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CURRENT ISSUES IN METHOD AND PRACTICE

A multicriteria-optimization model for cultural heritage renovation projects and public-private partnerships in the hospitality industry

Madjid Tavana [a,b], Abdolreza Azadmanesh[c], Arash Khalili Nasr[d] and Hassan Mina[e]

[a]Business Systems and Analytics Department, Distinguished Chair of Business Analytics, La Salle University, Philadelphia, PA, United States; [b]Business Information Systems Department, Faculty of Business Administration and Economics, University of Paderborn, Paderborn, Germany; [c]Department of Industrial Engineering, University of Eyvanekey, Eyvanekey, Iran; [d]Graduate School of Management and Economics, Sharif University of Technology, Tehran, Iran; [e]China Institute of FTZ Supply Chain, Shanghai Maritime University, Shanghai, China

ABSTRACT
The tourism and hospitality industry significantly impacts socio-economic development and cultural growth in developing countries. This study develops an integrated multicriteria decision-making and optimization model for partner selection in public-private partnership (PPP) projects in the hospitality industry. The proposed model uses a weighted influence non-linear gauge system to evaluate the partners. A multi-objective optimization model is then utilized to select a partner for each PPP project using a linear programming metric solution approach. A case study demonstrates the applicability of the proposed model in a PPP project in Iran to renovate and convert historic houses into hotels for the hospitality industry.

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1. Introduction

A public-private partnership (PPP) is a business arrangement between a private entity and a government agency where the government makes a public asset or service available to the private entity. The private entity agrees to take on the risks and management responsibilities in exchange for compensation linked to performance. In a PPP arrangement, the public sector shares its project(s) with the private sector due to a lack of financial resources and expertise or abilities to manage risks (Liu & Wei, 2018). These projects, which are often long-term, have the public sector as the owner of the project and the private sector as the contractor. The revenue obtained from the projects is divided between the public agency and the private partner on a pre-arranged contract. There is a considerable amount of research on PPPs. However, the literature on their use in the renovation and conservation of cultural heritage is limited and very little has been written about the economic impacts and benefits of PPPs on the renovation and conservation of cultural heritage (Macdonald & Cheong, 2014). The PPP initiatives have been successfully utilized for the renovation and conservation of cultural heritage projects worldwide, including the Brooke Army Medical Center in San Antonio (United States), Grainger Towne in Newcastle upon Tyne (United Kingdom), Quarantine Station in Sydney (Australia), Nottingham Lace Market in Nottingham (United Kingdome), General Post Office in Washington (United States), Presidio of San Francisco in San Francisco (United States), Walsh Bay in Sydney (Australia), Prince Henry at Little Bay in Sydney (Australia), and Sydney Harbour in Sydney (Australia) (Macdonald & Cheong, 2014).

CONTACT Madjid Tavana tavana@lasalle.edu
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A review of the literature shows that the PPP initiatives are widely implemented and documented in developed countries; however, their application and documentation are limited in developing countries, especially in the tourism sector of the economy. Governments face significant challenges in renovating and conserving cultural heritage buildings and properties due to the lack of required expertise and resources (Morkūnaitė et al., 2017; Morkunaite, Bausys, et al., 2019; Morkunaite, Podvezko, et al., 2019). For example, Morkunaite, Bausys, et al. (2019a) have Applied a combination of multicriteria decision-making (MCDM) methods for selecting partners to renovate cultural heritage buildings in Italy and Lithuania. Similarly, Morkunaite, Podvezko, et al. (2019b) presented an approach based on the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) technique for evaluating contractors to allocate the cultural heritage buildings in Lithuania. Selecting the most suitable partners in the PPP projects is a complex and multi-faced problem involving multiple and often conflicting criteria. MCDM methods are often used for partner selection in PPPs. The process of choosing the most suitable partners is inherently complex and involves multiple and often interdependent criteria. We propose an integrated MCDM and optimization method for partner selection in PPP projects in the hospitality industry.

One of the advantages of integrating the MCDM method and mathematical programming model in partner selection problems is that the selection process is based on qualitative and quantitative criteria. The partners are often initially evaluated using MCDM methods with qualitative criteria and scores. Then the best partners are selected using mathematical methods with quantitative scores considering several constraints. A large number of MCDM methods have been proposed in the literature. A review of the literature shows that the analytic hierarchy process (AHP) and best-worst method (BWM) are among the most widely used MCDM methods (Singh & Pant, 2021). However, AHP and BWM are not suitable for problems exhibiting interdependencies among the evaluation criteria (Wang & Niu, 2019). Methods grounded in structural modeling are usually recommended for problems with interdependencies (Fontela & Gabus, 1976). The decision-making trial and evaluation laboratory (DEMATEL) is one of the most popular structural modeling methods in MCDM (Kazancoglu et al., 2018). However, a major disadvantage of this method is ignoring the strength of criteria in the weighting process (Michnik, 2013). Previous studies have applied a combination of the DEMATEL method with other methods such as AHP and BWM to overcome this weakness (Ortiz-Barrios et al., 2020; Yazdi et al., 2020). Furthermore, the large number of pairwise comparisons in weighting methods such as AHP has always been a concern of decision-makers. As the number of pairwise comparisons increases, the decision-makers ofter demonstrate fatigue, resulting in inconsistencies in the decision-making process. The integration of the results in these models has also been a problem in MCDM. In response, this study employs the weighted influence non-linear gauge system (WINGS) method to evaluate partners. The WINGS method considers both the strength and influence intensity of the evaluation criteria simultaneously. WINGS can be implemented in hierarchical networks with intertwined components (i.e. criteria, sub-criteria, and alternatives). In addition, because the WINGS method is not based on pairwise comparisons, a large number of criteria do not affect its performance.

A multi-objective optimization model is then used to select the most suitable partner for each PPP project using a linear programming (LP) metric solution approach. A case study demonstrates the applicability of the proposed model in a PPP project in Iran to renovate and convert historic houses into hotels for the hospitality industry. The remainder of this paper is organized as follows. In Section 2, we review the relevant literature. In Section 3, we present the MCDM-optimization method proposed in this study. In Section 4, we present a case study to demonstrate the applicability of the method proposed in this study. Sections 5 and 6 are assigned to sensitivity analysis, discussion, and managerial implications. In Section 7, we conclude with our conclusions.

2. Literature review

MCDM is one of the most widely used methods for partner selection (Wu & Barnes, 2011; Jamshidi et al., 2019). Liu et al. (2018) developed an approach based on the technique of order preference similarity to the ideal solution (TOPSIS) for selecting partners in PPP projects. Venkatesh et al. (2019) proposed a hybrid approach with the AHP and fuzzy TOPSIS for partner selection in humanitarian supply chains. They calculated the weights of criteria with fuzzy AHP and ranked the partners using fuzzy TOPSIS. An MCDM-based approach was applied to select the most suitable recycling partners in the electronics industry (Kumar & Dixit, 2019). They calculated the weight of criteria using fuzzy AHP and ranked the partners with the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) technique. Govindan et al. (2019) developed a novel MCDM-based framework for partner selection to achieve sustainability in reverse logistics. They used the complex proportional assessment (COPRAS) method to evaluate attributes and the BWM for ranking selected attributes. By combining the BWM and VIKOR techniques, an efficient framework for sustainable partner selection was suggested by Garg and Sharma (2020). They used the BWM to weigh the criteria and prioritized partners with VIKOR. Similarly, Rani et al. (2020a) presented an efficient approach based on extended fuzzy TOPSIS for sustainable partner selection. A hybrid approach based on fuzzy AHP and fuzzy TOPSIS was developed by Musumba and Wario (2020) to filter out the inefficient partners and select suitable partners in virtual enterprises. In their proposed approach, criteria weights were determined by fuzzy AHP, and the partners were filtered using fuzzy TOPSIS.

MCDM methods are divided into two categories based on decision space, including multiple attribute decision-making (MADM) and multiple objective decision-making (MODM) (Korhonen et al., 1992; Chowdhury & Paul, 2020). MODM methods are applied to solve MCDM problems whose decision space is continuous and use the mathematical model to select the best alternative(s). But MADM methods select/rank alternatives in discrete decision space (Bozorg-Haddad et al., 2021). MADM methods are often used to overcome decision problems in management and evaluation areas (Zolghadr-Asli et al., 2021). Many researchers have employed MADM methods in various fields such as healthcare (Fei et al., 2020; Stević et al., 2020), energy (Solangi et al., 2019; Rani et al., 2020b), supplier selection (Kannan et al., 2020; Mina et al., 2021), blockchain technology (Farooque et al., 2020), hospitality (Tavana et al., 2020b), etc., which indicates the popularity and efficiency of these methods. The AHP is the most popular and widely used MADM method, first introduced by Saaty (1980). This method is used in problems with a hierarchical structure and in which criteria and alternatives are independent. If we are dealing with intertwined criteria, it will be helpful to use methods such as the analytical network process (ANP) and DEMATEL. The ANP is a generalization of the AHP that considers complex interdependencies between the criteria in a hierarchical structure (Saaty, 1996). DEMATEL is also a structural model that uses a graph to visualize causal relationships, with arrows representing the direction of influence and numbers at the nodes representing the influence intensity (Fontela & Gabus, 1976).

Michnik (2013) developed a novel structural method inspired by the DEMATEL technique called weighted influence non-linear gauge system (WINGS). This method has a similar structure to DEMATEL, except that in DEMATEL, only the influence intensity of factors is considered. However, the WINGS method uses the strength of factors in addition to the influence intensities. Therefore, WINGS has higher accuracy than DEMATEL. This method can be easily implemented in hierarchical problems. One of this method's features is that many factors and their intertwined relationships do not lead to an increase in computational complexity in this method. A review of the literature shows that this method has been applied in various fields such as project selection (Michnik, 2018), telecommunication industry (Banaś & Michnik, 2019), reverse logistics (Kaviani et al., 2020), urban planning (Adamus-Matuszyńska et al., 2019; Wang et al., 2021), cultural heritage (Radziszewska-Zielina & Śladowski, 2017; Fedorczak-Cisak et al., 2020), and healthcare (Michnik & Grabowski, 2020). This method can have a unique function in MCDM problems with discrete decision space due to its unique features.

Although MADM methods perform well in solving decision-making problems in discrete space, they are ineffective in dealing with problems that are a combination of continuous and discrete spaces (Lei et al., 2020; Mostafaeipour et al., 2020; Tavana et al., 2021). For this purpose, combining MADM methods with a mathematical programming model can be an excellent solution to overcome this problem (Govindan et al., 2020). In this type of problem, the evaluation or selection process is performed using MADM methods, and the result obtained from this evaluation is used as a parameter in the mathematical model. Finally, by implementing the model, optimal decisions are obtained. Many researchers in various fields have used a combination of MADM methods and mathematical models, some of which are given here. In project selection, Tavana et al. (2020a) proposed a hybrid fuzzy TOPSIS and a bi-objective mathematical model. They used a bi-objective model and validated the effectiveness of their approach using data from a cybersecurity industry. The combination of MADM methods with the mathematical model has received much attention in the supplier selection problem. Hamdan and Cheaitou (2017) combined AHP, fuzzy TOPSIS, and a multi-objective model to develop an efficient approach to supplier selection and order allocation. Similarly, a hybrid approach consisting of fuzzy AHP, fuzzy TOPSIS, and a multi-objective model for supplier selection problems was developed by Mohammed et al. (2019). Nasr et al. (2021) also presented a hybrid BWM and multi-objective model for sustainable supplier selection in closed-loop supply chains. Wu et al. (2009), Prakash and Barua (2016), and Tosarkani and Amin (2018) have combined MADM with mathematical modeling and optimization to solve partner selection problems. Although the combination of MADM methods with mathematical programming models is a well-known combination in the literature, there is still a significant research gap in applying this combination in various fields. Hence, this is the first study to use a combination of MADM methods and mathematical programming models for partner selection in cultural heritage renovation PPPs. In addition, this is the first paper to combine the WINGS method with the mathematical programming model. In general, the contributions of this paper can be expressed as follows:

- Developing a novel hybrid approach based on WINGS method and multi-objective mathematical programming model for partner selection in cultural heritage renovation PPPs.
- Validating the proposed approach with a PPP initiative at the Ministry of Cultural Heritage, Tourism, and Handicrafts (MCTH) in Iran.

3. Proposed approach

The tourism and hospitality industry significantly impacts economic, social, and cultural growth in developing countries. Many countries, especially those with rich cultural heritage and historical attractions, consider tourism an effective strategy to grow their economy. Iran is a tourism hub in the Middle East due to its geographical location, ancient civilization, rich culture, and numerous attractions. The Iranian economy is set to get a boost from the lifting of the sanctions, and the tourism and hospitality industry in Iran is expected to play a significant role in its economic growth over the next decade. The MCTH in Iran has launched a PPP project to renovate and convert historical houses into hotels for the tourism and hospitality industry. This project is expected to create jobs, promote economic development and neighborhood revitalization by transforming aging neighborhoods into vibrant communities that attract tourism, new business, and foreign investment. To successfully execute this plan, the Iranian government needs to attract money and expertise through PPPs. This study presents a two-stage multicriteria decision-making and optimization model to select qualified partners to renovate and convert historic houses into hotels for the hospitality industry. Table 1 presents the partner evaluation factors extracted from the literature for this study.

The proposed model first evaluates potential partners using WINGS (Michnik, 2013) in Stage 1 and then assigns a partner to each PPP project with an optimization model in Stage 2 as follows:

Stage 1: Partner evaluation with multicriteria decision making and WINGS

Step 1.1: In this step, the partner evaluation criteria are extracted from expert opinions and related literature. A brainstorming method is used to extract and classify the critical criteria in evaluating the partners. We then assign a limited number of criteria to each expert based on the expert's expertise to limit the number of pairwise comparisons and avoid mental fatigue among expert decision-makers.

Table 1. Partner evaluation factors extracted from literature.

Factors	Juan et al. (2009)	Cheng and Kang (2012)	Nieto-Morote and Ruz-Vila (2012)	Enshassi et al. (2013)	Vahdani et al. (2013)	Ulubeyli and Kazaz (2016)	de Araújo et al. (2016)	Abbasianjahromi et al. (2016)	Semaan and Salem (2017)	Hasnain et al. (2018)	Taylan et al. (2018)	Rao et al. (2018)	El-khalek et al. (2019)	Kasabreh and Tarawneh (2019)	El-Sayegh et al. (2019)
Quality	*			*		*	*			*		*	*	*	
Track record for completion to acceptable quality		*													
Service	*														
Reputation			*	*	*	*			*		*				
Past performance			*	*		*			*	*		*	*	*	
Litigation history						*									
Past relationships			*			*	*						*	*	
The magnitude of claims and disputes in past projects		*													
Occupational health and safety			*	*	*					*	*				
Safety records						*								*	
Risk								*					*		
Reliability						*									
Information	*														
Integration	*														
Financial management competency		*													
Financial stability			*		*	*	*				*	*	*		*
Financial evaluation				*											
Track record for completion on budget		*												*	
Bid estimate									*						
Amount of compensation for the delay						*									
Completeness of bid documents				*											
Cost	*					*		*		*			*	*	*
Technical expertise		*													
Technical capacity			*												
Technical resources					*	*					*		*		*
Equipment						*						*			

(*Continued*)

Table 1. Continued.

Factors	Juan et al. (2009)	Cheng and Kang (2012)	Nieto-Morote and Ruz-Vila (2012)	Enshassi et al. (2013)	Vahdani et al. (2013)	Ulubeyli and Kazaz (2016)	de Araújo et al. (2016)	Abbasianjahromi et al. (2016)	Semaan and Salem (2017)	Hasnain et al. (2018)	Taylan et al. (2018)	Rao et al. (2018)	El-khalek et al. (2019)	Kasabreh and Tarawneh (2019)	El-Sayegh et al. (2019)
Plant and equipment resources				*								*			
Adequacy of plant and equipment		*												*	
Track record for on-time completion		*													
Time							*	*							*
Workload						*								*	
On-time delivery														*	
Schedule	*											*		*	
Commitment to sustainability															*
Environmental considerations															*
Socio-economic scope															*
Management abilities of key personnel		*													
Management ability			*		*		*				*		*		
Labor productivity and improvement														*	
Personnel							*								
Staffing level		*											*	*	
Experience			*	*		*		*	*			*	*	*	*
Selfless attitudes						*									
Ability to solve problems						*									
Enthusiasm for the project						*									
Contractor site management/ execution				*											
Knowledge of project						*						*	*		
Level of communication						*									
Project control										*					*
Creativity and innovation													*		
Motivation														*	

Step 1.2: In this step, experts depict the interdependencies schematically by specifying the dependencies between:

- sub-criteria and criteria, and
- sub-criteria and alternatives.

Step 1.3: In this step, experts are asked to determine the influence intensity of criteria on each other, influence intensity of sub-criteria on criteria, and influence intensity of alternatives on sub-criteria using the fuzzy linguistic scale (Michnik, 2013) presented in Table 2.

Step 1.4: In this step, we construct a $n \times n$ matrix called direct strength-influence matrix (M), where n is the sum of the number of criteria, sub-criteria, and alternatives (assume that c represents the number of criteria and s represents the total number of sub-criteria).

$$
M=[m_{ij}]=\begin{array}{c}
\begin{array}{ccc} \quad\textit{criteria}\quad & \quad\textit{sub}-\textit{criteria}\quad & \quad\textit{alternatives}\quad \end{array} \\
\left[\begin{array}{ccc}
\boxed{\begin{matrix} m_{11} & \cdots & m_{1c} \\ \vdots & \ddots & \vdots \\ m_{c1} & \cdots & m_{cc} \end{matrix}} &
\boxed{\begin{matrix} m_{1(c+1)} & \cdots & m_{1(c+s)} \\ \vdots & \ddots & \vdots \\ m_{c(c+1)} & \cdots & m_{c(c+s)} \end{matrix}} &
\boxed{\begin{matrix} m_{1(c+s+1)} & \cdots & m_{1n} \\ \vdots & \ddots & \vdots \\ m_{c(c+s+1)} & \cdots & m_{cn} \end{matrix}} \\
\boxed{\begin{matrix} m_{(c+1)1} & \cdots & m_{(c+1)c} \\ \vdots & \ddots & \vdots \\ m_{(c+s)1} & \cdots & m_{(c+s)c} \end{matrix}} &
\boxed{\begin{matrix} m_{(c+1)(c+1)} & \cdots & m_{(c+1)(c+s)} \\ \vdots & \ddots & \vdots \\ m_{(c+s)(c+1)} & \cdots & m_{(c+s)(c+s)} \end{matrix}} &
\boxed{\begin{matrix} m_{(c+1)(c+s+1)} & \cdots & m_{(c+1)n} \\ \vdots & \ddots & \vdots \\ m_{(c+s)(c+s+1)} & \cdots & m_{(c+s)n} \end{matrix}} \\
\boxed{\begin{matrix} m_{(c+s+1)1} & \cdots & m_{(c+s+1)c} \\ \vdots & \ddots & \vdots \\ m_{n1} & \cdots & m_{nc} \end{matrix}} &
\boxed{\begin{matrix} m_{(c+s+1)(c+1)} & \cdots & m_{(c+s+1)(c+s)} \\ \vdots & \ddots & \vdots \\ m_{n(c+1)} & \cdots & m_{n(c+s)} \end{matrix}} &
\boxed{\begin{matrix} m_{(c+s+1)(c+s+1)} & \cdots & m_{(c+s+1)n} \\ \vdots & \ddots & \vdots \\ m_{n(c+s+1)} & \cdots & m_{nn} \end{matrix}}
\end{array}\right]
\end{array}
\begin{array}{l} \textit{criteria} \\[3em] \textit{sub}-\textit{criteria} \\[3em] \textit{alternatives} \end{array}
\tag{1}
$$

In this matrix, the strength of factors is placed on the main diameter, and the influence intensity of the items (criteria, sub-criteria, and alternatives) is placed on the corresponding element. For example, m_{c1} indicates the influence intensity of the last criterion on criterion 1. Also, $m_{(c+1)1}$ shows the influence intensity of sub-criterion 1 on criterion 1. The influence intensity of alternative 1 on sub-criteria 1 is represented by $m_{(c+s+1)(c+1)}$.

Step 1.5: In this step, matrix M is normalized using Eq. (2).

$$
N=[n_{ij}]=\frac{1}{s}M=\left[\frac{m_{ij}}{s}\right]
$$

$$
N=\begin{array}{c}
\begin{array}{ccc} \quad\textit{criteria}\quad & \quad\textit{sub}-\textit{criteria}\quad & \quad\textit{alternatives}\quad \end{array} \\
\left[\begin{array}{ccc}
\boxed{\begin{matrix} \frac{m_{11}}{s} & \cdots & \frac{m_{1c}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{c1}}{s} & \cdots & \frac{m_{cc}}{s} \end{matrix}} &
\boxed{\begin{matrix} \frac{m_{1(c+1)}}{s} & \cdots & \frac{m_{1(c+s)}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{c(c+1)}}{s} & \cdots & \frac{m_{c(c+s)}}{s} \end{matrix}} &
\boxed{\begin{matrix} \frac{m_{1(c+s+1)}}{s} & \cdots & \frac{m_{1n}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{c(c+s+1)}}{s} & \cdots & \frac{m_{cn}}{s} \end{matrix}} \\
\boxed{\begin{matrix} \frac{m_{(c+1)1}}{s} & \cdots & \frac{m_{(c+1)c}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{(c+s)1}}{s} & \cdots & \frac{m_{(c+s)c}}{s} \end{matrix}} &
\boxed{\begin{matrix} \frac{m_{(c+1)(c+1)}}{s} & \cdots & \frac{m_{(c+1)(c+s)}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{(c+s)(c+1)}}{s} & \cdots & \frac{m_{(c+s)(c+s)}}{s} \end{matrix}} &
\boxed{\begin{matrix} \frac{m_{(c+1)(c+s+1)}}{s} & \cdots & \frac{m_{(c+1)n}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{(c+s)(c+s+1)}}{s} & \cdots & \frac{m_{(c+s)n}}{s} \end{matrix}} \\
\boxed{\begin{matrix} \frac{m_{(c+s+1)1}}{s} & \cdots & \frac{m_{(c+s+1)c}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{n1}}{s} & \cdots & \frac{m_{nc}}{s} \end{matrix}} &
\boxed{\begin{matrix} \frac{m_{(c+s+1)(c+1)}}{s} & \cdots & \frac{m_{(c+s+1)(c+s)}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{n(c+1)}}{s} & \cdots & \frac{m_{n(c+s)}}{s} \end{matrix}} &
\boxed{\begin{matrix} \frac{m_{(c+s+1)(c+s+1)}}{s} & \cdots & \frac{m_{(c+s+1)n}}{s} \\ \vdots & \ddots & \vdots \\ \frac{m_{n(c+s+1)}}{s} & \cdots & \frac{m_{nn}}{s} \end{matrix}}
\end{array}\right]
\end{array}
\begin{array}{l} \textit{criteria} \\[3em] \textit{sub}-\textit{criteria} \\[3em] \textit{alternatives} \end{array}
\tag{2a}
$$

$$
s=\sum_{i=1}^{n}\sum_{j=1}^{n} m_{ij}
$$

Table 2. The fuzzy linguistic scale (Michnik, 2013).

Linguistic terms		
Strength	Influence	Score
No strength	No influence	0
Very low strength	Very low influence	1
Low strength	Low influence	2
High strength	High influence	3
Very high strength	Very high influence	4

Step 1.6: In this step, the total strength-influence matrix (T) is calculated using Eq. (3).

$$T = [t_{ij}] = \frac{N}{I - N}$$

$$\begin{array}{cl}
\qquad\qquad \begin{array}{ccc} \qquad\quad \textit{criteria} \qquad\qquad & \qquad \textit{sub} - \textit{criteria} \qquad\qquad & \qquad \textit{alternatives} \end{array} & \\
T = [t_{ij}] = \left[\begin{array}{ccc}
\boxed{\begin{matrix} t_{11} & \cdots & t_{1c} \\ \vdots & \ddots & \vdots \\ t_{c1} & \cdots & t_{cc} \end{matrix}} &
\boxed{\begin{matrix} t_{1(c+1)} & \cdots & t_{1(c+s)} \\ \vdots & \ddots & \vdots \\ t_{c(c+1)} & \cdots & t_{c(c+s)} \end{matrix}} &
\boxed{\begin{matrix} t_{1(c+s+1)} & \cdots & t_{1n} \\ \vdots & \ddots & \vdots \\ t_{c(c+s+1)} & \cdots & t_{cn} \end{matrix}} \\
\boxed{\begin{matrix} t_{(c+1)1} & \cdots & t_{(c+1)c} \\ \vdots & \ddots & \vdots \\ t_{(c+s)1} & \cdots & t_{(c+s)c} \end{matrix}} &
\boxed{\begin{matrix} t_{(c+1)(c+1)} & \cdots & t_{(c+1)(c+s)} \\ \vdots & \ddots & \vdots \\ t_{(c+s)(c+1)} & \cdots & t_{(c+s)(c+s)} \end{matrix}} &
\boxed{\begin{matrix} t_{(c+1)(c+s+1)} & \cdots & t_{(c+1)n} \\ \vdots & \ddots & \vdots \\ t_{(c+s)(c+s+1)} & \cdots & t_{(c+s)n} \end{matrix}} \\
\boxed{\begin{matrix} t_{(c+s+1)1} & \cdots & t_{(c+s+1)c} \\ \vdots & \ddots & \vdots \\ t_{n1} & \cdots & t_{nc} \end{matrix}} &
\boxed{\begin{matrix} t_{(c+s+1)(c+1)} & \cdots & t_{(c+s+1)(c+s)} \\ \vdots & \ddots & \vdots \\ t_{n(c+1)} & \cdots & t_{n(c+s)} \end{matrix}} &
\boxed{\begin{matrix} t_{(c+s+1)(c+s+1)} & \cdots & t_{(c+s+1)n} \\ \vdots & \ddots & \vdots \\ t_{n(c+s+1)} & \cdots & t_{nn} \end{matrix}}
\end{array}\right] &
\begin{array}{l} \textit{criteria} \\[3em] \textit{sub} - \textit{criteria} \\[3em] \textit{alternatives} \end{array}
\end{array} \tag{3a}$$

where I and N denote $n \times n$ identity and normalized strength-influence matrices.

Step 1.7: In this step, total impact (r_i) and total receptivity (c_j) are calculated using Eq. (4). Each component may affect one or more components and be affected by one or more components. The sum of the effect that component i exerts on other components is called total impact (r_i), and the sum of the effect that component i receives from other components is called total receptivity (c_j).

$$\begin{aligned} r_i &= \sum_{j=1}^{n} t_{ij} \\ c_j &= \sum_{i=1}^{n} t_{ij} \end{aligned} \tag{4}$$

Michnik (2013) states that alternatives can be ranked based on indicators such as r_i, c_j, $r_i + c_i$, and $r_i - c_i$. On the other hand, when there is no interrelationship between the alternatives, the total receptivity (c_j) is always zero. Thus, the values of r_i, $r_i + c_i$, and $r_i - c_i$ are equal to each other, and it only suffices to calculate the values of r_i for ranking. The r_i value is considered as the score/ weight of the partners. To better understand the alternatives' scores, we calculate the relative scores of the alternatives using Eq. (5). Based on this equation, the best partner gets the score of 1, and the score of other partners changes accordingly. This score is considered as the coefficient of the second objective function in the proposed mathematical model. This competent partner selection problem is known as the 'supplier selection and order allocation' problem in the literature (Lo et al., 2018; Mohammed et al., 2019; Nasr et al., 2021). We should note normalizing the scores using Eq. (5) does not affect partners' priorities and the mathematical model results.

$$SC_i = \frac{r_i}{Max\{r_i\}} \tag{5}$$

Stage 2: Partner selection with the optimization model

An optimization model is developed to assign each project (historic house) to the most suitable partner in this stage. For this purpose, the projects' time and cost proposed by potential partners are used in an optimization model to assign the most suitable partner to each project using the time and cost in conjunction with the partners' scores obtained in stage 1. In doing so, partners are asked to submit their optimistic, most likely, and pessimistic proposed times and costs for their project(s). The optimization model is designed to assign each partner to one and only one project. In other words, it is not possible to share a project between two or more partners. The proposed model is described below:

Mathematical model

Indices

$p \in \{1, 2, \ldots, P\}$	Project
$k \in \{1, 2, \ldots, K\}$	Partner
$t \in \{1, 2, \ldots, T\}$	Time period
$s \in \{1, 2, \ldots, S\}$	Scenario

Parameters

SC_k	The score of partner k in Stage 1
CP_{kps}	The proposed cost for project p by partner k under scenario s
TM_{kps}	The proposed time for project p by partner k under scenario s
RV_{kpts}	The revenue from project p assigned to partner k at the end of period t under scenario s
PR_s	The probability of occurrence of scenario s
IR	Interest rate
M	A big number

Variables

$X_{ks}\begin{cases}1\\0\end{cases}$ *Binary* If partner k is selected under scenario s; Otherwise

$Y_{kps}\begin{cases}1\\0\end{cases}$ *Binary* If project p is allocated to partner k under scenario s; Otherwise

Objective functions

$$Max\, Z_1 = \sum_{k,p,t,s} PR_s \times RV_{kpts} \times Y_{kps} \times (1 + IR)^{-t} - \sum_{k,p,s} PR_s \times CP_{kps} \times Y_{kps} \tag{6}$$

$$Max\, Z_2 = \sum_{k,s} PR_s \times SC_k \times X_{ks} \tag{7}$$

$$Min\, Z_3 = \underset{p}{Max} \sum_{k,s} PR_s \times TM_{kps} \times Y_{kps} \tag{8}$$

$s.t.$

$$\sum_{p} Y_{kps} \leq 1 \; \forall k, s \tag{9}$$

$$\sum_{k} Y_{kps} = 1 \; \forall p, s \tag{10}$$

$$Y_{kps} \leq M \times X_{ks} \; \forall k, p, s \tag{11}$$

$$X_{ks} \leq M \times \sum_{p} Y_{kps} \; \forall k, s \tag{12}$$

The first objective function maximizes the net present value and the second objective function aims at maximizing the total scores of partners. The third objective function minimizes the maximum completion time of the projects. In other words, the first objective function assigns projects to partners that lead to the most profit. Because the number of partners to be selected is constant, the second objective function selects the partners whose scores' sum is maximum. Based on the supplier selection and order allocation problem, an objective function is used to select a set of suitable suppliers with a maximum overall score. In this vein, the third objective function attempts to assign projects to partners to minimize the completion time of the projects.

According to constraint (9), each partner is assigned to zero or one project, and constraint (10) ensures that each project is assigned to one and only one partner, and it is not possible to share a project with two or more partners. Constraint (11) guarantees that a project is not assigned to a partner that is not selected. Constraint (12) ensures a partner is not selected if a project is not assigned to that partner. Not using this constraint will result in selecting a partner with no project.

The third objective is a non-linear function. For its linearization, we define a free variable (u) and replace it with $Max \sum_{k,s} PR_s \times TM_{kps} \times Y_{kps}$. Therefore, we will have:

$$u = Max \sum_{k,s} PR_s \times TM_{kps} \times Y_{kps} \tag{13}$$

Based on Eq. (13), the following formula is true:

$$u \geq \sum_{k,s} PR_s \times TM_{kps} \times Y_{kps} \; \forall p \tag{14}$$

Therefore, the proposed linearized model will be as follows:

$$Max\, Z_1 = \sum_{k,p,t,s} PR_s \times RV_{kpts} \times Y_{kps} \times (1 + IR)^{-t} - \sum_{k,p,s} PR_s \times CP_{kps} \times Y_{kps} \tag{15}$$

$$Max\, Z_2 = \sum_{k,s} PR_s \times SC_k \times X_{ks} \tag{16}$$

$$Min\, Z_3 = u \tag{17}$$

$$s.t.$$

$$u \geq \sum_{k,s} PR_s \times TM_{kps} \times Y_{kps} \; \forall p \tag{18}$$

$$Constraints\ (9)\ to\ (12)$$

There are various multi-objective mathematical programming methods to solve multi-objective problems, such as epsilon constraint, goal programming, weighted sum approach, and compromise programming. For example, the epsilon constraint method provides a Pareto optimum solution set to decision-makers and does not require any weights for the objective functions to generate these solutions. Although methods such as lexicographic optimization are suitable for calculating lower and upper bounds (Basirati et al., 2020), these methods do not guarantee accurate estimates (Mardan et al., 2019). The LP-metric method is often used to overcome this shortcoming because it does not require lower- and upper-bounds. One of the disadvantages of this method is that it cannot be implemented in minimization problems where the optimal value is zero. For example, this method cannot be used if one of the objective functions in a problem is to minimize lost demands. However, in the proposed model, the third objective function, which is of the minimization type, never takes a value of zero. In this method, each objective function's optimal value is calculated, and the proposed model is optimized separately for each objective function to calculate the optimal value of each objective function. One of the advantages of this method is that by changing the coefficients of the objective functions, a Pareto optimum solution set can be generated, as shown in the sensitivity analysis section. Below, the proposed multi-objective model has been converted to a single-objective one using the LP-metric method proposed by Mardan et al. (2019):

$$Z^{LP} = w_1 \times \frac{Z_1^* - Z_1}{Z_1^*} + w_2 \times \frac{Z_2^* - Z_2}{Z_2^*} + w_3 \times \frac{Z_3 - Z_3^*}{Z_3^*} \tag{19}$$

where w_1, w_2, and w_3 represent the weights of objective functions 1, 2, and 3, respectively; moreover, Z_1^*, Z_2^*, and Z_3^* represent the optimal values of objective functions 1, 2, and 3, respectively.

4. Case study

In this section, we present a case study to demonstrate the applicability of the proposed model in a PPP project in Iran to renovate and convert historic houses into hotels for the hospitality industry. The Fars province is one of the largest and the most historical provinces of Iran, with historical monuments dating back to 6500 years ago. To protect cultural heritage, maintain historical monuments, and attract tourists, Fars cultural heritage, tourism, and handicrafts organization intends to restore historic houses through a PPP initiative. The potential partners are invited to submit proposals, and they are evaluated using a set of criteria extracted from the literature and recommended by the experts of MCTH. It should be noted that the knowledge of five MCTH experts has been used to fill out questionnaires and collect data. For this purpose, experts with a management position and at least five years of related experience were selected. The demographic information of these experts is given in Table 3. The goal is to assign projects to the most suitable partners according to their project scores, cost, and time using the multi-objective model proposed in this study.

Stage 1: Partners evaluation using WINGS method

Step 1.1: This step is used to identify the evaluation criteria and their sub-criteria. We extracted a comprehensive set of evaluation criteria from the field of supplier/contractor selection in the construction industry because there are only a couple of partner selection studies published in the literature for the renovation of historic houses. The extracted factors are presented in Table 1. We then used brainstorming and consensus ranking to identify the most relevant factors for partner evaluation and selection. The following is the steps used to identify the most relevant criteria and sub-criteria through brainstorming and consensus ranking:

a. The factors presented in Table 1 were provided to the experts, and they were asked to select the most relevant evaluation factors for partner selections individually. They were also allowed to state the factor(s) they considered important but not listed in Table 1.
b. The factors presented jointly by at least three experts were selected as the most relevant factors in the first round (see Table 4). Each expert was given a few minutes to discuss their additions to their list.

Table 3. Demographic information of experts.

Demographic information	Categories	No. of experts
Gender	Male	5
	Female	0
Age	Less than 40 years	0
	41–50 years	3
	51–60 years	2
	Over 61 years	0
Experience	0–5 years	0
	6–10 years	2
	11–15 years	3
	Over 15 years	0
Expertise	Director of tourism training	1
	Director of tenders and auctions	1
	Direct of tourism service center	1
	Director of the preservation and restoration	1
	Director of tourism development and marketing	1

c. For the second time, the experts provided the remaining factors and extracted the most relevant factors. Table 5 presents the factors identified in the second round. Similarly, each expert was given a few minutes to discuss factors that other experts did not select.
d. Similarly, the remaining criteria were provided to the experts, and they were once again asked to identify the most relevant factors. The results showed that none of the identified factors were chosen by three or more experts at the same time. Therefore, no factor was added to the previously selected factors.
e. Finally, experts were asked to customize and categorize the selected factors based on the nature of the problem. To this end, they merged some factors and renamed others, and eventually classified the factors into six categories, including Service and Quality, Budgeting and Financial, Technical and Infrastructural, Time and workload, Environmental and Sustainability, and Management and Staffing. These operations are shown in Table 6.

Finally, partners' evaluation factors were compiled in the form of six criteria and 17 sub-criteria, which are presented in Table 7.

Step 1.2: In this step, the interrelationship among criteria is determined by the consensus of experts. In Figure 1, the relationship among criteria, sub-criteria, and alternatives has been illustrated.

Table 4. The selected factors in the first round.

Selected factors
Quality
Occupational health and safety
Safety records
Reliability
Reputation
Financial stability
Track record for completion on budget
Technical expertise
Technical resources
Equipment
Plant and equipment resources
Adequacy of plant and equipment
On-time delivery
Staffing level
Knowledge of project
Experience

Table 5. The selected factors in the second round.

Selected factors
Schedule
Time
Track record for on-time completion
Environmental considerations
Socio-economic scope
Personel
Budgetary control
Management expertise

Step 1.3: In this step, the strength of criteria and influence intensity of criteria on each other is determined by experts' consensus ranking using Table 2. A limited number of criteria and their sub-criteria were assigned to each expert. For example, the service and quality sub-criteria were assigned to the director of the tourism service center, the budgeting and financial sub-criteria were assigned to the director of tourism development and marketing, the technical and infrastructural sub-criteria were assigned to the director of preservation and restoration, time, workload, and environmental sub-criteria were assigned to the director of the tourism training unit, and management and staffing sub-criteria were assigned to the director of tenders and auctions unit. In Table 8, the influence intensity among criteria and the strength of criteria have been shown. The strength of sub-criteria and the influence intensity of sub-criteria on criteria are presented in Table 9. The influence intensity of alternatives on sub-criteria is also shown in Table 10.

Step 1.4: In this step, a direct strength-influence matrix (M) is formed using the data presented in Tables 8–10. This matrix is shown in Table A1 in the Appendix section.

Step 1.5: In this step, the matrix obtained from the previous step is normalized by Eq. (2). In Table A2, the normalized matrix (N) is presented.

Step 1.6: In this step, the total strength-influence matrix (T) is calculated by Eq. (3). This matrix is displayed in Table A3.

Table 6. The customization and classification process.

Selected factors	Customization/Merging	Category
Quality	Quality	Service and Quality
Occupational health and safety	Safety	
Safety records		
Reliability	Reliability	
Reputation	Reputation	
Financial stability	Financial stability	Budgeting and Financial
Track record for completion on budget	Track record for completion on budget	
Technical expertise	Technical expertise	Technical and Infrastructural
Technical resources		
Equipment	Plants and equipment	
Plant and equipment resources		
Adequacy of plant and equipment		
On-time delivery	Delivery schedule	Time and workload
Schedule		
Staffing level	Staffing skills	Management and staffing
Knowledge of project	Knowledge and experience	
Experience		
Time	Time management	Time and workload
Track record for on-time completion		
Environmental considerations	Environmental considerations	Environmental and Sustainability
Socio-economic scope	Socio-economic scope	
Personel	Staffing adequacy	Management and staffing
Budgetary control	Budgetary control	Budgeting and Financial
Management expertise	Management expertise	Management and Staffing

Table 7. Criteria and sub-criteria for evaluating partners.

Criteria	Sub-criteria
Service and Quality (SQ)	Quality (SQ1)
	Safety (SQ2)
	Reliability (SQ3)
	Reputation (SQ4)
Budgeting and Financial (BF)	Track record for completion on-budget (BF1)
	Financial stability (BF2)
	Budgetary control (BF3)
Technical and Infrastructural (TI)	Technical expertise (TI1)
	Plants and equipment (TI2)
Time and workload (TW)	Delivery schedule (TW1)
	Time management (TW2)
Environmental and Sustainability (ES)	Environmental considerations (ES1)
	Socio-economic scope (ES2)
Management and staffing (MS)	Staffing skills (MS1)
	Management expertise (MS2)
	Knowledge and experience (MS3)
	Staffing adequacy (MS4)

Step 1.7: In this step, the total impact (r_i) for each alternative (partner) is calculated using Eq. (4), and finally, the relative score of partners is determined by Eq. (5). The total impact and relative score of partners have been shown in Table 11. It should be noted that partners' relative score is considered the coefficient of the second objective function.

Stage 2: Assigning projects to partners

In stage 1, the performance of 23 partners was evaluated using the WINGS approach. The goal is to assign nine historic houses to nine partners using the proposed mathematical model (See Figure 2). For this purpose, the multi-objective mathematical programming model is validated using relative scores obtained from Stage 1 and the data collected from partners and MCTH experts (See online resources). The LP-metric method is used to solve the proposed multi-objective model. The proposed model is run in GAMS software for each objective function as described earlier by calculating the value of each objective function separately, as shown in Table 12.

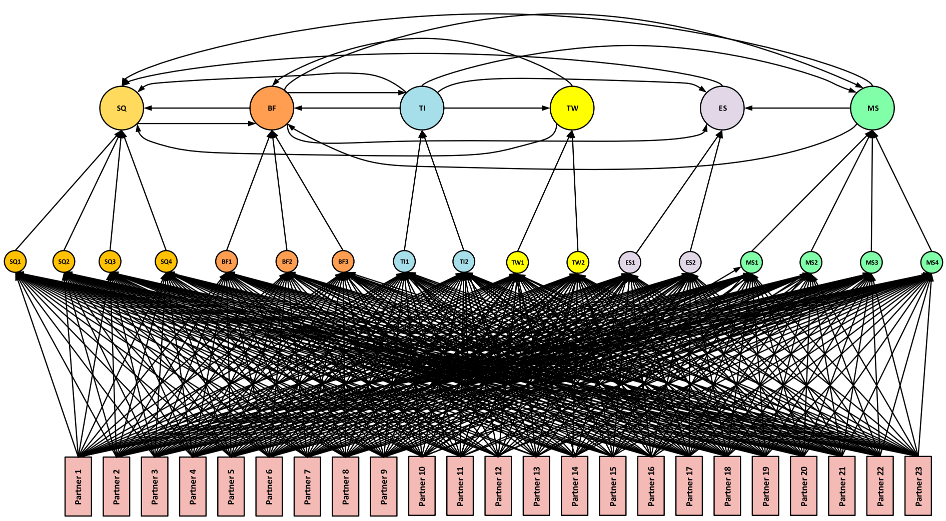

Figure 1. Relationship among criteria, sub-criteria, and alternatives.

Table 8. Strength of criteria and influence intensity between them.

From	To	Strength	Influence
SQ	BF	3	2
BF	SQ	4	3
	TI		2
	ES		2
	MS		2
TI	SQ	3	4
	BF		2
	TW		2
	ES		1
	MS		2
TW	SQ	2	2
	BF		1
ES	SQ	1	1
MS	SQ	2	3
	BF		2
	ES		1

Using the results presented in Table 12 and Eq. (19), the objective function of the proposed multi-objective model is converted into a single objective one as follows:

$$Z^{LP} = w_1 \times \frac{7,256,426 - Z_1}{7,256,426} + w_2 \times \frac{8.067 - Z_2}{8.067} + w_3 \times \frac{Z_3 - 14.75}{14.75} \tag{20}$$

By running a single objective model for $w_1 = 0.4$, $w_2 = 0.35$, and $w_3 = 0.25$ in GAMS software, the following results are obtained:

- The value of the first objective function was equal to \$ 6,623,706. Also, objective functions 2 and 3 functions were equal to 7.92 and 14.75, respectively.
- The selected partners in each scenario are shown in Table 13, and the projects assigned to each partner for each scenario are listed in Table 14.

For example, number 1 in the first line of Table 14 states that Project 8 should be assigned to Partner 2 under Scenario 2. The projects are assigned to each partner accordingly.

Table 9. Strength of sub-criteria and influence intensity criteria on their sub-criteria.

From	To (influence)						Strength
	SQ	BF	TI	TW	ES	MS	
SQ1	4	0	0	0	0	0	4
SQ2	3	0	0	0	0	0	4
SQ3	2	0	0	0	0	0	3
SQ4	2	0	0	0	0	0	3
BF1	0	3	0	0	0	0	3
BF2	0	4	0	0	0	0	4
BF3	0	3	0	0	0	0	3
TI1	0	0	3	0	0	0	4
TI2	0	0	4	0	0	0	3
TW1	0	0	0	3	0	0	3
TW2	0	0	0	2	0	0	3
ES1	0	0	0	0	1	0	2
ES2	0	0	0	0	2	0	2
MS1	0	0	0	0	0	3	4
MS2	0	0	0	0	0	2	4
MS3	0	0	0	0	0	4	3
MS4	0	0	0	0	0	2	2

Table 10. Influence intensity of alternatives on sub-criteria.

Partner	SQ1	SQ2	SQ3	SQ4	BF1	BF2	BF3	TI1	TI2	TW1	TW2	ES1	ES2	MS1	MS2	MS3	MS4
1	2	3	3	3	2	3	3	4	3	2	3	2	1	2	2	2	1
2	3	2	2	1	3	2	3	2	2	3	2	2	2	2	3	3	4
3	3	2	3	2	3	4	3	3	2	3	3	2	1	2	2	3	3
4	2	1	2	3	2	3	2	3	3	2	3	1	1	2	3	2	2
5	4	3	3	4	4	3	3	4	4	3	3	3	3	4	3	4	4
6	4	4	3	3	3	3	3	3	3	3	4	3	2	3	4	4	4
7	3	4	4	3	3	4	4	3	4	2	3	3	4	3	3	3	3
8	4	3	3	3	2	2	3	3	3	4	2	2	2	3	3	3	4
9	2	2	2	3	2	3	1	2	2	3	2	1	2	2	3	3	2
10	1	2	3	2	1	2	2	2	2	2	2	1	1	2	3	3	2
11	2	2	3	2	3	2	3	1	2	3	2	2	2	3	2	3	3
12	3	4	3	3	3	3	3	3	2	3	3	2	3	3	2	3	2
13	2	3	3	2	3	4	2	3	3	3	2	3	3	3	4	3	3
14	3	3	4	3	3	3	3	4	4	4	3	4	4	4	4	4	3
15	4	3	3	4	4	4	3	3	4	4	3	3	4	3	3	3	4
16	4	4	3	3	3	3	3	2	3	4	3	1	2	2	3	2	3
17	3	3	2	3	2	2	3	3	2	4	2	1	2	2	2	2	2
18	2	2	3	2	3	3	2	3	3	3	3	2	1	2	3	3	2
19	2	1	2	3	2	4	3	2	2	2	1	1	1	2	3	3	2
20	1	2	1	3	3	3	2	2	3	3	2	2	1	3	3	3	3
21	3	2	3	2	2	2	2	4	2	2	1	2	2	2	3	2	1
22	2	3	2	2	3	3	3	3	1	1	2	1	2	2	1	2	2
23	1	2	3	2	2	2	2	2	1	2	1	1	1	2	2	2	2

Table 11. Total impact and the relative score of partners.

Partner	Total impact	Relative score
1	0.035379	0.683455
2	0.035374	0.683354
3	0.037967	0.733444
4	0.031927	0.616769
5	0.050906	0.983404
6	0.048318	0.9334
7	0.048316	0.933372
8	0.042279	0.816739
9	0.031926	0.616754
10	0.028474	0.550054
11	0.03451	0.666657
12	0.041417	0.800086
13	0.042277	0.816711
14	0.051765	1
15	0.050904	0.983361
16	0.041419	0.800129
17	0.034516	0.666772
18	0.036241	0.700094
19	0.031067	0.600145
20	0.034513	0.66673
21	0.031927	0.616769
22	0.030202	0.583433
23	0.025885	0.500036

Table 12. The optimum value of objective functions.

Stand-alone optimization of Objective function 1 (Z_1^*)	Stand-alone optimization of function 2 (Z_2^*)	Stand-alone optimization of Objective function 3 (Z_3^*)
7,256,426	8.067	14.75

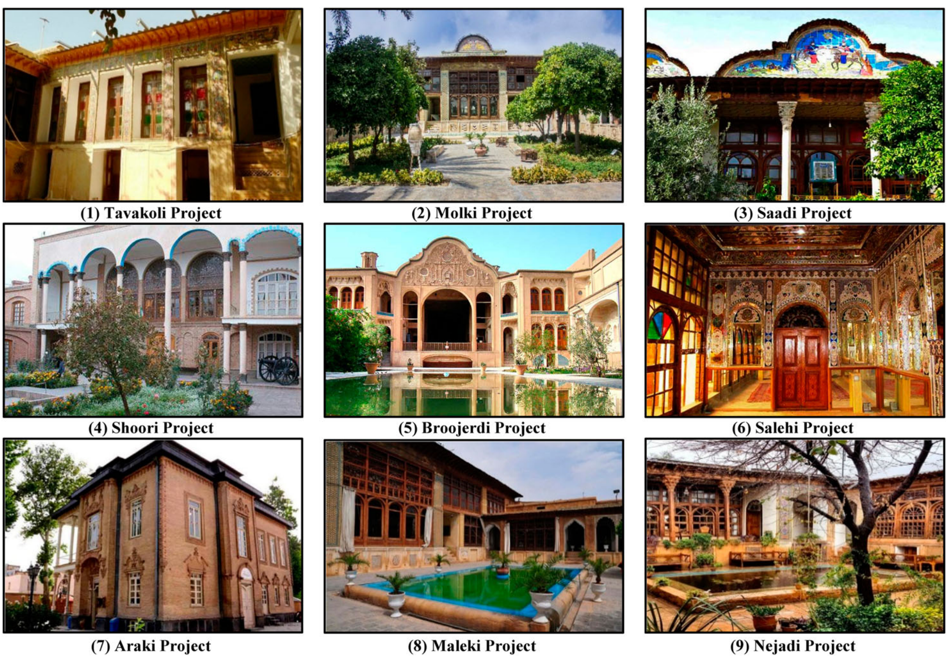

Figure 2*. The projects proposed for renovation by MCTH *Note: The project names are changed to protect their anonymity.

Table 13. Selected partners for each scenario.

X_{ks}	s=1 Pessimistic	s=2 Most Likely	s=3 Optimistic
k=2	0	1	0
k=5	1	1	1
k=6	1	1	1
k=7	1	1	1
k=8	1	1	0
k=11	0	0	1
k=12	1	0	0
k=13	1	1	1
k=14	1	1	1
k=15	1	1	1
k=16	1	1	1
k=19	0	0	1

These results are obtained by considering all three pessimistic, most likely, and optimistic scenarios with the 0.25, 0.5, and 0.25 probabilities. Table 15 shows the objective function values relative to the changes in the probabilities of occurrence of the scenarios.

The results presented in Table 15 show a net present value of $5,490,397 and the completion time of 16 months in the pessimistic conditions (P1). Similarly, under the optimistic conditions (P8), the net present value is increased to $7,782,973, and the completion time is reduced to 13 months. As shown in Table 15, when the probabilities of occurrence for the pessimistic scenario decreases and the probabilities of occurrence for the optimistic scenario increases, the net present value (objective function 1) increases (See Figure 3), and the value of objective function 3 decreases (See Figure 4). Since objective function 2 is not dependent on the probabilities of occurrence, changes in this objective function are not traceable. The results obtained from the sensitivity analysis are consistent with expectations. After carefully analyzing the results, the management team at MCTH decided to proceed with Policy 5 under the most likely scenario assumption and assign Project 1 to Partner 8, Project 2 to Partner 16, Project 3 to Partner 15, Project 4 to Partner 14, Project 5 to Partner 13, Project 6 to Partner 5, Project 7 to Partner 7, Project 8 to Partner 2, and Project 9 to Partner 6.

Table 14. The projects allocated to partners for each scenario.

Y_{kps}		s=1 Pessimistic	s=2 Most Likely	s=3 Optimistic
k=2	p=8	0	1	0
k=5	p=1	1	0	0
k=5	p=6	0	1	1
k=6	p=1	0	0	1
k=6	p=9	1	1	0
k=7	p=2	0	0	1
k=7	p=7	1	1	0
k=8	p=1	0	1	0
k=8	p=8	1	0	0
k=11	p=9	0	0	1
k=12	p=3	1	0	0
k=13	p=5	1	1	1
k=14	p=4	1	1	1
k=15	p=2	1	0	0
k=15	p=3	0	1	1
k=16	p=2	0	1	0
k=16	p=6	1	0	0
k=16	p=7	0	0	1
k=19	p=8	0	0	1

Table 15. The values of objective functions for change in occurrence probability of scenario.

Policy	Occurrence probability of scenarios			Objective function 1	Objective function 2	Objective function 3
	s=1 Pessimistic	s=2 Most Likely	s=3 Optimistic			
1	1	0	0	5,490,397	7.95	16
2	0.5	0.5	0	6,072,574	7.95	15.5
3	0.4	0.5	0.1	6,301,832	7.927	15.2
4	0.3	0.5	0.2	6,504,675	7.939	14.9
5	0.2	0.5	0.3	6,742,737	7.904	14.6
6	0.1	0.5	0.4	6,980,800	7.869	14.3
7	0	0.5	0.5	7,218,862	7.834	14
8	0	0	1	7,782,973	7.717	13

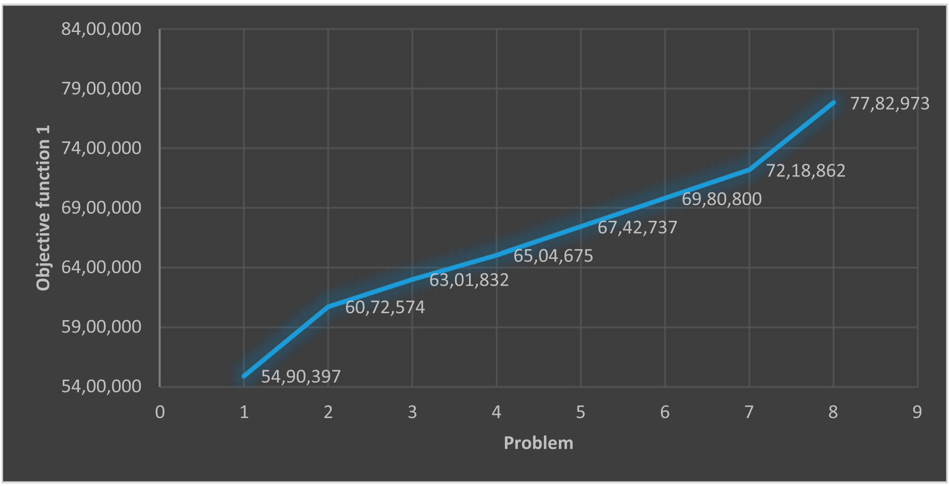

Figure 3. The behavior of the objective function 1 for changes in the values of the scenarios.

5. Sensitivity analysis

In this section, we used sensitivity analysis of the objective functions' coefficients to study the performance of the proposed model and solution approach. For this purpose, several scenarios were constructed by remaining one coefficient unchanged and simultaneously changing the other two coefficients. These scenarios are given in Table 16. It is expected that when the coefficient of an objective function increases (decreases), the value of that objective function will not worsen (improve). Table 16 shows the results from these scenarios.

As shown in Table 16, the results of each scenario correspond precisely to the logical expectations. For example, in Scenario 1, the coefficient of the first objective function remains unchanged, and the coefficient of the second and third objective functions are decreased and increased, respectively. It is expected that the value of the second objective function will not improve (either does not change or decrease), and the value of the third objective function will not worsen (either does not change or decrease). It should be noted that the second and the third objective functions are maximization and minimization objectives. Therefore, not improving the results of the maximization problem means either it does not change or decrease the value of the objective function, and not worsening the results of the minimization problem means either it does not change or decrease the value of the objective function. Another noteworthy point is that no scenario is dominated by any other scenario. In summary, the sensitivity analysis process produces a Pareto optimum solution set for the decision-makers to select according to their available budget and their required project completion time.

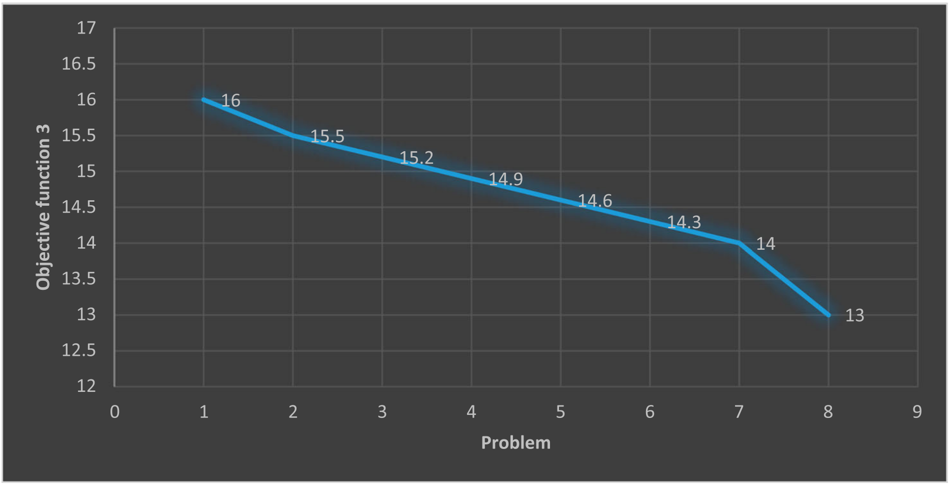

Figure 4. The behavior of the objective function 3 for changes in the values of the scenarios.

Table 16. The sensitivity analysis of the objective functions' coefficients.

		w_1	w_2	w_3	Z_1	Z_2	Z_3
Main problem		0.4	0.35	0.25	6,623,706	7.921	14.75
w_1 remained unchanged, w_2 decreased, w_3 increased	Scenario 1	0.4	0.3	0.3	6,645,718	7.892	14.75
	Scenario 2	0.4	0.25	0.35	6,645,718	7.892	14.75
w_1 remained unchanged, w_2 increased, w_3 decreased	Scenario 3	0.4	0.4	0.2	6,656,102	7.959	15
	Scenario 4	0.4	0.45	0.15	6,678,743	7.984	15.25
w_1 decreased, w_2 remained unchanged, w_3 increased	Scenario 5	0.35	0.35	0.3	6,623,706	7.921	14.75
	Scenario 6	0.3	0.35	0.35	6,623,706	7.921	14.75
w_1 increased, w_2 remained unchanged, w_3 decreased	Scenario 7	0.45	0.35	0.2	6,656,102	7.959	15
	Scenario 8	0.5	0.35	0.15	6,700,094	7.955	15.25
w_1 increased, w_2 decreased, w_3 remained unchanged	Scenario 9	0.45	0.3	0.25	6,645,718	7.892	14.75
	Scenario 10	0.5	0.25	0.25	6,671,175	7.842	14.75
w_1 decreased, w_2 increased, w_3 remained unchanged	Scenario 11	0.35	0.4	0.25	6,623,706	7.921	14.75
	Scenario 12	0.3	0.45	0.25	6,558,079	7.980	14.75

6. Iscussion and managerial implications

Assigning cultural heritage buildings to the private sector for renovation and conservation has many benefits, including saving money, preserving cultural heritage, creating jobs, and promoting domestic and foreign tourism. This study proposed an integrated approach for partner selection and project allocation through profit maximizations and completion time minimization. Although the selection of partners for the renovation and conservation of cultural heritage buildings has been considered in the literature, to the best of our knowledge, this is the first study proposing an integrated MCDM method and mathematical programming for this purpose. One of the main advantages of the proposed approach is considering both qualitative and quantitative criteria and practical constraints in the partner selection and project allocation process. This advantage is realized by integrating the WINGS method with an optimization model. A review of the literature also shows that previous researchers such as Morkūnaitė et al. (2017) and Morkunaite, Bausys, et al. (2019a; Morkunaite, Podvezko, et al., 2019b) have used the MCDM methods for partner selection of cultural heritage without considering the interdependencies among the selection factors. This research applies a structural model based on the WINGS method to weigh the partner evaluation factors and consider the interdependencies among them. This method can be easily implemented in networks with hierarchical structures and intertwined factors. The proposed approach as a decision support system can facilitate the partner evaluation and selection process. The proposed approach can also be implemented in other fields, including supplier selection and order allocation, project portfolio selection, and contractor selection, among others.

7. Conclusion

The renovation and conservation of cultural heritage require a great deal of investment and the involvement of multiple public and private actors (Boniotti, 2021). The conservation of historic urban cultural sites and buildings poses specific challenges requiring multidisciplinary approaches and expertise from the private sector to complement the governmental resources (Morkunaite, Bausys, et al., 2019a; Morkunaite, Podvezko, et al., 2019b). Partner evaluation and selection is essential and critical activity in PPP projects. Selecting the most suitable partners in a PPP project is a complex and multi-faced problem involving a comprehensive assessment of a series of multiple and often conflicting criteria. A literature review shows that the existing approaches suffer from two problems (Morkūnaitė et al., 2017; Morkunaite, Bausys, et al., 2019a; Morkunaite, Podvezko, et al., 2019b). First, the existing approaches are applied only to evaluate and rank partners. If the goal is to assign several projects to multiple partners, these approaches are ineffective. In addition, these approaches ignore the interdependencies among the evaluation and selection criteria. This study proposed an integrated approach based on WINGS and mathematical programming to overcome the shortcomings in the existing models. The proposed model evaluates partners and assigns several projects to multiple partners considering the constraints in the PPP projects involving the renovation and conservation of cultural heritage in developing countries. We used the MCDM method of WINGS to create a blueprint of the interdependencies among the selection criteria. A multi-objective optimization model was used in combination with WINGS to select the most suitable partner for each PPP project using an LP metric method. A case study for the renovation and conservation of ten historic homes in Iran demonstrated the applicability of the proposed method in the hospitality industry.

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Declaration of interest

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

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ORCID

Madjid Tavana http://orcid.org/0000-0003-2017-1723

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Appendix

Table A1. Direct strength-influence matrix (M).

		SQ	BF	TI	TW	ES	MS	SQ1	SQ2	SQ3	SQ4	BF1	BF2	BF3	TI1	TI2	TW1	TW2	ES1	ES2	MS1	MS2	MS3	MS4	Partner																						
																									1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
	SQ	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BF	3	4	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TI	4	2	3	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TW	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ES	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MS	3	2	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SQ1	4	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SQ2	3	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SQ3	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SQ4	2	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BF1	0	3	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BF2	0	4	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	BF3	0	3	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TI1	0	0	3	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TI2	0	0	4	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TW1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TW2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ES1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ES2	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MS1	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MS2	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MS3	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MS4	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partner	1	0	0	0	0	0	0	2	3	3	3	2	3	3	4	3	2	3	2	1	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	3	2	2	1	3	2	3	2	2	3	2	2	2	2	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	3	2	3	2	3	4	3	3	2	3	3	2	1	2	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	2	1	2	3	2	3	2	3	3	2	3	1	1	2	3	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	4	3	3	4	4	3	3	4	4	3	3	3	3	4	3	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	4	4	3	3	3	3	3	3	3	3	4	3	2	3	4	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	3	4	4	3	3	4	4	3	4	2	3	3	4	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	4	3	3	3	2	2	3	3	3	4	2	2	2	3	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	2	2	2	3	2	3	1	2	2	3	2	1	2	2	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	1	2	3	2	1	2	2	2	2	2	2	1	1	2	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	2	2	3	2	3	2	3	1	2	3	2	2	2	3	2	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	3	4	3	3	3	3	3	3	2	3	3	2	3	3	2	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	2	3	3	2	3	4	2	3	3	3	2	3	3	3	4	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	3	3	4	3	3	3	3	4	4	4	3	4	4	4	4	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	4	3	3	4	4	4	3	3	4	4	3	3	4	3	3	3	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	4	4	3	3	3	3	3	2	3	4	3	1	2	2	3	2	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	3	3	2	3	2	2	3	3	2	4	2	1	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18	0	0	0	0	0	0	2	2	3	2	3	3	2	3	3	3	3	2	1	2	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	2	1	2	3	2	4	3	2	2	2	1	1	1	2	3	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	1	2	1	3	3	3	2	2	3	3	2	2	1	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21	0	0	0	0	0	0	3	2	3	2	2	2	2	4	2	2	1	2	2	2	3	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22	0	0	0	0	0	0	2	3	2	2	3	3	3	3	1	1	2	1	2	2	1	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23	0	0	0	0	0	0	1	2	3	2	2	2	2	2	1	2	1	1	1	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A2. Normalized direct strength-influence matrix (N).

		SQ	BF	TI	TW	ES	MS	SQ1	SQ2	SQ3	SQ4	BF1	BF2	BF3	TI1	TI2	TW1	TW2	ES1	ES2	MS1	MS2	MS3	MS4	Partner																						
																									1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
SQ		0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BF		0.0026	0.0034	0.0017	0	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TI		0.0034	0.0017	0.0026	0.0017	0.0009	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TW		0.0017	0.0009	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES		0.0009	0	0	0	0.0009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS		0.0026	0.0017	0	0	0.0009	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQ1		0.0034	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQ2		0.0026	0	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQ3		0.0017	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQ4		0.0017	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BF1		0	0.0026	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BF2		0	0.0034	0	0	0	0	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BF3		0	0.0026	0	0	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TI1		0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TI2		0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TW1		0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TW2		0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES1		0	0	0	0	0.0009	0	0	0	0	0	0	0	0	0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES2		0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS1		0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS2		0	0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS3		0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS4		0	0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partner	1	0	0	0	0	0	0	0.0017	0.0026	0.0026	0.0026	0.0017	0.0026	0.0026	0.0034	0.0026	0.0017	0.0026	0.0017	0.0009	0.0017	0.0017	0.0017	0.0009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0.0026	0.0017	0.0017	0.0009	0.0026	0.0017	0.0026	0.0017	0.0017	0.0026	0.0017	0.0017	0.0017	0.0017	0.0026	0.0026	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0.0026	0.0017	0.0026	0.0017	0.0026	0.0034	0.0026	0.0026	0.0017	0.0026	0.0026	0.0017	0.0009	0.0017	0.0017	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0.0017	0.0009	0.0017	0.0026	0.0017	0.0026	0.0017	0.0026	0.0026	0.0017	0.0026	0.0009	0.0009	0.0017	0.0026	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	0	0	0	0	0	0.0034	0.0026	0.0026	0.0034	0.0034	0.0026	0.0026	0.0034	0.0034	0.0026	0.0026	0.0026	0.0026	0.0034	0.0026	0.0034	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0.0034	0.0034	0.0026	0.0026	0.0026	0.0026	0.0026	0.0026	0.0026	0.0026	0.0034	0.0026	0.0017	0.0026	0.0034	0.0034	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0.0026	0.0034	0.0034	0.0026	0.0026	0.0034	0.0034	0.0026	0.0034	0.0017	0.0026	0.0026	0.0034	0.0026	0.0026	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0.0034	0.0026	0.0026	0.0026	0.0017	0.0017	0.0026	0.0026	0.0026	0.0034	0.0017	0.0017	0.0017	0.0026	0.0026	0.0026	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0.0017	0.0017	0.0017	0.0026	0.0017	0.0026	0.0009	0.0017	0.0017	0.0026	0.0017	0.0009	0.0017	0.0017	0.0026	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0.0009	0.0017	0.0026	0.0017	0.0009	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0009	0.0009	0.0017	0.0026	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	0	0	0	0	0	0	0.0017	0.0017	0.0026	0.0017	0.0026	0.0017	0.0026	0.0009	0.0017	0.0026	0.0017	0.0017	0.0017	0.0026	0.0017	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0.0026	0.0034	0.0026	0.0026	0.0026	0.0026	0.0026	0.0026	0.0017	0.0026	0.0026	0.0017	0.0026	0.0026	0.0017	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	0.0017	0.0026	0.0026	0.0017	0.0026	0.0034	0.0017	0.0026	0.0026	0.0026	0.0017	0.0026	0.0026	0.0026	0.0034	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0.0026	0.0026	0.0034	0.0026	0.0026	0.0026	0.0026	0.0034	0.0034	0.0034	0.0026	0.0034	0.0034	0.0034	0.0034	0.0034	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0.0034	0.0026	0.0026	0.0034	0.0034	0.0034	0.0026	0.0026	0.0034	0.0034	0.0026	0.0026	0.0034	0.0026	0.0026	0.0026	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0.0034	0.0034	0.0026	0.0026	0.0026	0.0026	0.0026	0.0017	0.0026	0.0034	0.0026	0.0009	0.0017	0.0017	0.0026	0.0017	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	0.0026	0.0026	0.0017	0.0026	0.0017	0.0017	0.0026	0.0026	0.0017	0.0034	0.0017	0.0009	0.0017	0.0017	0.0017	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18	0	0	0	0	0	0	0.0017	0.0017	0.0026	0.0017	0.0026	0.0026	0.0017	0.0026	0.0026	0.0026	0.0026	0.0017	0.0009	0.0017	0.0026	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19	0	0	0	0	0	0	0.0017	0.0009	0.0017	0.0026	0.0017	0.0034	0.0026	0.0017	0.0017	0.0017	0.0009	0.0009	0.0009	0.0017	0.0026	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0.0009	0.0017	0.0009	0.0026	0.0026	0.0026	0.0017	0.0017	0.0026	0.0026	0.0017	0.0017	0.0009	0.0026	0.0026	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21	0	0	0	0	0	0	0.0026	0.0017	0.0026	0.0017	0.0017	0.0017	0.0017	0.0034	0.0017	0.0017	0.0009	0.0017	0.0017	0.0017	0.0026	0.0017	0.0009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22	0	0	0	0	0	0	0.0017	0.0026	0.0017	0.0017	0.0026	0.0026	0.0026	0.0026	0.0009	0.0009	0.0017	0.0009	0.0017	0.0017	0.0009	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23	0	0	0	0	0	0	0.0009	0.0017	0.0026	0.0017	0.0017	0.0017	0.0017	0.0017	0.0009	0.0017	0.0009	0.0009	0.0009	0.0017	0.0017	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A3. Total strength-influence matrix.

		SQ	BF	TI	TW	ES	MS	SQ1	SQ2	SQ3	SQ4	BF1	BF2	BF3	TI1	TI2	TW1	TW2	ES1	ES2	MS1	MS2	MS3	MS4	Partner																						
																									1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
SQ		2.59E-03	1.73E-03	2.97E-06	5.11E-09	2.97E-06	2.98E-06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BF		2.60E-03	3.46E-03	1.73E-03	2.97E-06	1.73E-03	1.73E-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TI		3.46E-03	1.74E-03	2.58E-03	1.72E-03	8.66E-04	1.73E-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TW		1.73E-03	8.66E-04	1.49E-06	1.72E-03	1.49E-06	1.49E-06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES		8.61E-04	1.48E-06	2.55E-09	4.39E-12	8.59E-04	2.56E-09	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS		2.59E-03	1.73E-03	2.98E-06	5.12E-09	8.64E-04	1.72E-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQ1		3.45E-03	5.95E-06	1.02E-08	1.76E-11	1.02E-08	1.03E-08	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQ2		2.59E-03	4.46E-06	7.68E-09	1.32E-11	7.68E-09	7.69E-09	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQ3		1.73E-03	2.97E-06	5.12E-09	8.80E-12	5.12E-09	5.12E-09	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SQ4		1.73E-03	2.97E-06	5.12E-09	8.80E-12	5.12E-09	5.12E-09	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BF1		6.72E-06	2.59E-03	4.46E-06	7.67E-09	4.46E-06	4.46E-06	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BF2		8.97E-06	3.46E-03	5.95E-06	1.02E-08	5.95E-06	5.96E-06	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BF3		6.72E-06	2.59E-03	4.46E-06	7.67E-09	4.46E-06	4.46E-06	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TI1		8.95E-06	4.49E-06	2.59E-03	4.46E-06	2.24E-06	4.46E-06	0	0	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TI2		1.19E-05	5.98E-06	3.45E-03	5.94E-06	2.98E-06	5.95E-06	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TW1		4.46E-06	2.24E-06	3.85E-09	2.59E-03	3.85E-09	3.85E-09	0	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TW2		2.97E-06	1.49E-06	2.56E-09	1.72E-03	2.56E-09	2.57E-09	0	0	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES1		7.41E-07	1.28E-09	2.20E-12	3.78E-15	8.61E-04	2.20E-12	0	0	0	0	0	0	0	0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ES2		1.48E-06	2.55E-09	4.39E-12	7.55E-15	1.72E-03	4.40E-12	0	0	0	0	0	0	0	0	0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS1		6.70E-06	4.47E-06	7.69E-09	1.32E-11	2.23E-06	2.59E-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS2		4.46E-06	2.98E-06	5.13E-09	8.82E-12	1.49E-06	1.73E-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS3		8.92E-06	5.96E-06	1.03E-08	1.76E-11	2.97E-06	3.45E-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MS4		4.46E-06	2.98E-06	5.12E-09	8.81E-12	1.49E-06	1.72E-03	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Partner	1	2.17E-05	2.01E-05	1.78E-05	8.91E-06	3.02E-06	1.49E-05	0.0017	0.0026	0.0026	0.0026	0.0017	0.0026	0.0026	0.0034	0.0026	0.0017	0.0026	0.0017	0.0009	0.0017	0.0017	0.0017	0.0009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	1.80E-05	1.94E-05	1.04E-05	9.64E-06	4.49E-06	2.37E-05	0.0026	0.0017	0.0017	0.0009	0.0026	0.0017	0.0026	0.0017	0.0017	0.0026	0.0017	0.0017	0.0017	0.0017	0.0026	0.0026	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	2.09E-05	2.53E-05	1.26E-05	1.11E-05	3.03E-06	2.08E-05	0.0026	0.0017	0.0026	0.0017	0.0026	0.0034	0.0026	0.0026	0.0017	0.0026	0.0026	0.0017	0.0009	0.0017	0.0017	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	1.57E-05	1.79E-05	1.56E-05	8.91E-06	2.28E-06	1.78E-05	0.0017	0.0009	0.0017	0.0026	0.0017	0.0026	0.0017	0.0026	0.0026	0.0017	0.0026	0.0009	0.0009	0.0017	0.0026	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	2.91E-05	2.46E-05	2.08E-05	1.11E-05	6.74E-06	3.12E-05	0.0034	0.0026	0.0026	0.0034	0.0034	0.0026	0.0026	0.0034	0.0034	0.0026	0.0026	0.0026	0.0026	0.0034	0.0026	0.0034	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	2.99E-05	2.24E-05	1.56E-05	1.26E-05	5.25E-06	3.04E-05	0.0034	0.0034	0.0026	0.0026	0.0026	0.0026	0.0026	0.0026	0.0026	0.0026	0.0034	0.0026	0.0017	0.0026	0.0034	0.0034	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7	2.84E-05	2.76E-05	1.86E-05	8.91E-06	8.21E-06	2.45E-05	0.0026	0.0034	0.0034	0.0026	0.0026	0.0034	0.0034	0.0026	0.0034	0.0017	0.0026	0.0026	0.0034	0.0026	0.0026	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	2.76E-05	1.72E-05	1.56E-05	1.19E-05	4.50E-06	2.60E-05	0.0034	0.0026	0.0026	0.0026	0.0017	0.0017	0.0026	0.0026	0.0026	0.0034	0.0017	0.0017	0.0017	0.0026	0.0026	0.0026	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	1.79E-05	1.57E-05	1.04E-05	9.64E-06	3.75E-06	2.08E-05	0.0017	0.0017	0.0017	0.0026	0.0017	0.0026	0.0009	0.0017	0.0017	0.0026	0.0017	0.0009	0.0017	0.0017	0.0026	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	1.50E-05	1.27E-05	1.04E-05	7.42E-06	2.26E-06	2.08E-05	0.0009	0.0017	0.0026	0.0017	0.0009	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0009	0.0009	0.0017	0.0026	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	11	1.79E-05	1.94E-05	8.18E-06	9.63E-06	4.49E-06	2.30E-05	0.0017	0.0017	0.0026	0.0017	0.0026	0.0017	0.0026	0.0009	0.0017	0.0026	0.0017	0.0017	0.0017	0.0026	0.0017	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	12	2.69E-05	2.24E-05	1.26E-05	1.11E-05	5.98E-06	2.15E-05	0.0026	0.0034	0.0026	0.0026	0.0026	0.0026	0.0026	0.0026	0.0017	0.0026	0.0026	0.0017	0.0026	0.0026	0.0017	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13	2.02E-05	2.31E-05	1.56E-05	9.65E-06	6.72E-06	2.60E-05	0.0017	0.0026	0.0026	0.0017	0.0026	0.0034	0.0017	0.0026	0.0026	0.0026	0.0017	0.0026	0.0026	0.0026	0.0034	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	2.62E-05	2.24E-05	2.08E-05	1.34E-05	8.95E-06	3.12E-05	0.0026	0.0026	0.0034	0.0026	0.0026	0.0026	0.0026	0.0034	0.0034	0.0034	0.0026	0.0034	0.0034	0.0034	0.0034	0.0034	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	2.91E-05	2.76E-05	1.86E-05	1.34E-05	8.21E-06	2.60E-05	0.0034	0.0026	0.0026	0.0034	0.0034	0.0034	0.0026	0.0026	0.0034	0.0034	0.0026	0.0026	0.0034	0.0026	0.0026	0.0026	0.0034	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	16	2.98E-05	2.24E-05	1.34E-05	1.33E-05	3.76E-06	1.93E-05	0.0034	0.0034	0.0026	0.0026	0.0026	0.0026	0.0026	0.0017	0.0026	0.0034	0.0026	0.0009	0.0017	0.0017	0.0026	0.0017	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17	2.31E-05	1.72E-05	1.26E-05	1.19E-05	3.75E-06	1.63E-05	0.0026	0.0026	0.0017	0.0026	0.0017	0.0017	0.0026	0.0026	0.0017	0.0034	0.0017	0.0009	0.0017	0.0017	0.0017	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18	1.80E-05	2.01E-05	1.56E-05	1.11E-05	3.02E-06	2.08E-05	0.0017	0.0017	0.0026	0.0017	0.0026	0.0026	0.0017	0.0026	0.0026	0.0026	0.0026	0.0017	0.0009	0.0017	0.0026	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	19	1.57E-05	2.31E-05	1.04E-05	5.94E-06	2.28E-06	2.08E-05	0.0017	0.0009	0.0017	0.0026	0.0017	0.0034	0.0026	0.0017	0.0017	0.0017	0.0009	0.0009	0.0009	0.0017	0.0026	0.0026	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	20	1.35E-05	2.01E-05	1.34E-05	9.64E-06	3.02E-06	2.45E-05	0.0009	0.0017	0.0009	0.0026	0.0026	0.0026	0.0017	0.0017	0.0026	0.0026	0.0017	0.0017	0.0009	0.0026	0.0026	0.0026	0.0026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	21	2.09E-05	1.49E-05	1.48E-05	5.95E-06	4.48E-06	1.63E-05	0.0026	0.0017	0.0026	0.0017	0.0017	0.0017	0.0017	0.0034	0.0017	0.0017	0.0009	0.0017	0.0017	0.0017	0.0026	0.0017	0.0009	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	22	1.87E-05	2.23E-05	9.67E-06	5.20E-06	3.75E-06	1.49E-05	0.0017	0.0026	0.0017	0.0017	0.0026	0.0026	0.0026	0.0026	0.0009	0.0009	0.0017	0.0009	0.0017	0.0017	0.0009	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	23	1.49E-05	1.49E-05	7.44E-06	5.93E-06	2.26E-06	1.63E-05	0.0009	0.0017	0.0026	0.0017	0.0017	0.0017	0.0017	0.0017	0.0009	0.0017	0.0009	0.0009	0.0009	0.0017	0.0017	0.0017	0.0017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0