OECD Public Governance Reviews). Organization for Economic Co-operation and Development (OECD).

OECD. (2019). *Using Digital Technologies to Improve the Design and Enforcement of Public Policies* (OECD Digital Economy Papers). Organization for Economic Co-operation and Development (OECD).

Project Management Institute (PMI). (2009). *A Guide to the Project Management Body of Knowledge (PMBOK Guide)* [in Turkish]. Project Management Institution of Turkey (PMI TR).

Ragowsky, A., Ahituv, N., & Neumann, S. (1996). Identifying the value and importance of an information system application. *Information & Management*, *31*(2), 89–102. https://doi.org/10.1016/S0378-7206(96)01072-5

Rosen, H. S. (2005). *Public Finance* (7th ed.). McGraw-Hill.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, *15*(3), 234–281. https://doi.org/10.1016/0022-2496(77)90033-5

Saaty, T. L. (1980). *The Analytic Hierarchy Process* (1.). McGraw-Hill.

Presidency of Strategy and Budget (PSB). (2020a). *2021-2023 Investment Program Preparation Guide* [Guide, in Turkish]. Presidency of Strategy and Budget.

Presidency of Strategy and Budget (PSB). (2020b). *Development Plans* [Government Agency Website, in Turkish]. Presidency of Strategy and Budget. http://www.sbb.gov.tr/kalkinma-planlari/

Presidency of Strategy and Budget (PSB). (2020c). *Commercial and Financial Analysis of Public Investment Projects* [Guide, in Turkish]. Presidency of the Republic of Turkey, Strategy and Budget Office, Directorate General of Sectors and Public Investments.

Presidency of Strategy and Budget (PSB). (2022). *Public Information and Communication Technology Investment Principles* [in Turkish]. Presidency of Strategy and Budget.

Presidency of Strategy and Budget (PSB). (2023a). *2024-2026 Investment Program Preparation Guide* [in Turkish]. Presidency of Strategy and Budget.

Presidency of Strategy and Budget (PSB). (2023b). *Public Information and Communication Technology Investments Report (2023)* [in Turkish]. Presidency of the Republic of Turkey, Strategy and Budget Office, Directorate General of Sectors and Public Investments.

Schneider, L., Wech, D., & Wrede, M. (2022). Political alignment and project funding. *International Tax and Public Finance*, *29*(6), 1561–1589. https://doi.org/10.1007/s10797-022-09758-6

Şeker, M. (2019). *Public Finance* [in Turkish]. Istanbul University, Faculty of Open and Distance Education.

Sharma, D., Sridhar, S., & Claudio, D. (2020). Comparison of AHP-TOPSIS and AHP-AHP methods in multi-criteria decision-making problems. *International Journal of Industrial and Systems Engineering*, *34*(2), 203–223. https://doi.org/10.1504/IJISE.2020.105291

Sowlati, T., Paradi, J., & Suld, C. (2005). Information systems project prioritization using data envelopment analysis. *Mathematical and Computer Modelling*, *41*, 1279–1298. https://doi.org/10.1016/j.mcm.2004.08.010

Stillwell, W. G., von Winterfeldt, D., & John, R. S. (1987). Comparing Hierarchical and Nonhierarchical Weighting Methods for Eliciting Multiattribute Value Models. *Management Science*, *33*(4), 442–450. https://doi.org/10.1287/mnsc.33.4.442

Taylan, O., Bafail, A. O., Abdulaal, R. M. S., & Kabli, M. R. (2014). Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. *Applied Soft Computing*, *17*, 105–116. https://doi.org/10.1016/j.asoc.2014.01.003

Tregear, R., & Jenkins, T. (2007). Government Process Management: A review of key differences between the public and private sectors and their influence on the achievement of public sector process management. *BPTrends, October 2007*.

Triantaphyllou, E., Lootsma, F., Pardalos, P., & Mann, S. (1994). On the Evaluation and Application of Different Scales For Quantifying Pairwise Comparisons in Fuzzy Sets. *Journal of Multi-Criteria Decision Analysis*, *3*, 133–155. https://doi.org/10.1002/MCDA.4020030302

Turnpenny, J., Radaelli, C. M., Jordan, A., & Jacob, K. (2009). The Policy and Politics of Policy Appraisal: Emerging Trends and New Directions. *Journal of European Public Policy*, *16*(4), 640–653. https://doi.org/10.1080/13501760902872783

Wallenius, J., Dyer, J. S., Fishburn, P. C., Steuer, R. E., Zionts, S., & Deb, K. (2008). Multiple Criteria Decision Making, Multiattribute Utility Theory: Recent Accomplishments and What Lies Ahead. *Management Science*, *54*(7), 1336–1349. https://doi.org/10.1287/mnsc.1070.0838

Weber, M., Eisenführ, F., & von Winterfeldt, D. (1988). The Effects of Splitting Attributes on Weights in Multiattribute Utility Measurement. *Management Science*, *34*(4), 431–445. https://doi.org/10.1287/mnsc.34.4.431

Yadav, A., & Jayswal, S. C. (2013). Using Geometric Mean Method of Analytical Hierarchy Process for Decision Making in Functional Layout. *International Journal of Engineering Research and Technology*, *2(10)*, 775-779.

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