An MCDM analysis of critical success criteria for medium and large construction projects in Australia and New Zealand

Neda Kiani Mavi, Kerry Brown and Richard Glenn Fulford
School of Business and Law, Edith Cowan University, Joondalup, Australia, and Mark Goh
School of Business and Law, Edith Cowan University, Joondalup, Australia and NUS Business School, National University of Singapore, Singapore

Abstract

Purpose – The global construction industry has a history of poor project success, with evident and frequent overruns in cost and schedule. This industry is a highly interconnected and complex system in which the components, i.e. suppliers, contractors, end-users, and stakeholders, are delicately linked to each other, the community, and the environment. Therefore, defining and measuring project success can be challenging for sponsors, contractors, and the public. To address this issue, this study develops and analyzes a more comprehensive set of success criteria for medium and large construction projects.

Design/methodology/approach – After reviewing the existing literature, this study identified 19 success criteria for medium and large construction projects, which were categorized into five groups. The fuzzy decision-making trial and evaluation laboratory (fuzzy DEMATEL) method was used to gain further insight into the interrelationships between these categories and explain the cause-and-effect relationships among them. Next, this study applied the modified logarithmic least squares method to determine the importance weight of these criteria using the fuzzy analytic hierarchy process.

Findings – 28 project managers working in the construction industries in Australia and New Zealand participated in this study. Results suggest that “project efficiency” and “impacts on the project team” are cause criteria that affect “business success,” “impacts on stakeholders,” and “impacts on end-users.” Effective risk management emerged as the most crucial criterion in project efficiency, while customer satisfaction and return on investment are top criteria in “impacts on end-users” and “business success.”

Originality/value – Although numerous studies have been conducted on project success criteria, multicriteria analyses of success criteria are rare. This paper presents a comprehensive set of success criteria tailored to medium and large construction projects. The aim is to analyze their interrelationships and prioritize them thoroughly, which will aid practitioners in focusing on the most important criteria for achieving higher success rates.

Keywords Project success, Success criteria, Construction industry, Medium and large projects, Project efficiency, Fuzzy DEMATEL, Fuzzy AHP

Paper type Research paper

1. Introduction

The complex nature of construction projects requires effective collaboration among stakeholders to achieve success (Mashali et al., 2022). However, the meaning of “project success” remains unclear (Korhonen et al., 2023). Project success has evolved from a one-dimensional and simplistic concept into a more dynamic, multifaceted, and all-inclusive construct (Ika and Pinto, 2022) because the field of project management has expanded significantly owing to the growing number of companies engaging in projects on both national and international scales (Vaez-Alaei et al., 2024). Overall, project success has two
Recent scholarship in project management assumes several dimensions of project success related to project management (Ika, 2018; Maltzman and Shirley, 2015; Zwikel and Meredith, 2021), greenness (Huang et al., 2022), project deliverables (Ika, 2018), project ownership, and project investment (Zwikael and Meredith, 2021). More recently, by critically synthesizing the existing literature, Ika and Pinto (2022) developed a new model for project success built on four pillars: project plan success (deliberates on project efficiency and effectiveness), business case success (focuses on business and direct success), green efficacy (represents project success in terms of future preparation), and stakeholder success (including impacts on customers and project teams). They referred to the intersection of all success dimensions as the “Holy Grail” of project success, where the project is unquestionably successful.

The construction industry contributes significantly to the economic development and social welfare of societies despite its undesirable impacts on the natural environment (Kiani Mavi and Standing, 2018). Many construction projects, ranging from small to medium and large to mega-scale, are being undertaken worldwide (Chen et al., 2024). McKinsey estimated that to grow the global gross domestic product (GDP) at the expected rate by 2030, infrastructure construction demands over US$57tn investment (Garemo et al., 2015; Wang et al., 2022). Several megaprojects in the construction industry suffer from poor performance in terms of “over budget, over time, under benefits, over and over again” (Flyvbjerg, 2017; Foroutan Mirhosseini et al., 2023). This can be attributed to the frequent misinformation regarding the costs and schedules of these projects. Research shows that railway projects have the highest average cost overrun at 44.7%, and 20.4% for road projects (Flyvbjerg, 2014). In addition, large-scale dam projects take approximately 45% longer than the initial schedule (Ansar et al., 2014). There are many factors behind the substandard performance of medium and large construction projects, such as inadequate capabilities of the owner (Adedokun et al., 2021), highly complicated technology, lack of competency and in-depth knowledge of success criteria and critical success factors (CSFs) (Vora et al., 2024; Wang et al., 2022), and limited use of lessons learned and best practices in megaprojects (Unegbu et al., 2022). Moreover, in addition to technical concerns, managers of large construction projects face several social, political, and cultural challenges to attend (Mashali et al., 2022).

Project success criteria are measures that evaluate project performance, and may be referred to as project performance measures (Unegbu et al., 2022). Atkinson (1999) suggested that project success should be measured according to the “iron triangle”: time, cost, and quality. The major drawback of this framework is its lack of focus on a wide range of project stakeholders, and its focus solely on project deliverables. According to Kerzner (2017), project success results from the implementation of a sound project management methodology that emphasizes careful control of project scope, faster delivery, higher quality of deliverables, and enhanced customer satisfaction through effective information sharing among key stakeholders. Other project success criteria include health and safety, project team satisfaction, meeting customer expectations, and environmental performance (Bhattacharjee et al., 2024; Chan and Chan, 2004; Volden and Welde, 2022). The United Nations and many relevant organizations commonly employ an evaluation model recommended by the OECD Development Assistance Committee (OECD-DAC), which consists of five key criteria (Foroutan Mirhosseini et al., 2023):

1. Relevance: Assessing the necessity and appropriateness of the project.
2. Efficiency: Evaluating the careful use of time and resources.
(3) Effectiveness: Determining the extent to which the project accomplishes its intended objectives.

(4) Other Impacts: Examining additional positive or negative consequences resulting from project implementation.

(5) Sustainability: Gauging the enduring positive impacts beyond the project’s completion.

Given the multiplicity of project success criteria, most of those variables are interrelated and mutually influence each other, making it essential for project managers to understand the dynamics of these interrelations for effective management of project success criteria and allocating and coordinating resources (Çelik and Arslankaya, 2023; Chen et al., 2012). Because medium and large construction projects are strategically important, developing and compiling a more comprehensive set of project success criteria is imperative to accurately evaluate their success. Multicriteria decision-making (MCDM) techniques are frequently used by decision-makers to address complex problems that involve multiple, often conflicting, criteria, facilitating informed decisions (Sheng et al., 2024). By gathering data from multiple experts, MCDM fosters a transparent decision-making process, promotes consensus-building toward final decisions, and mitigates the risk of incorrect choices (Alshahrani et al., 2024). Therefore, MCDM approaches are the most appropriate options for systematically analyzing project success by transforming the subjective judgments of experts into a measurable solution (Mubarik et al., 2021). Using the principles of graph theory, the decision-making trial and evaluation laboratory (DEMATEL) method offers a robust framework for evaluating comprehensive relationships and establishing linkages between components within a system. It considers the causal importance and centrality of each element within a complex system (Sheng et al., 2024). Therefore, by analyzing the interconnections and reciprocal links among project success criteria, DEMATEL facilitates a finer understanding of the relationships among them (Ni et al., 2023; Zheng et al., 2024). Furthermore, it reveals the dynamics of cause and effect and manages cyclic dependencies, guaranteeing a thorough and actionable analysis of complex problems (Aditi et al., 2024) such as project success. In contrast, the analytic hierarchy process (AHP) converts subjective factors conceptually into quantitative variables via mathematical transformations. It establishes a systematic and hierarchical structure to dissect complex decisions into smaller, more manageable components (Alshahrani et al., 2024). This process assists in gauging the relevance and significance of these factors in the context of decision problems (Merhi, 2021). This study combined the DEMATEL and AHP techniques with fuzzy sets to address ambiguity in linguistic variables and enhance the applicability of evaluations provided by decision-making experts (Kuzu, 2023; Wu et al., 2023), consequently, mitigating the biases associated with human judgments (Wu et al., 2023). Therefore, this study employs fuzzy DEMATEL to understand and analyze the interrelations between project success criteria and fuzzy AHP to determine their relative importance and rank them. Specifically, this study answers the following three questions:

1. What are the major success criteria for medium and large construction projects?
2. What are the cause-and-effect relationships among the success criteria in medium and large construction projects using fuzzy DEMATEL?
3. What is the relative importance (weight) of success criteria in medium and large construction projects using fuzzy AHP?

The contribution of this study lies in the establishment of a more comprehensive set of project success criteria for credibly evaluating the success of medium and large construction projects.
projects. In addition, MCDM analysis enables project managers and policymakers to pay more attention to highly important criteria and allocate more resources to accomplish them to enhance overall project success. This analysis also sheds light on the interrelations among the success criteria and their importance in medium and large construction projects.

The remainder of this paper is organized as follows. Section 2 reviews the literature on project success criteria in the construction industry, focusing on medium and large projects. Fuzzy DEMATEL and fuzzy AHP are discussed in Section 3. Section 4 presents a case study and analysis of the findings. Section 5 concludes the study.

2. Literature review

2.1 Success criteria for construction projects

Bygballe et al. (2013) identified four key models of economic logic of construction: (1) transaction cost economics, (2) project orientation, (3) supply chain, and (4) network. The literature on project management is dominated by the project-oriented models, in which an individual construction project is the unit of analysis and the construction industry is considered a set of independent projects (Engwall, 2003). This model assumes that a construction project is a coalition of different firms involved in its successful execution of the project (Vaez-Alaee et al., 2024; Winch, 2006) given the (pre)specified time and financial and technical objectives. This model centers on systematically managing mutual interrelations among members in the project coalition (Winch, 2006).

Characteristics of projects are specific to every project and they should be considered in terms of specific contexts such as stakeholders, operational environment and risks (Cserháti and Szabó, 2014). In addition, projects are unique based on the size and complexity (Alias et al., 2014) of their activities during the project lifecycle. The differences among projects make it difficult to evaluate their success using the common criteria of time, cost, and quality (Mashwama et al., 2017). This difficulty arises from the differing perspectives of stakeholders, each of which prioritizes distinct performance metrics. Despite extensive research on the multidimensional concept of project success, there is no consensus on how to measure project success accurately and reliably (Volden and Welde, 2022). For instance, a project may be viewed as successful by one stakeholder but unsuccessful by another because of such differences. Evaluating project success becomes especially complex when, for example, a project exceeds its budget by 10% but finishes 10% ahead of schedule. In such cases, determining a project’s success becomes subjective (Aboseif and Hanna, 2023). Therefore, it is essential to define project success accurately from a more holistic perspective to provide a common understanding of project success measurements (Chen et al., 2012) and avoid detrimental outcomes for project managers. This study follows the contingency theory of organizations (Donaldson, 2001) to extend the project-oriented model by compiling an all-inclusive set of project success criteria for the construction industry. The contingency theory of organizations can effectively explain organizational structure and performance (Donaldson, 2001). It states that the performance of an organization is contingent on the alignment and fit between the organization and both environmental and internal factors, collectively termed contingencies (Donaldson, 2001; Kaiser et al., 2015).

Often, organizations and their management are unclear about how success should be measured. This can lead to incorrect decisions regarding the project manager’s rewards or punishments. This can lead other project managers to adopt the wrong approaches, which may negatively affect their projects (Ika and Pinto, 2022; Korhonen et al., 2023). Furthermore, without linking success to an organization’s strategic objectives, the definition of success can become vague, with different stakeholders using different criteria to judge success. Strategic partnerships in projects stem from competitive pressures and a growing need for innovation.
Vaez-Alaei et al. (2024) revealed that project complexity, trust between partners, and knowledge compatibility influence project success. When a construction project finishes on schedule, within budget, and in line with predefined specifications, it is deemed successful (Nguyen et al., 2004). However, over time, by recognizing the value and benefits delivered by the project, the accomplishment of strategic objectives of the project stakeholders, such as sponsors and owners (Zwikael and Meredith, 2021), efficiency and effectiveness (Volden, 2018), impacts on the project team, impacts on customers and end users, immediate business success, and extending potential opportunities in the future (Dai Prá Martens et al., 2018) are taken into account. Overall, project success relates to the effectiveness, objectives, and benefits that the project provides to the organization (Dai Prá Martens et al., 2018) and is directly linked to the strategic compatibility of project’s outputs and organizational objectives in terms of new/enhanced products or services (Müller and Turner, 2010; Scheepers et al., 2022). In addition, over the last decade, multiple new criteria have been used to measure the performance of construction projects, such as sustainability, energy-saving/efficiency, carbon reduction (Carvalho and Rabechini Junior, 2015; Kiani Mavi and Standing, 2018), environmental impacts (Maltzman and Shirley, 2015), and compliance with the government regulations/legislations (Carvalho and Rabechini Junior, 2015). The project’s health and safety performance, generation of new knowledge through lessons learned, enhancement of project reputation, improvement in workforce productivity, and enhancing the functionality of project outputs (Amies et al., 2023; Kissi et al., 2019; Wuni et al., 2021) are emerging as recently identified criteria for project success.

Contemporary project success criteria predominantly regard projects mainly as long-term strategic initiatives rather than simply isolated sequences of activities aimed at short-term goals (Ika and Pinto, 2022). Consequently, this study encompasses both efficiency-oriented (short-term project objectives) and effectiveness-oriented (long-term project objectives) measures (Serrador and Turner, 2015), which may originate internally or externally, to assess project success accurately. Therefore, this study delves into additional criteria beyond the traditional list to comprehensively explore overall project success.

Several project success criteria were identified and assembled into Table 9 and organized according to the existing categorization schemes, which shows the project success criteria and their dominant success dimensions. Table A1 in the Supplementary Materials shows the supporting references for each success criterion. The five primary dimensions of project success are described below:

**Project efficiency** is often evaluated based on its time and cost performance, metrics commonly employed to gauge project management success (Foroutan Mirhosseini et al., 2023; Montalbán-Domingo et al., 2024). Given its focus on short-term project objectives, project efficiency also encompasses considerations of quality and technical performance (Sposito et al., 2023).

Organizations are initiating projects intending to maximize the benefits derived from their business endeavors. **Business success** in project management is evaluated according to its contributions to the strategic goals and objectives of the business (Waseem et al., 2024) through criteria such as value-adding and profitability, return on investment, and optimized use of available resources (Chou et al., 2023; Lin et al., 2023).

The **impacts on end users** represent the culmination of a project efforts when its outcomes are not only effectively utilized but also directly benefit the intended end users. These benefits manifest in various forms, such as improved efficiency or effectiveness, ultimately enhancing the end users’ experiences (Siddiquei et al., 2023). This category encompasses criteria such as functionality of the construction projects and fulfilling needs of the end users (Alashwal et al., 2017; Kiani Mavi et al., 2023).

**Stakeholder satisfaction** plays a significant role in achieving success. One or more stakeholder groups may still be unsatisfied even if all KPIs are achieved. One possibility is
that the project manager made judgments based on the dominant stakeholders’ power and authority that were at odds with the objectives of some low-influence stakeholders (Ghanbaripour et al., 2023; Ingle et al., 2023). Hence, very careful managerial efforts are required to undertake proper planning and need analysis at the early stages of a construction project to ensure the project is introduced in line with expected outcomes set by major stakeholders and policymakers (Amies et al., 2023).

**Project team satisfaction** has a profound impact on the success of a project (Vaez-Alaei et al., 2024). As organizations recognize the significance of project teams, they are increasingly forming them to address varying organizational objectives (Oke, 2022b). The team’s capacity to exchange tacit knowledge enhances the project’s agility, particularly in problem-solving, thereby advancing its progress towards meeting deadlines and controlling costs (Ciric Lalic et al., 2022).

### 2.2 Applications of MCDM techniques in construction project management

Several studies incorporate MCDM techniques because they are capable of addressing real-world problems involving multiple criteria for decision-making (Xu et al., 2024). Project success in the construction industry is not an exception. The operational environment of construction projects is uncertain, dynamic, and complex, leading to the emergence of complex interrelations between project performance indicators (Naji et al., 2022), that is, between critical success criteria and critical success factors. This technique has also been successfully utilized to assess the complexity of construction projects, allocate resources, and effectively evaluate project performance (Nguyen et al., 2018). Lai et al. (2022) employed DEMATEL to investigate the interrelations among factors that influence outsourcing decisions in the construction industry. They realized that most outsourcing decisions were made to improve the project cost efficiency. Increasing attention to environmental deprivation by governments and end-users has compelled construction projects to improve sustainability by implementing lean practices. As accurate identification of key enablers is a prerequisite for the successful implementation of lean practices, Dehdasht et al. (2022) integrated DEMATEL and social network analysis (SNA) for this purpose. They found that enhanced teamwork was the most influential factor among 22 drivers. The most evident “effect” of improving leanness is “decreased project cost” (Dehdasht et al., 2022). Rostamnezhad et al. (2020) employed fuzzy DEMATEL along with system dynamics to explore the mutual interrelations among the factors influencing the social sustainability of highway projects. They reported that, to become socially sustainable, projects must significantly reflect community issues and perceptions. Using the same methods to analyze schedule delays, Parchami Jalal and Shoar (2017) reported that client-related factors such as inaccurate feasibility studies for projects and disputes with contractors result in extended delays in construction projects. More recently, Mohandes et al. (2022) analyzed the interrelations among the factors resulting in construction accidents. They suggested that organizational factors, such as inappropriate communication systems and poor risk management strategies, are major causes of accidents at construction sites. AlKheder et al. (2023) utilized fuzzy AHP to analyze the complexity of mega construction projects in Kuwait. Their findings revealed the greater importance of technological complexity compared to organizational, environmental, and cultural complexities. In their study aimed at evaluating multiple locations based on various criteria to determine the optimal site location for installing a solar power plant, Islam et al. (2024) employed a GIS-based AHP methodology. Balsara et al. (2019) utilized both AHP and DEMATEL techniques to analyze the cement manufacturing industry. The findings from AHP highlighted that reducing fuel emissions is the top priority in this sector, followed by process emission reduction and electric energy-related emissions. It is noteworthy that process emission reduction and fuel emission
reduction are grouped as cause factors, while electric energy-related emissions and management mitigation measures are categorized as effect factors.

2.3 Research gap
The imperative for an enhanced and nuanced understanding of project success, which transcends the rudimentary practice of evaluating it based on a limited set of criteria, highlights the absence of a more comprehensive framework encompassing a wide range of success criteria. This acknowledgment underscores the complexity inherent in measuring project success, necessitating a multifaceted and more inclusive approach that accommodates diverse dimensions of project success in terms of its outputs, outcomes, and benefits. Methodologically, this research implements fuzzy DEMATEL, preferred over other MCDM techniques because of its proficiency in analyzing complex interdependencies among decision-making elements (Aditi et al., 2024; Narang et al., 2024), to analyze the interrelationships among critical success criteria for construction projects and determine their cause-and-effect relations. Subsequently, fuzzy AHP is utilized to determine the relative importance of those criteria. This integration enables a thorough analysis of project success by examining both hierarchical relationships (how project success criteria are structured) and causal relationships (how project success criteria influence each other). By employing these techniques, practitioners can attain a deeper insight into project success by pinpointing the most influential criteria, thereby enhancing strategic decision-making. Therefore, the utilization of the developed set of criteria for measuring project success results in more robust outcomes. It is anticipated that this study will support project owners, sponsors, project managers, and other stakeholders in vividly understanding the interrelationships among project success criteria. Such enhanced comprehension will facilitate more objective resource allocation, thereby fostering the improvement of project success.

3. Research methodology
The accurate identification of project success criteria requires careful and extensive analysis of construction projects and the utilization of expert viewpoints. Therefore, this is a MCDM problem that includes many criteria that are not measurable and require expert judgment (Alshahrani et al., 2024). The fuzzy set theory is a popular solution for handling the uncertainty inherent in human judgment (Narang et al., 2024). Utilizing fuzzy set theory enables the integration of unquantifiable, incomplete, non-obtainable, and partially unknown information into the decision model (Kulak and Kahraman, 2005). Project success criteria in the construction industry represent a large-scale decision problem requiring the evaluation of multiple criteria, often assessed subjectively. These criteria are organized hierarchically, highlighting the need for AHP to assign weights by pairwise comparisons (Chen et al., 2019). Although AHP relies on straightforward theoretical principles, its effectiveness in assigning weights to multiple criteria has rendered it a widely favored MCDM technique across various disciplines (Islam et al., 2024). Since DEMATEL does not need all pairwise comparisons, it significantly reduces the complexity of decision operation (Xue et al., 2024). Therefore, integrating AHP with DEMATEL provides a synergetic approach that minimizes the complexity of the problem (Karasan et al., 2022), enhances the understanding of causal relationships and the determination of relative priority weights (Alshahrani et al., 2024), and accurately measures the overall influence of each criterion and group of criteria on others in the decision-making problem, resulting in more robust decision-making outcomes (Chou et al., 2012; Xue et al., 2024). These advantages have made DEMATEL-AHP one of the most successful and highly applicable hybrid MCDM techniques in business and management, providing reliable findings for decision-makers.
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(Karasan et al., 2022). Figure 1 illustrates the methodology used in this study. To guarantee the replicability and reproducibility of the methods outlined in this research, they are explained with step-by-step instructions, including details on data collection approaches, analysis techniques, and any necessary software tools.

3.1 Fuzzy DEMATEL

DEMATEL stands out as a highly effective tool for multi-criteria decision-making. It employs a structural modeling approach to unveil causal relationships among the elements of complex systems (Wu et al., 2023). This method empowers decision-makers to tackle even the most intricated real-life problems by capturing the dyadic connections between criteria and pinpointing influential factors among commonly considered elements (Xue et al., 2024). Fuzzy DEMATEL was conducted following Chou et al. (2012) and Kiani Mavi and Standing (2018).

Step 1: Compose a panel of experts/decision-makers.

Step 2: Identify project success criteria. The project success criteria are outlined in Table 9, having been identified through a two-phase Delphi study (for further details, please refer to Kiani Mavi et al. (2023)).

Step 3. Construct a fuzzy linguistic scale using triangular fuzzy numbers (TFNs). To minimize the potential for errors in human judgments, it is imperative to define linguistic variables. These variables comprise linguistic terms, such as words or sentences, and are denoted by the triangular fuzzy number (TFN) \( \tilde{Z} = (l, m, u) \) on \( X \). Its membership function \( \mu_A(x) \): \( X \rightarrow [0, 1] \) must follow Eq. (1).

\[
\mu_A(x) = \begin{cases} 
\frac{(x - l)}{(m - l)}, & l \leq x \leq m \\
\frac{(u - x)}{(u - m)}, & m \leq x \leq u \\
0, & \text{otherwise}
\end{cases} \tag{1}
\]

Figure 1.
Generic fuzzy DEMATEL-AHP framework for prioritizing critical success criteria in construction projects

Source(s): Authors’ own work
In this study, five linguistic terms are utilized to evaluate the impact of factors on each other, ranging from “Very High” to “No” influence. The fuzzy scales and membership functions of these terms are illustrated in Table 1.

**Step 4: Conduct the fuzzy DEMATEL approach to generate the causal diagram**

**Step 4.1. Collect the assessments of decision-makers**

Let \( i = 1, 2, \ldots, n \) represent the \( n \) evaluation criteria. Construction project managers were requested to compare categories of project success criteria in pairs to establish \( \tilde{Z}_{(1)}, \tilde{Z}_{(2)}, \ldots, \tilde{Z}_{(p)} \). The initial direct-relation fuzzy matrix of decision-maker \( k \), \( \tilde{Z}^{(k)} \), can be determined by Eq. (2):

\[
\tilde{Z}^{(k)} = \begin{bmatrix}
0 & \tilde{Z}^{(k)}_{12} & \cdots & \tilde{Z}^{(k)}_{1n} \\
\tilde{Z}^{(k)}_{21} & 0 & \cdots & \tilde{Z}^{(k)}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{Z}^{(k)}_{n1} & \tilde{Z}^{(k)}_{n2} & \cdots & 0 \\
\end{bmatrix} \\
k = 1, 2, \ldots, p
\]

where \( \tilde{Z}^{(k)}_{ij} = (l^{(k)}_{ij}, m^{(k)}_{ij}, u^{(k)}_{ij}) \).

**Step 4.2. Normalize the direct-relation fuzzy matrix**

\( \tilde{\alpha}^{(k)} \) and \( \beta^{(k)} \) are TFNs where,

\[
\tilde{\alpha}^{(k)} = \sum \tilde{Z}^{(k)} = \left( \sum_{j=1}^{n} l^{(k)}_{ij}, \sum_{j=1}^{n} m^{(k)}_{ij}, \sum_{j=1}^{n} u^{(k)}_{ij} \right) \quad (3)
\]

\[
\beta^{(k)} = \max \left( \sum_{j=1}^{n} u^{(k)}_{ij} \right) \quad 1 \leq i \leq n (4)
\]

Linear scale transformation is a method used to convert the scales of criteria into comparable forms (Chou et al., 2012). By normalizing the initial direct-relation fuzzy matrix, a normalized fuzzy direct-relation matrix \( \tilde{X}^{(k)} \) is generated.

<table>
<thead>
<tr>
<th>Linguistic variable</th>
<th>Influence score</th>
<th>Triangular fuzzy number (TFN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high influence (VH)</td>
<td>4</td>
<td>(0.75, 1.0, 1.0)</td>
</tr>
<tr>
<td>High influence (H)</td>
<td>3</td>
<td>(0.5, 0.75, 1.0)</td>
</tr>
<tr>
<td>Low influence (L)</td>
<td>2</td>
<td>(0.25, 0.5, 0.75)</td>
</tr>
<tr>
<td>Very low influence (VL)</td>
<td>1</td>
<td>(0, 0.25, 0.5)</td>
</tr>
<tr>
<td>No influence (NO)</td>
<td>0</td>
<td>(0, 0, 0)</td>
</tr>
</tbody>
</table>

**Source(s):** Vardopoulos (2019)

Table 1. Fuzzy linguistic variables for the influence of elements.
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\[
\tilde{X}^{(k)} = \begin{bmatrix}
X_{11}^{(k)} & X_{12}^{(k)} & \cdots & X_{1n}^{(k)} \\
X_{21}^{(k)} & X_{22}^{(k)} & \cdots & X_{2n}^{(k)} \\
\vdots & \vdots & \ddots & \vdots \\
X_{n1}^{(k)} & X_{n2}^{(k)} & \cdots & X_{nn}^{(k)} 
\end{bmatrix}; \ k = 1, 2, \ldots, p \tag{5}
\]

where \( \tilde{X}_{ij}^{(k)} = (Z_{ij}^{(k)}/\beta^{(k)}) = ((l_{ij}^{(k)}/\beta^{(k)}), (m_{ij}^{(k)}/\beta^{(k)}), (u_{ij}^{(k)}/\beta^{(k)})). \)

It is assumed that there exists an \( i \) such that \( \sum_{j=1}^{n} u_{ij}^{(k)} < \beta^{(k)}. \) The average matrix, \( \tilde{X} \), is obtained using Eqs. (6-7):

\[
\tilde{X} = \left( \tilde{X}^{(1)} \oplus \tilde{X}^{(2)} \oplus \cdots \oplus \tilde{X}^{(p)} \right) / p \tag{6}
\]

\[
\tilde{X} = \begin{bmatrix}
\tilde{X}_{11} & \tilde{X}_{12} & \cdots & \tilde{X}_{1n} \\
\tilde{X}_{21} & \tilde{X}_{22} & \cdots & \tilde{X}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{X}_{n1} & \tilde{X}_{n2} & \cdots & \tilde{X}_{nn} 
\end{bmatrix} \tag{7}
\]

where \( \tilde{X}_{ij} = (\sum_{k=1}^{p} \tilde{X}_{ij}^{(k)}/p). \)

\textit{Step 4.3. Build and analyze the structural model.} The aim of this step is to derive the fuzzy total-relation matrix, \( \tilde{T} \), using Eqs. (8-10).

\[
\tilde{T} = \lim_{W \to \infty} \left( \tilde{X}^1 + \tilde{X}^2 + \cdots + \tilde{X}^W \right) \tag{8}
\]

\[
\tilde{T} = \begin{bmatrix}
\tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\
\tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nn} 
\end{bmatrix} \tag{9}
\]

where \( \tilde{t}_{ij} = (l'_{ij}, m''_{ij}, u''_{ij}). \)

\begin{align*}
\text{Matrix } [l'_{ij}] &= X_i \times (I - X_i)^{-1} \\
\text{Matrix } [m''_{ij}] &= X_m \times (I - X_m)^{-1} \\
\text{Matrix } [l''_{ij}] &= X_u \times (I - X_u)^{-1} \tag{10}
\end{align*}

\textit{Step 4.4. Produce the causal diagram.} The sum of rows and columns of the total relation fuzzy matrix are denoted by \( D_i \) and \( R_i \), respectively. By combining these vectors, a “Prominence” horizontal axis vector, \( (D_i + R_i) \), is obtained to gauge measures the “importance” of each category of project success criteria. The “Relation”, vertical axis
vector, \((\tilde{D}_i - \tilde{R}_i)\), is derived by subtracting \(\tilde{R}_i\) from \(\tilde{D}_i\), enabling the classification of criteria into cause and effect groups. A positive \((\tilde{D}_i - \tilde{R}_i)\) indicates criterion \(i\) as a cause; while a negative \((\tilde{D}_i - \tilde{R}_i)\) suggests criterion \(i\) as an effect. Subsequently, the causal model is mapped using the set of \((\tilde{D}_i, \tilde{R}_i)\). The fuzzy values of \((\tilde{D}_i + \tilde{R}_i)\) and \((\tilde{D}_i - \tilde{R}_i)\) should be converted into crisp values using Eq. (11).

\[
\tilde{N}_k^{\text{def}} = L + \Delta \times \frac{(m - L)(\Delta + u - m)^2(R - l) + (u - L)^2(\Delta + m - l)^2}{(\Delta + m - l)(\Delta + u - m)^2(R - l) + (u - L)(\Delta + m - l)^2(\Delta + u - m)}
\]

\[L = \min(l_k), R = \max(u_k), \Delta = R - L\]

\[\text{Eq. (11)}\]

### 3.2 Fuzzy AHP

Fuzzy Analytic Hierarchy Process (fuzzy AHP) is a well-established technique that converts qualitative inputs into quantitative values. It is frequently applied to tackle complex multi-criteria decision-making problems, effectively adeptly managing and accommodating the uncertainties inherent in human judgments (Shameem et al., 2020). The subsequent steps outline the procedure for conducting fuzzy AHP.

**Step 1. Gather data through conduction pairwise comparisons using a TFN linguistic scale.** Each expert was tasked with individually compare every pair of project success categories and related criteria. The importance of element \(i\) relative to element \(j\) by each decision-maker \(k\) was denoted as \(\tilde{a}_{ij}^{(k)} = (l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)})\). These comparisons spanned from 1 (absolutely less important) to 9 (absolutely more important), as detailed in Table 2.

**Step 2. Determine the consistency ratio (CR) of all individual matrices.** Independently assessing the consistency of all decision matrices is crucial to ensure the reliability of the resulting weights. Saaty’s method is the most widely used technique for determining the consistency ratio, capable of computing a crisp consistency for all types of fuzzy sets (Liu et al., 2020). For more details on calculating crisp CR, refer to Eskander (2018). By substituting \(m_{ij}^{(k)}\) for \(\tilde{a}_{ij}^{(k)} = (l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)})\) in the decision matrix, the crisp CR becomes a highly reliable proxy for fuzzy CR (Mahmoudzadeh and Bafandeh, 2013).

<table>
<thead>
<tr>
<th>Linguistic term</th>
<th>Fuzzy value</th>
<th>Triangular fuzzy number (TFN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolutely more important</td>
<td>9</td>
<td>(9,9,9)</td>
</tr>
<tr>
<td>Very strongly more important</td>
<td>7</td>
<td>(6,7,8)</td>
</tr>
<tr>
<td>Essentially more important</td>
<td>5</td>
<td>(4,5,6)</td>
</tr>
<tr>
<td>Slightly more important</td>
<td>3</td>
<td>(2,3,4)</td>
</tr>
<tr>
<td>Equally important</td>
<td>1</td>
<td>(1,1,1)</td>
</tr>
<tr>
<td>Slightly less important</td>
<td>(\frac{1}{3})</td>
<td>((\frac{1}{3}), (\frac{1}{3}), (\frac{1}{3}))</td>
</tr>
<tr>
<td>Essentially less important</td>
<td>(\frac{2}{5})</td>
<td>((\frac{2}{5}), (\frac{2}{5}), (\frac{2}{5}))</td>
</tr>
<tr>
<td>Very strongly less important</td>
<td>(\frac{2}{7})</td>
<td>((\frac{2}{7}), (\frac{2}{7}), (\frac{2}{7}))</td>
</tr>
<tr>
<td>Absolutely less important</td>
<td>(\frac{1}{9})</td>
<td>((\frac{1}{9}), (\frac{1}{9}), (\frac{1}{9}))</td>
</tr>
<tr>
<td>Intermediate values between two adjacent judgments</td>
<td>(2, 4, 6, 8, 2^{-1}, 4^{-1}, 6^{-1}, 8^{-1})</td>
<td>Table 2. Linguistic terms and the corresponding triangular fuzzy numbers</td>
</tr>
</tbody>
</table>
Step 3. Aggregate the decision matrices obtained from the panel of construction project managers. The geometric mean (Eq. 13) is used to drive the aggregated decision matrix.

\[
\tilde{A} = [\tilde{a}_{ij}]_{n \times n} : \tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})
\]

in which

\[
l_{ij} = \left( \prod_{k=1}^{K} l_{ij}^{(k)} \right)^{1/K}, m_{ij} = \left( \prod_{k=1}^{K} m_{ij}^{(k)} \right)^{1/K}, u_{ij} = \left( \prod_{k=1}^{K} u_{ij}^{(k)} \right)^{1/K}
\]

Step 4: Determine the priority weights utilizing the Modified Logarithmic Least Square method. This study determines priority weights using the modified logarithmic least-squares method (LSSM). To overcome the drawbacks of other methods such as extent analysis and fuzzy LLSM in providing incorrect weights, Wang et al. (2006) proposed a modified fuzzy LLSM as a constrained nonlinear optimization program (14).

\[
\begin{align*}
\min J = & \sum_{i=1}^{n} \sum_{j=1, j \neq i}^{n} \sum_{k=1}^{S_{ij}} \left[ \left( \ln w_{i}^{l} - \ln w_{j}^{u} - \ln a_{ij}^{(k)} \right)^{2} + \left( \ln w_{i}^{m} - \ln w_{j}^{m} - \ln a_{ij}^{(k)} \right)^{2} \right. \\
& \left. + \left( \ln w_{i}^{u} - \ln w_{j}^{l} - \ln a_{ij}^{(k)} \right)^{2} \right] \\
\text{Subject to:}
\end{align*}
\]

\[
\begin{align*}
w_{i}^{l} + \sum_{j=1, j \neq i}^{n} w_{j}^{u} & \geq 1 \\
w_{i}^{m} + \sum_{j=1, j \neq i}^{n} w_{j}^{l} & \leq 1 \\
\sum_{i=1}^{n} w_{j}^{m} & = 1; i = 1, 2, \ldots, n \\
\sum_{i=1}^{n} (w_{i}^{l} + w_{i}^{u}) & = 2 \\
w_{i}^{m} & \geq w_{i}^{l} \geq w_{i}^{u} > 0
\end{align*}
\]

The optimal solution of program (14) is the normalized fuzzy weights \( \tilde{w}_{i} = (w_{i}^{l}, w_{i}^{m}, w_{i}^{u}) \) for each project success criterion. As the centroid method (center of area, COA) provides more reliable crisp weights (Liu et al., 2020), Eq. (15) was used to transform the fuzzy weights into crisp weights (Hsieh et al., 2004).

\[
w_{i} = \frac{(w_{i}^{m} - w_{i}^{l}) + (w_{i}^{u} - w_{i}^{l})}{3} + w_{i}^{l}
\]
Step 5. Prioritize project success criteria. The evaluated project success criteria are prioritized based on their importance weight. Criteria with higher importance weights will receive higher rankings.

4. Findings and discussion
This study collected data from 28 construction project managers practicing in Australia and New Zealand with over five years of experience in this industry. An anonymous online survey was developed and conducted using Qualtrics in 2021 and 2022. To ensure the questionnaire items were easily understandable and to guarantee both content and construct validity, two academic experts and one practitioner reviewed the survey items. They also confirmed the readability of the questions before data collection commenced. This study established three specific eligibility criteria for participants: (1) being over the age of 18, (2) possessing a minimum of five years of experience in managing construction projects, and (3) having successfully managed at least one medium or large-scale construction project to completion within the past five years. Potential participants were identified through targeted searches on social media platforms like LinkedIn, as well as through the snowball sampling method (Balsara et al., 2019; Sood et al., 2023), ensuring complete participant anonymity via Qualtrics. The demographic information of the participants is presented in Table 3.

Given that fuzzy DEMATEL and fuzzy AHP techniques rely on data provided by experts, a relatively small number of respondents is typically required. Previous studies have employed various expert counts, e.g. three (Vasantha Lakshmi and Udaya Kumara, 2024), five (Aditi et al., 2024; Chen et al., 2019; Dağdır and Özkan, 2024; Sarwar and Bashir, 2024), 10 (Balsara et al., 2019), 11 (Govindan et al., 2020), 12 (Vardopoulos, 2019), 18 (Alzahrani and Khan, 2024), 26 (Kiani Mavi and Standing, 2018), 29 (Feng et al., 2024), and 30 experts (Yadegaridehkordi et al., 2018) to apply fuzzy DEMATEL or fuzzy AHP techniques. This study gathered data from 28 experts, thereby enhancing the validity and credibility of the findings.

The research data were analyzed using MATLAB R2022b. As the number of participants increases, research indicates a decrease in the risk of sampling bias (Volden and Welde, 2022). The consistency ratio (CR) in AHP serves as the standard measure for the reliability of findings, with a threshold of less than 0.1 considered acceptable. In this study, the CR for each pairwise comparison matrix (decision matrix) was initially computed individually. Once it was confirmed that \( CR < 0.10 \) for each decision matrix, they were aggregated to determine the priority weights (Sood et al., 2023) of success criteria. In addition to the CR index, this study implemented an ANOVA test to examine the differences in findings, such as the

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Categories</th>
<th>No. of experts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>9</td>
</tr>
<tr>
<td>Experience (year)</td>
<td>5–10</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>10–15</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>15–20</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Over 20</td>
<td>5</td>
</tr>
<tr>
<td>Job title</td>
<td>Project Manager</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Senior Project Manager</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Project Director</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Project and Program Director</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3. Demographic characteristics of participants

Source(s): Authors’ own work
importance and relations derived from fuzzy DEMATEL, and the priority weights derived from fuzzy AHP, across various respondent groups (Onubi et al., 2022). Obtaining \( p \)-values greater than 0.05 confirmed that there were no significant differences in the findings among the different groups. For example, the results of the ANOVA test for \( D_i + R_i \) for \( C_1 \), conducted according to years of experience, are depicted in Tables 4 and 5. The \( p \)-value of 0.598 confirmed that respondents across various categories of practical experience do not significantly vary in their assessment of the importance of \( C_1 \).

### 4.1 Findings of fuzzy DEMATEL to evaluate project success criteria

Following the fuzzy DEMATEL steps, the normalized aggregated (average) direct-relation fuzzy matrix and fuzzy total relations matrix were obtained, as shown in Table 6.

To distinguish the cause and effect of the project success criteria, \((D_i + R_i)\) and \((D_i - R_i)\) were calculated for each criterion and transformed into crisp values. The results are summarized in Table 7.

The results show that project efficiency \((C_1)\) and impacts on the project team \((C_5)\) are the causes, whereas business success \((C_2)\), impacts on end-users \((C_3)\) and impacts on stakeholders \((C_4)\) are the effects.

Relations over the average value of the defuzzified total relations matrix, 0.867, were considered important for producing the causal diagram. The cause-and-effect relationships among the project success criteria categories in the construction industry are shown in Figure 2.

An array of interdependent and interrelated criteria should be considered when analyzing project success. The value of \( D_i + R_i \) in Table 7 shows that project efficiency \((C_1)\) has the strongest relationship with other project success criteria; therefore, it is the most prominent criterion. \( D_i - R_i \) represents the relationship between the project success criteria. The value for project efficiency \((C_1)\) was 0.179, indicating that this criterion influenced other project success criteria. Project efficiency refers to the meeting of project objectives in terms of the iron triangle (Deep et al., 2022), which has been the focus of research on project success for decades (Jitpaboon et al., 2019). Project success criteria are interconnected, and directly and indirectly influence each other. From Figure 2, it is evident that project efficiency affects all other project success criteria, that is, business success, impacts on end-users, impacts on

<table>
<thead>
<tr>
<th>Groups (Years of experience)</th>
<th>Count</th>
<th>Sum</th>
<th>Average</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>5–10</td>
<td>8</td>
<td>60.8</td>
<td>7.60</td>
<td>0.17</td>
</tr>
<tr>
<td>10–15</td>
<td>12</td>
<td>90.1</td>
<td>7.51</td>
<td>0.19</td>
</tr>
<tr>
<td>15–20</td>
<td>3</td>
<td>21.8</td>
<td>7.27</td>
<td>0.25</td>
</tr>
<tr>
<td>Over 20</td>
<td>5</td>
<td>38.2</td>
<td>7.64</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Source(s): Authors’ own work

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>( p )-value</th>
<th>( F ) Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>0.313</td>
<td>3</td>
<td>0.104</td>
<td>0.634</td>
<td>0.598</td>
<td>3.009</td>
</tr>
<tr>
<td>Within Groups</td>
<td>3.928</td>
<td>24</td>
<td>0.164</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4.241</td>
<td>27</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source(s): Authors’ own work
<table>
<thead>
<tr>
<th>Dimensions</th>
<th>$l_1$</th>
<th>$m_1$</th>
<th>$u_1$</th>
<th>$l_2$</th>
<th>$m_2$</th>
<th>$u_2$</th>
<th>$l_3$</th>
<th>$m_3$</th>
<th>$u_3$</th>
<th>$l_4$</th>
<th>$m_4$</th>
<th>$u_4$</th>
<th>$l_5$</th>
<th>$m_5$</th>
<th>$u_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C1</strong></td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.102</td>
<td>0.169</td>
<td>0.224</td>
<td>0.140</td>
<td>0.207</td>
<td>0.246</td>
<td>0.132</td>
<td>0.199</td>
<td>0.243</td>
<td>0.126</td>
<td>0.192</td>
<td>0.229</td>
</tr>
<tr>
<td><strong>C2</strong></td>
<td>0.108</td>
<td>0.172</td>
<td>0.216</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.102</td>
<td>0.169</td>
<td>0.224</td>
<td>0.134</td>
<td>0.200</td>
<td>0.241</td>
<td>0.106</td>
<td>0.165</td>
<td>0.206</td>
</tr>
<tr>
<td><strong>C3</strong></td>
<td>0.117</td>
<td>0.176</td>
<td>0.212</td>
<td>0.120</td>
<td>0.187</td>
<td>0.237</td>
<td>0.000</td>
<td>0.000</td>
<td>0.099</td>
<td>0.163</td>
<td>0.207</td>
<td>0.133</td>
<td>0.197</td>
<td>0.231</td>
<td></td>
</tr>
<tr>
<td><strong>C4</strong></td>
<td>0.119</td>
<td>0.182</td>
<td>0.223</td>
<td>0.105</td>
<td>0.170</td>
<td>0.216</td>
<td>0.114</td>
<td>0.181</td>
<td>0.226</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.107</td>
<td>0.169</td>
<td>0.214</td>
</tr>
<tr>
<td><strong>C5</strong></td>
<td>0.118</td>
<td>0.185</td>
<td>0.231</td>
<td>0.134</td>
<td>0.201</td>
<td>0.245</td>
<td>0.111</td>
<td>0.175</td>
<td>0.216</td>
<td>0.130</td>
<td>0.196</td>
<td>0.232</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

**Normalized aggregated direct-relations fuzzy matrix ($\bar{X}$)**

**Fuzzy total relations matrix ($\bar{T}$)**

**Source(s):** Authors' own work
stakeholders, and impacts on the project team. However, their influence on project efficiency is not significant, except for the impacts on the project team.

Effective and optimal resource allocation leads to streamlined processes, enhanced project management practices, reduced costs, and improved returns on investment (Larson and Gray, 2021). These factors positively affect stakeholder and end-user satisfaction and retention, improve profitability, and increase growth potential. In addition, timely project completion is crucial for meeting customer expectations and maintaining a competitive edge in the market. This can be achieved through effective project management and sound risk management practices (Akbari Ahmadabadi and Heravi, 2019). Project managers must acknowledge that effective and mature risk management practices can lead to cost reductions and quality improvements, while keeping the project duration unchanged. However, overdoing risk management without improving the approach can prolong the project duration. Therefore, it is crucial for organizations to focus on learning and improving their risk management practices to simultaneously enhance project time, cost, and quality (Heravi and Gholami, 2018).

Implementing effective and efficient project management practices and communicating them to stakeholders and end-users throughout the project lifecycle are essential to avoid unexpected issues such as extended delays or quality problems. This builds trust and confidence in the project and keeps stakeholders informed about the project's progress (Alkilani and Loosemore, 2022). As stakeholders view project success from different angles, their perception of it is critical (Oke, 2022a), and is predominantly affected by project efficiency. In addition, business success in terms of preparation for future and organizational benefits and satisfaction of stakeholders (including end-users) are impacted by project efficiency and how the final product of the project functions and fits the purpose (Ahmad et al., 2022; Joslin and Müller, 2015).

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>$\hat{D}_i + \hat{R}_i$</th>
<th>$\hat{D}_i - \hat{R}_i$</th>
<th>$\hat{R}_i + \hat{D}_i$</th>
<th>$\hat{R}_i - \hat{D}_i$</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>1.821</td>
<td>5.502</td>
<td>18.923</td>
<td>−8.271</td>
<td>0.179</td>
</tr>
<tr>
<td>$C_2$</td>
<td>1.732</td>
<td>5.343</td>
<td>18.791</td>
<td>−8.688</td>
<td>−0.064</td>
</tr>
<tr>
<td>$C_3$</td>
<td>1.779</td>
<td>5.419</td>
<td>18.726</td>
<td>−8.579</td>
<td>−0.024</td>
</tr>
<tr>
<td>$C_4$</td>
<td>1.782</td>
<td>5.429</td>
<td>18.743</td>
<td>−8.710</td>
<td>−0.182</td>
</tr>
<tr>
<td>$C_5$</td>
<td>1.824</td>
<td>5.495</td>
<td>18.760</td>
<td>−8.256</td>
<td>0.107</td>
</tr>
</tbody>
</table>

Table 7. Cause and effect values Source(s): Authors’ own work

Figure 2. Impact relationship map of the project success dimensions Source(s): Authors’ own work
Effective communication with stakeholders and engaging them early in the project help the project team understand and adapt to changing expectations and requirements. This improves project team satisfaction and efficiency by aligning project goals with new requirements, ensuring that stakeholders are satisfied with the project outcome and their needs are met (Liu et al., 2020; Nevstad et al., 2021). However, if stakeholders are not content with a project, they may withhold support, provide negative feedback, or even withdraw entirely. In extreme cases, this may result in delays, cost overruns, and project failures (Pacagnella et al., 2019). Therefore, businesses must prioritize stakeholder satisfaction, as it increases the likelihood of achieving project objectives and sustaining long-term success (Oke, 2022a).

Team members who appreciate and engage tend to be more productive and dedicated to achieving project objectives. Project managers can greatly enhance team engagement by utilizing constructive leadership styles and acknowledging team members’ emotional intelligence and other soft human factors (Shahzad et al., 2023; Zaman et al., 2022). Moreover, Siddiquei et al. (2023) reported that in instances of elevated time pressure within a construction project, temporal leadership plays a crucial role in boosting project success through vigilant monitoring and effective management of the pace of task completion within the team. Integrated teams effectively exchange knowledge, enhance project agility, improve troubleshooting skills, and contribute to project efficiency by tracking project schedules and budgets (Pacagnella et al., 2019). Therefore, projects with integrated teams have a higher chance of success (Agbejule and Lehtineva, 2022; Ciric Lalic et al., 2022). Thus, by following the principles of total quality management and striving for continuous improvement in delivering high-quality project outputs, the project team can significantly contribute to the organization’s profitability and long-term success.

4.2 Findings of fuzzy AHP to weigh project success criteria

To ensure the consistency of the pairwise comparisons in fuzzy AHP, all decision matrices should be evaluated independently. For more details on the calculation of the crisp CR, see (Eskander, 2018). Mahmoudzadeh and Bafandeh (2013) found that when \( m_{ij}^{(k)} \) replaces \( e_{ij}^{(k)} = (l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)}) \) in a decision matrix, a crisp CR is a reliable proxy for a fuzzy CR.

In this study, all pairwise comparisons demonstrated a CR value of less than 0.10, which enabled us to prioritize the criteria. Table 8 presents the aggregated pairwise comparison matrix for success criteria categories. The normalized fuzzy weights (using program 14) and crisp weights (using Eq. 15) are listed in the last four columns of Table 8.

The findings reveal that project efficiency has the highest importance \( (w_1 = 0.265) \), followed by impact on the project team \( (w_5 = 0.230) \) and stakeholders \( (w_4 = 0.193) \). Researchers and project professionals have highlighted the importance of achieving project efficiency as a crucial component of project success (Ahmad et al., 2022; Fortune and White, 2006). Meeting project time goals, cost targets, and scope specifications is widely accepted as the most significant indicator of project success in terms of project management (Ahmad et al., 2022; Fernando et al., 2018). However, evaluating a project’s impact on end-users, the project team, business success, and potential for future collaborations can be more complex (Bond-Barnard et al., 2018; Fernando et al., 2018). Although meeting time, cost, and quality objectives are often considered the primary measures of success and are more visible (Becker et al., 2014), fulfilling project scope specifications—one of the fundamental components of the iron triangle—is critical for the success of construction projects. This is because it improves project efficiency by saving costs, facilitating the realization of expected benefits (Ajmal et al., 2021), and enhancing satisfaction for the project team, stakeholders, and end-users (Larson and Gray, 2021). Research shows that a poorly defined project scope can hinder
Table 8: Aggregated fuzzy decision matrix. A

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>$C_1$</th>
<th>$C_2$</th>
<th>$C_3$</th>
<th>$C_4$</th>
<th>$C_5$</th>
<th>Fuzzy weight</th>
<th>Crisp weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$l_1$</td>
<td>$m_1$</td>
<td>$u_1$</td>
<td>$l_2$</td>
<td>$m_2$</td>
<td>$u_2$</td>
<td>$l_3$</td>
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<td>$C_1$</td>
<td>1.000</td>
<td>1.000</td>
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<td>2.314</td>
<td>1.000</td>
</tr>
<tr>
<td>$C_2$</td>
<td>0.432</td>
<td>0.517</td>
<td>0.629</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>$C_3$</td>
<td>0.826</td>
<td>1.008</td>
<td>1.247</td>
<td>1.007</td>
<td>1.300</td>
<td>1.673</td>
<td>1.000</td>
</tr>
<tr>
<td>$C_4$</td>
<td>0.548</td>
<td>0.676</td>
<td>0.875</td>
<td>1.061</td>
<td>1.354</td>
<td>1.705</td>
<td>1.719</td>
</tr>
<tr>
<td>$C_5$</td>
<td>0.465</td>
<td>0.585</td>
<td>0.800</td>
<td>0.990</td>
<td>1.277</td>
<td>1.619</td>
<td>1.184</td>
</tr>
</tbody>
</table>

Source(s): Authors' own work
project success by causing time and cost overruns, a challenge that over half of construction projects experience (Shehu et al., 2014).

Implementing program (14) and Eq. (15), the normalized fuzzy weights and crisp weights for the criteria within each category were obtained, as shown in Table 9.

Owing to the intricate nature of construction projects, several risk factors impede their success and cause them to fall below acceptable levels (Adedokun et al., 2021). Effective risk management, ranked as the most important efficiency criterion, enables organizations to manage and monitor risks by employing strategies such as resource reallocation. Success criteria related to project efficiency, such as meeting time, cost, and quality objectives and success criteria related to effectiveness, such as stakeholder and project team satisfaction, are directly linked to effective risk management (Oke, 2022a). Therefore, it is prudent for project managers and senior executives to pay ample attention to risk management to optimize the performance of construction projects. With the projectification of businesses, organizations seek to invest in projects that are likely to maximize profitability because of financial limitations (Badewi, 2022; Waseem et al., 2024). In addition to project efficiency and the satisfaction of stakeholders and end users, sponsors also prioritize the functionality of the project product and return on investment. Therefore, the managerial, technical, and financial performance of all parties involved in a construction project is essential to ensure its success. By contrast, schedule delays and cost overruns negatively affect a project’s return on investment (Adedokun and Egbelakin, 2022).

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Critical success criteria</th>
<th>Fuzzy weight $w^f_i$</th>
<th>Crisp weight $w^c_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$: Project efficiency (0.261, 0.266, 0.268)</td>
<td>Meeting budget goals</td>
<td>0.129 0.129 0.129 0.129</td>
<td>0.129 0.129 0.129 0.129</td>
</tr>
<tr>
<td></td>
<td>Meeting time goals</td>
<td>0.144 0.144 0.144 0.144</td>
<td>0.144 0.144 0.144 0.144</td>
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<td></td>
<td>Meeting scope and specifications</td>
<td>0.175 0.175 0.175 0.175</td>
<td>0.175 0.175 0.175 0.175</td>
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<tr>
<td></td>
<td>Technical performance</td>
<td>0.133 0.133 0.133 0.133</td>
<td>0.133 0.133 0.133 0.133</td>
</tr>
<tr>
<td></td>
<td>Efficient project processes</td>
<td>0.197 0.197 0.197 0.197</td>
<td>0.197 0.197 0.197 0.197</td>
</tr>
<tr>
<td></td>
<td>Effective risk management</td>
<td>0.222 0.222 0.222 0.222</td>
<td>0.222 0.222 0.222 0.222</td>
</tr>
<tr>
<td>$C_2$: Business success (0.146, 0.146, 0.146)</td>
<td>Value-adding and profitability</td>
<td>0.189 0.195 0.200 0.195</td>
<td>0.189 0.195 0.200 0.195</td>
</tr>
<tr>
<td></td>
<td>Return on investment</td>
<td>0.214 0.214 0.215 0.215</td>
<td>0.214 0.214 0.215 0.215</td>
</tr>
<tr>
<td></td>
<td>Handing over the final construction</td>
<td>0.200 0.204 0.209 0.204</td>
<td>0.200 0.204 0.209 0.204</td>
</tr>
<tr>
<td></td>
<td>Establishing long-term relations and partnerships</td>
<td>0.217 0.217 0.217 0.217</td>
<td>0.217 0.217 0.217 0.217</td>
</tr>
<tr>
<td></td>
<td>Optimized use of available resources</td>
<td>0.170 0.170 0.170 0.170</td>
<td>0.170 0.170 0.170 0.170</td>
</tr>
<tr>
<td>$C_3$: Impact on end-users (0.163, 0.164, 0.170)</td>
<td>Quality of construction</td>
<td>0.277 0.304 0.330 0.304</td>
<td>0.277 0.304 0.330 0.304</td>
</tr>
<tr>
<td></td>
<td>Functionality</td>
<td>0.182 0.192 0.200 0.191</td>
<td>0.182 0.192 0.200 0.191</td>
</tr>
<tr>
<td></td>
<td>Customer satisfaction</td>
<td>0.326 0.342 0.360 0.342</td>
<td>0.326 0.342 0.360 0.342</td>
</tr>
<tr>
<td></td>
<td>Fulfilling needs</td>
<td>0.162 0.162 0.162 0.162</td>
<td>0.162 0.162 0.162 0.162</td>
</tr>
<tr>
<td>$C_4$: Impact on stakeholders (0.193, 0.193, 0.193)</td>
<td>Stakeholders’ satisfaction</td>
<td>0.469 0.516 0.562 0.516</td>
<td>0.469 0.516 0.562 0.516</td>
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<tr>
<td></td>
<td>Delivering the promised benefits to stakeholders</td>
<td>0.438 0.484 0.531 0.484</td>
<td>0.438 0.484 0.531 0.484</td>
</tr>
<tr>
<td>$C_5$: Impact on the project team (0.230, 0.230, 0.230)</td>
<td>Project team satisfaction</td>
<td>0.382 0.422 0.468 0.424</td>
<td>0.382 0.422 0.468 0.424</td>
</tr>
<tr>
<td></td>
<td>Health and safety (in terms of injuries on site)</td>
<td>0.532 0.578 0.618 0.576</td>
<td>0.532 0.578 0.618 0.576</td>
</tr>
</tbody>
</table>

Source(s): Authors’ own work

Table 9. Fuzzy and crisp weights of criteria
4.3 Theoretical implications
This research significantly adds to the existing body of knowledge on project success by identifying and classifying critical success criteria within the context of medium and large construction projects. While existing literature has touched upon project success, this research offers a more comprehensive synthesis of success criteria, consolidating diverse perspectives. In addition, while many studies have focused on the traditional “golden triangle” of time, cost, and quality as primary success criteria, this research extends previous studies by targeting project managers as key informants. By delving into the nuances of these criteria and assessing their relative importance, this study makes a significant contribution to the existing body of knowledge. The findings underscore the pivotal role of “project efficiency” and its impact on broader outcomes such as “business success”, “stakeholder satisfaction”, and “end-user experiences”. Within the category of project efficiency, effective risk management emerges as the cornerstone criterion. Furthermore, customer satisfaction and return on investment emerge as leading indicators of success in terms of “impacts on end-users”, and “business success”, respectively.

4.4 Practical implications
The emergence and continuation of the coronavirus disease 2019 (COVID-19) have caused supply chain disruptions, inflation, contractor bankruptcies, and additional delays in completing construction projects in Australia, resulting in cost overruns (KPMG, 2023). According to Infrastructure Australia (2021), one of the primary causes of these unexpected delays is the shortage of skilled labor, and it is estimated that the demand for skilled labor will likely reach “unprecedented levels” by 2025. The report warns that labor shortages may peak “at a likely shortfall of 93,000 workers in early 2023 or 48% higher than projected supply”. Given the highly competitive and restricted market, where everyone is in search of skilled and experienced construction laborers and professionals, federal and state governments are recommended to offer professional skills and competency training programs to attract more workforce and reduce the impacts of labor shortages resulting from the COVID-19 pandemic and aging human resources. As part of its economic recovery plan, the Australian government will invest $218bn in infrastructure construction between 2023 and 2027. The Australian Constructors Association (ACA) has designed a tool called Future of Australian Infrastructure Rating (FAIR) to evaluate the performance of government-funded projects against various key indicators such as improved productivity and enhanced innovation (Australian Constructors Association, 2022). This research can help government agencies and policymakers strengthen the FAIR project evaluation system by including the critical success criteria identified in this study. By focusing on productivity, efficiency, innovation, and sustainability and developing an appropriate process to evaluate the success of medium and large construction projects, this research enables contractors to bid for projects that align with their resources. While major construction companies have started adopting artificial intelligence (AI) and automation, their implementation is still in its early stages. The application of AI tools and advanced technologies can aid project managers and decision-makers in enhancing project success by providing detailed project planning and monitoring, leading to more accurate estimates, decreasing time and cost overruns by approximately 10–20%, optimizing the efficiency of resource use, improving safety, foreseeing project risks and estimating their potential impacts, developing project documents and reports, enabling informed decisions, and lowering total construction costs by approximately 10–15% (BacktoBasics, 2022).

Lower efficiency and productivity pose significant challenges for the construction industry, and Australia and New Zealand are no exception to this. The industry’s decentralized structure, coupled with the high complexity of its services and the tendency to operate in silos, results in a significant waste of resources, with Australia alone experiencing...
approximately 30% wastage of effort. If this one-third of the wasted effort can be reduced, Australian residential and non-residential construction output is estimated to increase by over $10bn annually (Australian Construction Industry Forum, 2016). The current approach to infrastructure delivery in Australia fails to meet the demands of a digital future. This inadequacy is primarily due to the lack of integration and collaboration among key players in the sector. To ensure the development of high-quality and high-performance infrastructure assets, systems, and networks, the infrastructure sector, including the construction sector, must be innovative, efficient, and financially robust, as highlighted by Infrastructure Australia (2022).

Considering the present state of the construction industry in Australia, it is evident that substantial reforms are necessary in the way infrastructure projects are planned, procured, operated, delivered, and maintained throughout their lifecycles. To achieve best practices and drive significant improvements in the construction industry, thereby enabling it to deliver the expected values and benefits to end-users, the environment, and the wider community, all participating organizations, including the government, sponsors, suppliers, and contractors, are recommended to take action and collaborate closely to:

1. Improve end-user and stakeholder satisfaction by establishing effective professional relationships to enhance the consistency and quality of construction products, and accelerate their delivery. This can be achieved by carefully selecting the right partners and skillfully managing the complexities of a project at every stage of its lifecycle.

2. Boost project efficiency by investing in and mandating digital technologies, such as building information modeling (BIM) and digital twins, in federal and state construction projects to improve productivity and efficiency and facilitate industry upskilling and innovative delivery techniques.

3. Improve project efficiency by establishing a more resilient and optimized supply chain to mitigate the potential impacts of future disruptions. This can be achieved by integrating equitable risk sharing while ensuring that the best value is delivered to end-users, contractors, and sponsors.

4. Enhance business success through establishing clear information processes that define the requirements of customers, users, and operators to facilitate data-driven decision making and ensure the success of current projects. These processes should provide underlying and standardized frameworks for projects and programs at each stage of their life cycle, enabling efficient management and effective delivery.

5. Make informed decisions and adopt strategies that align with the success of construction projects. It is, therefore, prudent for senior executives to prioritize efforts directed at enhancing labor productivity. This involves not only recruiting project managers with substantial hard skills but also placing emphasis on soft skills.

5. Conclusion
The main objective of this study was to develop a comprehensive list of project success criteria for medium and large construction projects. We identified 19 success criteria and grouped them into five clusters: project efficiency, business success, impact on end users, impact on stakeholders, and impact on project teams. Employing fuzzy DEMATEL to identify their causal relationships, we learned that project efficiency and impact on the project team were the cause criteria, while the rest were the effects. Project efficiency showed
the strongest overall relationship with other criteria, indicating its importance in measuring project success. To accurately and realistically determine the priority weight of the success criteria and overcome the limitations of other methods for computing weights, we used the modified LSSM in fuzzy AHP. We found that project efficiency had the highest weight (0.263), followed by impact on the project team (0.230) and stakeholders (0.193). The findings also revealed the importance of efficient and effective risk management practices, returns on investment, customer satisfaction, stakeholder satisfaction, and the health and safety of team members in each category. To improve the productivity and efficiency of construction projects, we recommend that governments and policymakers undertake industry reforms by investing in and promoting digital technologies, implementing innovative project management approaches, cultivating a strong supplier base, and standardizing the procurement processes and documentation. This study offers valuable information to professionals regarding resource allocation and identifies areas that require more attention. However, several limitations are evident in this study. Firstly, due to the data being sourced from participants in Australia and New Zealand, the findings have greater relevance within the context of construction projects in these regions. Consequently, to enhance the generalizability of findings, future researchers are recommended to adopt a global perspective, facilitating comparative analysis across diverse geographical areas and the formulation of tailored solutions. Secondly, the data collection occurred during the peak of the COVID-19 pandemic, potentially impacting the significance and influence levels of the identified criteria. Thus, it is recommended that researchers conduct similar studies within the construction industry to explore how pandemics and other disruptions can affect project success. Lastly, apart from determining the relative importance weight of critical success criteria through fuzzy AHP, the integration of fuzzy DEMATEL with other MCDM techniques such as total interpretive structural modeling (TISM), can prove effective. This integration can generate a multi-level hierarchical structure for success criteria in the construction industry, revealing both direct and transitive relations in a graphical representation.

References


## Supplementary material

<table>
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<tr>
<th>Dimensions</th>
<th>Critical success criteria</th>
<th>Reference(s)</th>
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</thead>
<tbody>
<tr>
<td>Project efficiency</td>
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<td>Aboseif and Hanna (2023), Amies et al. (2023), Arantes and Ferreira (2021), Castro et al. (2019), He et al. (2021), Ilka and Donnelly (2017), Magxaka et al. (2023), Martens et al. (2018), Radujković et al. (2021), Volden (2018)</td>
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<td></td>
<td>Meeting time goals</td>
<td>Aboseif and Hanna (2023), Amies et al. (2023), Arantes and Ferreira (2021), Castro et al. (2019), He et al. (2021), Ilka and Donnelly (2017), Magxaka et al. (2023), Martens et al. (2018), Radujković et al. (2021), Tariq and Shujaa Safdar Gardezi (2023), Volden (2018)</td>
</tr>
<tr>
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<td>Meeting scope and specifications</td>
<td>Amies et al. (2023), Arantes and Ferreira (2021), Castro et al. (2019), He et al. (2021), Magxaka et al. (2023), Martens et al. (2018), Radujković et al. (2021), Tariq and Shujaa Safdar Gardezi (2023), Volden (2018)</td>
</tr>
<tr>
<td></td>
<td>Technical performance</td>
<td>Amies et al. (2023), Castro et al. (2019), He et al. (2021), Martens et al. (2018), Oke and Aigbavboa (2017)</td>
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<td>Efficient project processes</td>
<td>Aboseif and Hanna (2023), Amies et al. (2023), Carvalho and Rabechini (2017), Fathi and Shrestha (2023), He et al. (2021), Martens et al. (2018), Volden (2018)</td>
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<td>Effective risk management</td>
<td></td>
<td>Ahmadabadi and Heravi (2019), Osei-Kyei and Chan (2017), Sa’d Issa Alkhawaja and Varouqa (2023), Tariq and Shujaa Safdar Gardezi (2023)</td>
</tr>
<tr>
<td>Business success</td>
<td>Value-adding and profitability</td>
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<td>Return on investment</td>
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</tr>
<tr>
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<td>Handing over the final construction</td>
<td>Castro et al. (2019), Khan et al. (2013), Volden (2018), Wang et al. (2022)</td>
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<td></td>
<td>Establishing long-term relations and partnerships</td>
<td>Ahmadabadi and Heravi (2019), He et al. (2021), Osei-Kyei et al. (2017), Wang et al. (2022)</td>
</tr>
<tr>
<td></td>
<td>Optimised use of available resources</td>
<td>Aboseif and Hanna (2023), Amies et al. (2023), Fathi and Shrestha (2023), Radujković et al. (2021), Ribeiro et al. (2013)</td>
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<td>Impact on end-users</td>
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</tr>
</tbody>
</table>

Table A1. Success criteria for the construction projects (continued)


**Corresponding author**
Neda Kiani Mavi can be contacted at: n.kianimavi@ecu.edu.au

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