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A DEVELOPMENT MODEL FOR IDENTIFYING THE UNCERTAINTY SOURCES AND THEIR IMPACTS ON BRIDGE CONSTRUCTION PROJECTS

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Abstract. Bridge construction projects are rife with uncertainty because of their unique features, from execution of the work, time estimation, inspection and assessment to fund allocation. Therefore, a critical step is recognise and categorise the uncertainties associated in bridge building in order to meet project objectives in terms of quality, cost, schedule, environmental, safety, and technical indicators. Various models, however, have been created to detect

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and prioritise the uncertainty. One of the most commonly used approaches for dealing with uncertainty is the spherical fuzzy set. To formulate an issue, this technique uses a mathematical procedure. The analytic hierarchy process (AHP), on the other hand, is a computer technique that solves a complicated problem by breaking it down into numerous basic problems. A hybrid model based on spherical fuzzy sets and AHP (SAHP) can benefit from both approaches. This study proposes a SAHP based on group decision making (GSAHP) to prioritise the sources of uncertainty in bridge construction projects. Likewise, a modified algorithm is proposed for checking the consistency of the spherical fuzzy matrices. To show the model potential, a real case study is illustrated and evaluated. The model demonstrates its capabilities in modelling uncertainty under an environment with a number of unknown components. The findings reveal that the "delays" factor is of the highest, and the "project team conflicts" parameter is of the least importance. The research findings could be used by decision makers and managers to develop preventive measures.

Keywords: bridge construction project, GSAHP, spherical fuzzy set, uncertainty.

Introduction

The bridge construction industry is known as a primary conduit for infrastructure and superstructure development. This industry often includes a set of the tasks that should be completed within a specific timeline to finish a project for a deadline (Weishaar, 2018). The project manager, responsible for planning and scheduling, has to make complex decisions for the successful execution of the project.

The bridge construction industry is an ever-changing and complex industry that has crucial and pivotal contribution to transportation development. The market size of the global bridge construction is estimated to be $1212.6 billion in 2027; whereas, it was valued at $908.0 billion in 2019 (AMR, 2020). This means that there is a compound annual growth rate of 4.6%. Since economic growth in developing and developed economies increases, the global bridge construction market can register strong growth. In addition, new technologies with the purpose of reducing time and cost can increase the growth of the market even further.

Based on the reports, the cable-stayed bridge sector had a high share in 2019; including approximately one-third of the world market (AMR, 2020). It is estimated to this sector will maintain its position during the next decade. This has resulted from making government investments in transportation development.

However, a cable-stayed bridge construction project copes with different uncertainties because of the unknown nature of land, operations, and activities (Gimsing & Georgakis, 2012; Ghousi et al., 2018; Mohammadi Atashgah et al., 2022). These uncertainties are originated from political, social, economic, and physical circumstances. These circumstances affect all the fundamental parameters, resulting in planning, scheduling, controlling, adjustment, and decision making. However, a bridge construction project is inherently uncertain and risky because of its unique nature. Uncertainty is a situation in which there is an incomplete understanding of the system to be managed (Zheng & Carvalho, 2016).

Different researchers have demonstrated the key role of risk and uncertainty in construction projects. A formal model for qualitative risk assessment based on a hierarchical risk breakdown structure was developed by Carr & Tah (2001). Szymański (2017) presented a risk management process to assess the challenges in construction projects. Akintoye & MacLeod (1997) demonstrated that risk analysis and management in construction mainly depended on intuition, judgment, and experience. Moghayedi & Windapo (2019) investigated the uncertainty events involved in the process of constructing highways and evaluated their impact on construction time. Bahamid & Doh (2017) introduced a systematic approach, including risk response, risk analysis, and risk identification, to assess risk management in the construction industry. Schieg (2006) proposed a risk management process comprising of six steps. Banaitiene & Banaitis (2012) used risk management techniques to identify the hazards in construction projects.

Iqbal et al. (2015) developed a questionnaire-based survey on risk management in construction projects, reporting the significance of the different types of risk. They investigated two types of risk management techniques, namely, preventive and remedial techniques. The first technique was employed in the design and planning phase. Whereas, the second technique was used in the executive phase. Ward & Chapman (2008) proposed a new framework based on project uncertainty with nine phases, including project definition, uncertainty management, uncertainty sources, problem definition, ownership clarification, variability estimation, uncertainty implications, development plans, and management implementation. Zheng & Carvalho (2016) used a systematic literature review to propose a framework for managing uncertainties. Katrekar et al. (2018) described a methodology to systemise, model, and diminish uncertainty.

However, most of the aforementioned studies used fuzzy set theory and demonstrated this tool as a reliable problem-solving approach. Nonetheless, the ordinary fuzzy set has some drawbacks in facing the uncertainty involved in a practical project, including disability in defining the thoughts of decision makers on membership functions with more details. Therefore, to overcome such shortage issues, several techniques have been extended, including spherical fuzzy sets, orthopair fuzzy sets, picture fuzzy sets, Pythagorean fuzzy sets, hesitant fuzzy sets, non-stationary fuzzy sets, neutrosophic fuzzy sets, intuitionistic fuzzy sets, and type 2 fuzzy sets (Kahraman & Gündoğdu, 2018; Yager, 2016; Cuong, 2014; Yager & Abbasov, 2013; Torra & Narukawa, 2009; Garibaldi & Ozen, 2007; Smarandache, 1998; Zadeh, 1975; Atanassov, 1986). The spherical fuzzy sets are the last version of the fuzzy set theory that can formulate a problem by three indices – degree of positive membership, degree of neutral membership, and degree of negative membership. However, the process of identification and priority of the uncertainty challenges resulting in a critical disaster for managers is a key problem in project management. This process prevents financial and non-financial resources from wasting by a resource allocating process. In this paper, the Rumsfeld matrix is used to extract the uncertainty sources under a systematic approach. On the other hand, the analytic hierarchy process (AHP) is a mathematical tool to solve a complex problem by decomposing the issue into several simple problems. In order to minimise the decision errors, a group decision based on an expert team is made. The main aim of the paper is to propose a reliable framework in order to (i) identify the major threats; (ii) prioritise the sources of uncertainty; (iii) take into account both numerical data and subjective information in the process of modelling; (iv) formulate a problem by a group of experts instead of individual decision making; (v) check the consistency of the spherical fuzzy matrices by developing a modified algorithm; (vi) recognise the most important sources of uncertainty, and (vii) diminish, mitigate, and eliminate the most of these sources.

The rest of the paper is organised as follows. The next section illustrates the definition of uncertainty. Then, the uncertainty sources are identified by a literature survey and face-to-face interviews in Section 3. The spherical AHP (SAHP), including spherical fuzzy sets, SAHP, and GSAHP, is described in Section 4. Section 5 describes how a real problem is solved by the proposed model. Finally, the conclusions are explained in the last section.

1. Uncertainty

Uncertainty has been initially discussed by economists and psychologists (Perminova, 2011). Then, the uncertainty has been integrated with other scientific fields such as project management and risk analysis (Asadi et al, 2018). Based on the literature survey, there is a lack of consensus pertaining to the definition of uncertainty (Padalkar & Gopinath, 2016). Therefore, different researchers have proposed new definitions of uncertainty in the literature. However, these arguments define the uncertainty as a situation where full knowledge is not available or it is difficult to clearly understand a particular situation (Ranasinghe et al., 2021).

The bridge construction industry is distinguished as a project-based activity (Dubois & Gadde, 2002). Based on the general context of a bridge construction project, there are ill-defined and unknown challenges resulted from unknown-unknowns (Ramasesh & Browning, 2014). Baccarini (2019) illustrated the scope of uncertainties as known-knowns (total certainty), known-unknowns (risks), and unknowns-unknowns (unfathomable uncertainty). Such unknowns can lead to a great deal of uncertainty about the project's future. However, a basic assumption in bridge project management expresses that the implementation process has a linear and sequential pattern. Nonetheless, Wood & Ashton (2009) demonstrated that the construction process is a dynamic and sophisticated approach with a lot of uncertainties. On the other hand, at the beginning of a project, there is a lack of information and knowledge on the project life cycle that proliferates the uncertainty imposed by the project. These unknowns can lead to time delays, unsafe conditions, and cost overruns (Ranasinghe et al, 2021). However, a project can be divided into three main phases, including the conceptual phase, design phase, and construction phase (Yacob et al, 2017). Whilst uncertainties are not well identified and assessed at an early phase (design and planning), vulnerabilities can be revealed at the construction phase (Nibbelink et al, 2017). Therefore, it is vital to extract the uncertainty sources at the early phase (planning and design phase). However, there is a lack of consistency in recognising the challenging uncertainties. Therefore, further study is critical to develop a robust model for identifying the most important uncertainty sources in bridge construction projects.

The impact of uncertainty on the critical infrastructures has been investigated by different studies (Yazdani et al., 2011; Fouladgar et al., 2012; Yazdani-Chamzini et al., 2013; Yazdani-Chamzini, 2014a; Antunes & Gonzalez, 2015; Moret & Einstein, 2016; Asadi et al., 2018; Alkhaleel et al., 2022). Since bridge construction projects have unique features, uncertainty events are more frequent in comparison with other construction projects. These events result from mobile construction sites, repetitive non-linear processes, dynamic processes, the lengthy duration of construction, and the complexity of interaction between major construction activities (Flyvbjerg, 2007).

2. Identification of uncertainty sources in bridge construction projects

The proposed model used a literature review and interviews with experts to classify all the potential uncertainty events and factors. Aziz & Abdel-Hakam (2016) identified 15 major delay groups, including 293 disruptive events, to analyse the delay causes of projects. Odediran & Windapo (2018) extracted 5 major parameters, comprising 81 risks, in construction markets. They grouped these risks into design and construction, procurement, economic/financial, social, and political. Assaf & Al-Hejji (2006) classified 73 uncertainty events into eight groups, containing equipment, design, materials, contractor, owner, project, labour, and external parameters, to evaluate reasons for delays in construction projects. In this paper, the uncertainty events in bridge projects are categorised into seven main indicators: financial, technical, social, political, legal, environmental, and economic (as presented in Table 1).

However, a long list of uncertain events is recognised by a review of the literature. These events are classified into the main groups mentioned above. Table 2 lists the most critical uncertainty indicators and their corresponding sub-indicators in bridge construction projects.

3. Rumsfeld matrix

The Rumsfeld matrix is one of the widely used methods in uncertainty identification (McManus & Haddad, 2014). This method divides the challenges into four main groups: known-unknowns, known-knowns, unknowns-known, and unknowns-unknowns (Table 2). The first group shows that we know there are some things we do not know. Therefore, although the data are unknown, the technique of retrieval is known. The second group reflects that these are some things that we can quickly assess and can accurately estimate because we have done similar things in the past (Tercan, 2019). Therefore, a known-known is perceived as something absolutely certain. The third quadrant expresses that the technique to determine retrieval strategy is unknown but the dataset is available. The last quadrant indicates that both the data and retrieval strategy are unknown. This group is recognized as the most difficult one (Valk & Goldbach, 2021). This category not only reflects some things we do not know; but only takes into account a technique in order to trace unknown-unknowns. In other words, it is almost impossible to predict some things that can seriously impact the aim.

Table 1. Criteria and their description

Criteria	Description	Reference
Monetary indicators	Monetary indicators reflect concerns connected to the project finance and the micro and macro-economic impacts on the bridge project implementation. Several researchers have demonstrated the change in the foreign exchange rate, the monopoly of equipment and material providers, poor financial program, cash flow problems, and the fluctuation in prices of equipment and materials can significantly affect project outcomes.	Liu et al., 1995; Leu & Yang, 1999; Yang et al., 2014; Cheng & Tran, 2015; Zou et al., 2017; Choi & Park, 2019; Ahadian et al., 2016; Lu et al., 2016; Tran & Long, 2018; Hosseinzadeh et al., 2020; Kannimuthu et al., 2019; Liu et al., 2020; Orm & Jeunet, 2018; Leyman et al., 2019
Environmental indicators	Environmental indicators comprise the problems related to biological, natural, and ecological actions confronting the project. Air contamination, weather pollution, flood, fire, and topological condition of the site are recognised as the most critical environmental components affecting project performance.	Cheng & Tran, 2015; Panwar & Jha, 2019; Zheng, 2017
Labour utilization indicators	Manpower or labour, one of the most crucial resources in many countries, requires an organised schedule because of its beneficial impact on the project performance. A powerful schedule can lead to the enhancement of on-site safety and the reduced costs of temporary facilities for workers (Hoang et al., 2015).	Adeli & Karim, 1997; Tran et al., 2016; Tran et al., 2017; Lu et al., 2016
Quality indicators	Quality is among the most essential components in project management, so, without considering the standards, the accomplished structure may pose severe safety and health hazards. A structure that ignores quality standards may also lead to rework costs and cause reputational damage, potentially diminishing future work opportunities[1].	Bingol & Polat, 2015; Ahadian et al., 2016; Kannimuthu et al., 2019; Hosseinzadeh et al., 2020; Orm & Jeunet, 2018; Luong et al., 2018; Zheng, 2017
Time indicators	The key role of time management in construction projects is critical and necessary. To create effective time management, a project schedule based on reasonable time estimation is implemented (El-Karim et al., 2017; Naderpour et al., 2019).	Liu et al., 1995; Leu & Yang, 1999; Yang et al., 2014; Cheng & Tran, 2015; Zou et al., 2017; Choi & Park, 2019; Ahadian et al., 2016; Tran & Long, 2018; Hosseinzadeh et al., 2020; Kannimuthu et al., 2019; Liu et al., 2020; Orm & Jeunet, 2018
Technical indicators	Technical indicators show the concerns related to the design and implementation. These technical indicators reflect different events associated with technology, safety, design changes, professional consultants, materials, equipment, and skilled labour.	Elhag & Wang, 2007; Gosling et al., 2012; Aziz & Abdel-Hakam, 2016; Lu et al., 2016; Odediran & Windapo, 2018; Tran & Long, 2018; Hosseinzadeh et al., 2020; Ning & Lam, 2013

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Since these things are unpredictable with the existing data, it is critical to develop a robust model in order to formulate the problem by using subjective and judgment information.

To achieve the aim, a top-down inventory is made to identify the factors resulting in a potential threat. To better understand, you are aware that the threat is present, but the exact results are generally uncertain and unknown. Therefore, some techniques can be employed to evaluate and face the sources of uncertainty.

4. Spherical analytic hierarchy process (SAHP)

4.1. Spherical fuzzy soft sets

The real problems are rife with vagueness, imprecision, and uncertainty. Generally, information that results from different sources is often precise and less adapted to real world issues because of the uncertainty imposed by the problem under consideration. Therefore, a number of theories such as fuzzy set (Zadeh, 1965), vague set (Gau & Buehrer, 1993), and rough set (Pawlak, 1982) have been developed to consider the uncertainty. However, these techniques have some limitations and drawbacks, such as disability in defining the thoughts of decision makers on membership functions with more details. To overcome such limitations, new algorithms have been proposed such as intuitionistic fuzzy sets (Atanassov, 1986), Pythagorean fuzzy sets (Yager, 2013), picture fuzzy sets (Cuong & Kreinovich, 2013), and spherical fuzzy sets (Ashraf et al., 2019).

The spherical fuzzy set (SFS) has been developed to conquer the drawbacks of earlier versions. This technique provides incredible significance to efficiently manage human opinions (Gündo & Kahraman, 2019). This method uses three degrees to an element x, namely degree of positive membership α, degree of neutral membership γ, and degree of negative membership β, under the constraint $0 \leq \alpha(x)^2 + \beta(x)^2 + \gamma(x)^2 \leq 1$. Therefore, the SFS can cover more space in comparison with the picture

Table 2. Rumsfeld matrix

Data Retrieval	Known	Unknown
Known	Known-Known	Known-Unknown
Unknown	Unknown-Known	Unknown-Unknown

fuzzy set (PFS). Figure 1 depicts the difference between the space of SFS and PFS.

An *SFS* (δ) on a universe U is an object of the form

$$\delta = \left\{ \left(x, \alpha_\delta(x), \beta_\delta(x), \gamma_\delta(x) \right) \middle| x \in U \right\} \tag{1}$$

where α_δ, γ_δ, and β_δ satisfy the following constraint:

$$\forall x \in U, \alpha_\delta^2(x) + \beta_\delta^2(x) + \gamma_\delta^2(x) \le 1 \tag{2}$$

and

$$\alpha_\delta(x), \gamma_\delta(x), \text{ and } \beta_\delta(x) \in [0,1].$$

Then for $x \in U, \pi_\delta(x) = \sqrt{1 - \alpha_\delta^2(x) - \gamma_\delta^2(x) - \beta_\delta^2(x)}$ denotes the degree of refusal-membership of x in U.

The union, intersection, and complement for two SFSs A and B over a universe U can be described as follows:

$$A \subseteq B \text{ if } \forall x \in U, \alpha_A(x) \le \alpha_B(x), \gamma_A(x) \le \gamma_B(x); \tag{3}$$

$$A = B \text{ if and only if } A \subseteq B \text{ and } B \subseteq A; \tag{4}$$

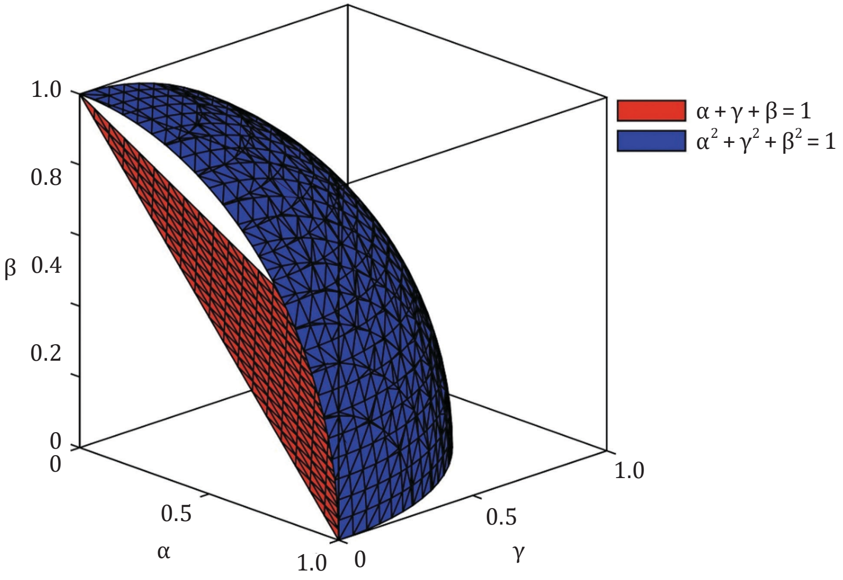

Figure 1. Comparison between spaces of SFS and PFS (Akram, 2021)

$$A \cap B = \left\{ \begin{pmatrix} x, \\ \min\{\alpha_A(x),\alpha_B(x)\}, \\ \min\{\gamma_A(x),\gamma_B(x)\}, \\ \max\{\beta_A(x),\beta_B(x)\} \end{pmatrix} \middle| x \in U \right\}; \tag{5}$$

$$Co(A) = A^c = \left\{ \left(x, \beta_A(x), \alpha_A(x), \gamma_A(x) \right) \middle| x \in U \right\}; \tag{6}$$

$$A \cup B = \left\{ \begin{pmatrix} x, \\ \max\{\alpha_A(x),\alpha_B(x)\}, \\ \min\{\gamma_A(x),\gamma_B(x)\}, \\ \min\{\beta_A(x),\beta_B(x)\} \end{pmatrix} \middle| x \in U \right\}. \tag{7}$$

4.2. SAHP

The analytic hierarchy process (AHP), one of the widely employed techniques in science and engineering, is capable of determining the priority of the elements in the form of a multi-criteria decision-making (MCDM) method. This technique uses a structured approach to solve a complex problem by decomposing the issue into several simple problems (Rabbani et al., 2014; Yazdani-Chamzini, 2014b). The AHP method employs a five-step process to obtain the priority of the elements (Xu & Liao, 2014), including problem definition, decomposition, comparative judgments, consistency check, and prioritization.

In real-world problems, decision-makers are unable to evaluate the importance weights of the elements by using an exact numerical value because of a lack of information, incomplete knowledge, and the vagueness of data. In such situations, fuzzy sets and later versions, such as SFS are well-known as the most critical techniques in capturing the uncertainty connected to the human judgment process.

A spherical fuzzy evaluation on a limited set of criteria $C = \{c_1, c_2, \ldots, c_n\}$ is represented by a decision matrix:

$$R = \left[r_{ij} \right]_{n \times n}, \tag{8}$$

where

$$r_{ij} = \left\langle (x_i, x_j), \alpha(x_i, x_j), \beta(x_i, x_j), \gamma(x_i, x_j) \right\rangle, \forall i, j = 1, 2, \ldots, n. \tag{9}$$

The above relation can be simply rewritten as:

$$r_{ij} = \left(\alpha_{ij}, \beta_{ij}, \gamma_{ij} \right). \tag{10}$$

The degree to which the element x_i is preferred to the element x_j is represented by $\alpha(x_i, x_j)$, while $\beta(x_i, x_j)$ expresses the degree to which the element x_i is not preferred to the element x_j, and $\gamma(x_i, x_j)$ indicates the inability to represent the evaluation under the following conditions:

$$\alpha_{ij} = \beta_{ji}, \beta_{ij} = \alpha_{ji}, \text{ and } \gamma_{ij} = \gamma_{ji}$$

and

$$\alpha_{ii} = \beta_{ii} = \gamma_{ii} = 0.5, \forall i, j = 1,2,\ldots,n. \quad (11)$$

The procedure of the proposed SAHP under group decision making (GSAHP) can be defined as follows:

Step 1. Problem definition and hierarchy construction. The first step is similar to the traditional AHP.

Step 2. Construction of spherical fuzzy pairwise comparison matrix. This study makes two-by-two comparisons in order to form the spherical pairwise comparison matrix.

Step 3. Combine questionnaire results. To obtain the overall output, the individual matrices are aggregated by using the spherical geometric mean (SGM) operator as follows (Mahmood et al., 2019):

$$SGM\left(r_{jk}^{(1)}, r_{jk}^{(2)}, \ldots, r_{jk}^{(n)}\right) =$$

$$= \left(\left(\prod_{s=1}^{n} \left(\alpha_{kj}^{(s)} + \gamma_{jk}^{(s)} \right) \right)^{\frac{1}{n}} - \left(\prod_{s=1}^{n} \gamma_{jk}^{(s)} \right)^{\frac{1}{n}}, \sqrt{1 - \left(\prod_{s=1}^{n} \left(1 - \left(\beta_{jk}^{2} \right)^{(s)} \right) \right)^{\frac{1}{n}}}, \left(\prod_{s=1}^{n} \gamma_{jk}^{(s)} \right) \right). \quad (12)$$

Step 4. Check the consistency. There are two methods to check the consistency (i) by converting the SFS numbers into a corresponding crisp value with defuzzification process and then using the Saaty method (Saaty, 1980) and (ii) by employing the algorithm developed by Xu & Liao (2014). The authors developed a modified version of the algorithm to check the consistency of the SFS matrices. This algorithm uses the following phases to check the consistency for a perfect multiplicative consistent spherical preference relation $R' = (r'_{ik})_{n\times n}$.

Phase 1. For $k > i + 1$, let $r'_{ik} = \left(\alpha'_{ik}, \beta'_{ik}, \gamma'_{ik}\right)$, where (Xu & Liao, 2014):

$$\alpha'_{ik} = \frac{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1} \alpha_{it}\alpha_{tk}}}{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1} \alpha_{it}\alpha_{tk}} + \sqrt[k-i-1]{\prod_{t=i+1}^{k-1} (1-\alpha_{it})(1-\alpha_{tk})}}; \quad (13)$$

$$\beta'_{ik} = \frac{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1} \beta_{it}\beta_{tk}}}{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1} \beta_{it}\beta_{tk}} + \sqrt[k-i-1]{\prod_{t=i+1}^{k-1} (1-\beta_{it})(1-\beta_{tk})}}; \quad (14)$$

$$\gamma'_{ik}=\frac{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1}\gamma_{it}\gamma_{tk}}}{\sqrt[k-i-1]{\prod_{t=i+1}^{k-1}\gamma_{it}\gamma_{tk}}+\sqrt[k-i-1]{\prod_{t=i+1}^{k-1}(1-\gamma_{it})(1-\gamma_{tk})}}. \qquad (15)$$

Phase 2. For $k = i + 1$, let $r'_{ik} = r_{ik}$.

Phase 3. For $k < i$, let $r'_{ik} = (\beta'_{ki}, \alpha'_{ki}, \gamma'_{ki})$.

Phase 4. Measure the distance between the given sphere preference relation R and its corresponding perfect multiplicative consistent sphere preference relation R' by the following equation:

$$d(R',R)=\frac{1}{2(n-1)(n-2)}\sum_{i=1}^{n}\sum_{k=1}^{n}\left(\left|\alpha'_{ik}-\alpha_{ik}\right|+\left|\beta'_{ik}-\beta_{ik}\right|+\left|\gamma'_{ik}-\gamma_{ik}\right|\right). \qquad (16)$$

The matrix is consistent if $d(R',R) < \tau$,
where τ indicates the consistency threshold. If $d(R',R) > \tau$, then construct the fused preference relation by using the following equations $[\tilde{R}' = (\tilde{r}'_{ik})_{n\times n}, \tilde{r}'_{ik} = (\tilde{\alpha}'_{ik}, \tilde{\beta}'_{ik}, \tilde{\gamma}'_{ik})]$:

$$\tilde{\alpha}'_{ik}=\frac{(\alpha_{ik})^{1-\sigma}(\alpha'_{ik})^{\sigma}}{(\alpha_{ik})^{1-\sigma}(\alpha'_{ik})^{\sigma}+(1-\alpha_{ik})^{1-\sigma}(1-\alpha'_{ik})^{\sigma}}; \qquad (17)$$

$$\tilde{\beta}'_{ik}=\frac{(\beta_{ik})^{1-\sigma}(\beta'_{ik})^{\sigma}}{(\beta_{ik})^{1-\sigma}(\beta'_{ik})^{\sigma}+(1-\beta_{ik})^{1-\sigma}(1-\beta'_{ik})^{\sigma}}; \qquad (18)$$

$$\tilde{\gamma}'_{ik}=\frac{(\gamma_{ik})^{1-\sigma}(\gamma'_{ik})^{\sigma}}{(\gamma_{ik})^{1-\sigma}(\gamma'_{ik})^{\sigma}+(1-\gamma_{ik})^{1-\sigma}(1-\gamma'_{ik})^{\sigma}}, \qquad (19)$$

where σ indicates a controlling parameter given by the decision team. The smaller the value of σ, the closer $\tilde{R}'$ is to R'.

By using this process, the consistency rate of any preference relation can be improved without losing much basic information. This process also can modify the time-consuming procedure of the interactive method for the decision makers. This helps decision makers to quickly reach a decision.

Next, the distance $d(R',\tilde{R}')$ is calculated by the following equation:

$$d(R',\tilde{R}')=\frac{1}{2(n-1)(n-2)}\sum_{i=1}^{n}\sum_{k=1}^{n}\left(\left|\alpha'_{ik}-\tilde{\alpha}'_{ik}\right|+\left|\beta'_{ik}-\tilde{\beta}'_{ik}\right|+\left|\gamma'_{ik}-\tilde{\gamma}'_{ik}\right|\right). \qquad (20)$$

If $d(R',\tilde{R}') < \tau$, then output $\tilde{R}'$; otherwise, change the controlling parameter and accomplish similar calculations.

Step 5. Determine the local and global priorities. To achieve the aim, the following equation is used to aggregate each row:

$$r^{i}=\left(\prod_{j=1}^{n}r_{ij}\right)^{1/n}. \qquad (20)$$

To find the weight of each aggregated row, several functions have been introduced. Gündoğdu & Kahraman (2019) defined the score function as $Score(\tilde{A}_s) = (\alpha_{\tilde{A}_s} - \gamma_{\tilde{A}_s})^2 - (\beta_{\tilde{A}_s} - \gamma_{\tilde{A}_s})^2$. Gündoğdu & Kahraman (2021) introduced the score function as

$$Score(\tilde{A}_s) = \left(2\alpha_{\tilde{A}_s} - \frac{\gamma_{\tilde{A}_s}}{2}\right)^2 - \left(\beta_{\tilde{A}_s} - \frac{\gamma_{\tilde{A}_s}}{2}\right)^2.$$

Karasan et al. (2021) defined the score function as

$$Score(\tilde{A}_s) = \left(\alpha_{\tilde{A}_s} - \frac{\gamma_{\tilde{A}_s}}{2}\right)^2 - \left(\beta_{\tilde{A}_s} - \frac{\gamma_{\tilde{A}_s}}{2}\right)^2.$$

These functions have some drawbacks in obtaining the importance weights. The score function based on the algorithm introduced by Gündoğdu & Kahraman (2019) may lead to an error in the results. For instance, a spherical set with the values (0.6, 0.6, 0.4) gives a value of zero, while a set with the values (0.1, 0.9, 0.1) gives a negative score of 0.64. Likewise, for two different sets, the algorithm may give a similar score. For instance, the spherical sets (0.4, 0.3, 0.1) and (0.7, 0.6, 0.4) produce the equal value of 0.05.

Likewise, the score function based on the algorithm developed by Gündoğdu & Kahraman (2021) may produce an error value. For instance, a set with values (0.3, 0.6, 0.2) produces a value of zero, while a set with values (0.3, 0.7, 0.2) produces a negative value of 0.11. In the same way, the algorithm developed by Karasan et al. (2021) can also produce a value of negative or zero. Therefore, Sharaf (2021) proposed the score function as $F(\tilde{A}_s) = \alpha(1-\beta)(1-\gamma)$. However, the Sharaf's algorithm also has some disadvantages. For instance, two spherical sets (0.8, 0.4, 0.1) and (0.8, 0.1, 0.4) produce the equal value of 0.432. Hence, in this study, a new function score is introduced to obtain the value of each combined row as follows:

$$F\left(\tilde{A}_s\right) = \alpha\left(1-\beta\right)\left(1-\frac{\gamma}{2}\right). \tag{22}$$

Then, the overall weight is obtained by the following equation:

$$\sum_{i=1}^{n} F(r^i). \tag{23}$$

Finally, the priority vector is obtained by the following equation:

$$w_i = \frac{F\left(r^i\right)}{\sum_{i=1}^{n} F\left(r^i\right)}. \tag{24}$$

5. Model development

5.1. A real case

Cable-stayed bridge projects in Iran are illustrated to investigate the effectiveness of the model proposed by this research. Since the first modern cable-stayed bridge in Iran was built in 1997, cable-stayed bridges were popularly structured (Maleki, 2013). This is due to the versatile nature of cable-stayed bridges, selected for different span lengths from footbridges less than 50 m in length up to spans of more than 1000 m (Vejrum & Nielsen, 2014). This bridge carries vertical loads by transferring tensions into the towers under a mechanical transformation system.

5.2. The implementation process

In the first step, the possible uncertain components are extracted by using the Rumsfeld matrix. A cable stayed bridge project has three main phases, including conceptual analysis, design and planning, and construction. Each phase can be known as a potential source of uncertainties. Hence, to reduce the uncertainty level, it is critical to recognise all uncertain events involved in the phases. The Rumsfeld matrix proposes a practical framework to identify the uncertainties (unknown-unknowns) dramatically impacting project development. By using the literature review and interviews with the expert team under the Rumsfeld matrix, twenty uncertain events (sub-criteria) are recognized as shown in Table 3. From the table, it is obvious that these events are classified into six main groups, including time, monetary, labour utilization, environment, technical, and quality criteria.

After defining the decision problem and forming the decision hierarchy, the decision team with seven experts is asked to express their opinions based on the scale given in Table 4. A sample of the questionnaire filled by the expert team is presented in Table 5.

Then, the questionnaires are aggregated by using the SGM equation. The aggregated decision matrix is shown in Table 6. Next, the consistency of the decision matrix is checked by using the modified version of the algorithm developed by Xu & Liao (2014). The R' matrix is obtained after the developed calculation process as depicted in Table 7. Since $d(R',R)=0.1685>0.1$, the fused preference relation should be formed. After considering σ = 0.8 under a trial and error process, the decision matrix is constructed as shown in Table 8. Since $d(R',\tilde{R}')=0.03<0.1$, the resulted matrix is now consistent.

Table 3. Structure of the decision hierarchy

No.	Criteria	Sub-criteria
1	Time (C1)	C11. Delays C12. Scheduling errors C13. Material delivery
2	Monetary indicators (C2)	C21. Cash inflow C22. Financing C23. Cost overrun C24. Inflation rate C25. Exchange rate
3	Labour utilization (C3)	C31. Inexperienced workforce C32. Labour productivity C33. Project team conflicts
4	Environment (C4)	C41. Unexpected weather situation C42. Natural disasters C43. Air and water pollution
5	Technical (C5)	C51. Safety C52. Design changes C53. Technology changes
6	Quality (C6)	C61. Customer satisfaction C62. Quality requirements C63. Design errors

Table 4. Linguistic terms and their corresponding spherical fuzzy numbers

Linguistic terms	Spherical fuzzy numbers
Strongly high importance (SHI)	(0.9,0.1,0.1)
Very high importance (VHI)	(0.8,0.2,0.2)
High importance (HI)	(0.7,0.3,0.3)
Relatively high importance (RHI)	(0.6,0.4,0.4)
Equally importance (EI)	(0.5,0.5,0.5)
Relatively low importance (RLI)	(0.4,0.6,0.4)
Low importance (LI)	(0.3,0.7,0.3)
Very low importance (VLI)	(0.2,0.8,0.2)
Strongly low importance (SLI)	(0.1,0.9,0.1)

Table 5. A sample of the questionnaire filled by one of the team members

	C1	**C2**	**C3**	**C4**	**C5**	**C6**
C1	EI	EI	VHI	RHI	RHI	HI
C2	EI	EI	SHI	HI	RHI	HI
C3	VLI	SLI	EI	LI	VLI	LI
C4	RLI	LI	HI	EI	RLI	EI
C5	RLI	RLI	VHI	RHI	EI	HI
C6	LI	LI	HI	HI	LI	EI

Table 6. The aggregated matrix

	C1			**C2**			**C3**			**C4**			**C5**			**C6**		
C1	0.50	0.50	0.50	0.53	0.47	0.47	0.77	0.22	0.22	0.63	0.37	0.37	0.61	0.38	0.38	0.73	0.27	0.27
C2	0.47	0.53	0.47	0.50	0.50	0.50	0.88	0.11	0.11	0.70	0.30	0.30	0.60	0.40	0.40	0.70	0.30	0.30
C3	0.22	0.77	0.22	0.11	0.88	0.11	0.50	0.50	0.50	0.30	0.70	0.30	0.21	0.78	0.21	0.27	0.73	0.27
C4	0.37	0.63	0.37	0.30	0.70	0.30	0.70	0.30	0.30	0.50	0.50	0.50	0.41	0.58	0.41	0.51	0.48	0.48
C5	0.38	0.61	0.38	0.40	0.60	0.40	0.78	0.21	0.21	0.58	0.41	0.41	0.50	0.50	0.50	0.71	0.28	0.28
C6	0.27	0.73	0.27	0.30	0.70	0.30	0.73	0.27	0.27	0.48	0.51	0.48	0.28	0.71	0.28	0.50	0.50	0.50

Table 7. The R' matrix

	C1			**C2**			**C3**			**C4**			**C5**			**C6**		
C1	0.50	0.50	0.50	0.53	0.47	0.47	0.53	0.47	0.47	0.66	0.34	0.18	0.55	0.44	0.21	0.68	0.31	0.21
C2	0.47	0.53	0.47	0.50	0.50	0.50	0.88	0.11	0.11	0.77	0.22	0.05	0.65	0.34	0.09	0.75	0.25	0.14
C3	0.47	0.53	0.47	0.11	0.88	0.11	0.50	0.50	0.50	0.30	0.70	0.30	0.23	0.77	0.23	0.35	0.64	0.17
C4	0.34	0.66	0.18	0.22	0.77	0.05	0.70	0.30	0.30	0.50	0.50	0.50	0.40	0.60	0.40	0.64	0.36	0.22
C5	0.44	0.55	0.21	0.34	0.65	0.09	0.77	0.23	0.23	0.60	0.40	0.40	0.50	0.50	0.50	0.71	0.28	0.28
C6	0.31	0.68	0.21	0.25	0.75	0.14	0.64	0.35	0.17	0.36	0.64	0.22	0.28	0.71	0.28	0.50	0.50	0.50

Table 8. The fused preference relation

	C1			**C2**			**C3**			**C4**			**C5**			**C6**		
C1	0.50	0.50	0.50	0.53	0.47	0.47	0.58	0.41	0.41	0.65	0.34	0.21	0.56	0.43	0.24	0.69	0.30	0.22
C2	0.47	0.53	0.47	0.50	0.50	0.50	0.88	0.11	0.11	0.75	0.24	0.07	0.64	0.35	0.13	0.74	0.26	0.17
C3	0.41	0.58	0.41	0.11	0.88	0.11	0.50	0.50	0.50	0.30	0.70	0.30	0.23	0.77	0.23	0.34	0.66	0.19
C4	0.34	0.65	0.21	0.24	0.75	0.07	0.70	0.30	0.30	0.50	0.50	0.50	0.40	0.60	0.40	0.61	0.38	0.26
C5	0.43	0.56	0.24	0.35	0.64	0.13	0.77	0.23	0.23	0.60	0.40	0.40	0.50	0.50	0.50	0.71	0.28	0.28
C6	0.30	0.69	0.22	0.26	0.74	0.17	0.66	0.34	0.19	0.38	0.61	0.26	0.28	0.71	0.28	0.50	0.50	0.50

Next, the importance weights are locally determined by using the aggregation process resulted from Equation (21) as follows:

$$r^1=\left(\prod_{j=1}^{6} r_{1j}\right)^{1/6}=(0.58,0.4,0.32),$$

$$r^3=\left(\prod_{j=1}^{6} r_{3j}\right)^{1/6}=(0.28,0.67,0.26),$$

$$r^4=\left(\prod_{j=1}^{6} r_{4j}\right)^{1/6}=(0.44,0.51,0.25),$$

$$r^5=\left(\prod_{j=1}^{6} r_{5j}\right)^{1/6}=(0.54,0.41,0.27),$$

$$r^6=\left(\prod_{j=1}^{6} r_{6j}\right)^{1/6}=(0.37,0.58,0.25).$$

Then, the relative weights are determined by using Equation (22) as follows:

$$F(r^1)=0.292, F(r^2)=0.415, F(r^3)=0.081,$$

$$F(r^4)=0.189, F(r^5)=0.277, F(r^6)=0.138.$$

Finally, the priority vector is determined by using Equations (23) and (24) to assign the local weights as follows:

$$w_i=(0.21,0.299,0.058,0.136,0.199,0.099).$$

Similar computations are accomplished to obtain the final local weights as shown in Table 9.

Then, the global weights are determined by multiplying the local weights of the main criteria with those of the sub-criteria. These final weights are listed in Table 10 and illustrated in Figure 2. From the table,

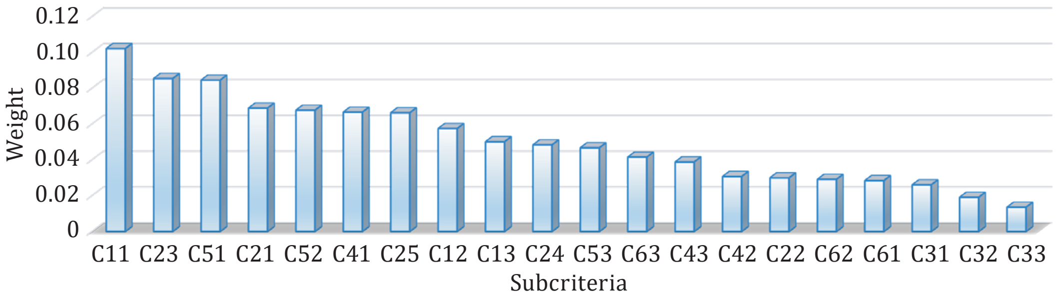

Figure 2. Priority of uncertain sources

it is clear that the most important uncertain source is delays (C11); while the least important one is project team conflict (C33) in cable-stayed bridge projects in Iran. Therefore, it is advised that authorities should reduce/mitigate/eliminate the challenges pertaining to the delays in cable-stayed projects.

Table 9. Final local weights

		C1	**C2**	**C3**	**C4**	**C5**	**C6**
		0.21	0.299	0.058	0.136	0.199	0.099
C1	**C11**	0.487					
	C12	0.274					
	C13	0.239					
C2	**C21**		0.231				
	C22		0.100				
	C23		0.286				
	C24		0.162				
	C25		0.222				
C3	**C31**			0.444			
	C32			0.325			
	C33			0.231			
C4	**C41**				0.490		
	C42				0.225		
	C43				0.285		
C5	**C51**					0.425	
	C52					0.340	
	C53					0.235	
C6	**C61**						0.287
	C62						0.294
	C63						0.419

Table 10. Final results

Factor	C11	C12	C13	C21	C22	C23	C24	C25	C31	C32	C33	C41	C42	C43	C51	C52	C53	C61	C62	C63
Weight	0.10	0.06	0.05	0.07	0.03	0.09	0.05	0.07	0.03	0.02	0.01	0.07	0.03	0.04	0.08	0.07	0.05	0.03	0.03	0.04
Rank	1	8	9	4	15	2	10	7	18	19	20	6	14	13	3	5	11	17	16	12

Conclusion

The site environment permanently poses uncertain and unknown conditions, leading to the loss of machinery and facilities or damage to public safety and health. The Rumsfeld matrix is an analytical investigation of actions to particularly examine the unknown and uncertain sources. This tool helps decision-makers create a clear boundary to what we know. This is a proper approach for predicting and quantifying future events. However, uncertainty is the main reason for possible delays and cost overruns. The merit of using a spherical fuzzy set is to properly formulate an uncertain problem. On the other hand, the AHP technique has demonstrated itself as an engineering problem-solving tool. This paper has proposed a new framework based on the Rumsfeld matrix, spherical fuzzy set, AHP, and group decision making (GSAHP) to prioritize the uncertain sources. The main goal of the proposed model is to identify and eliminate/reduce the unknowns and uncertain phenomena. This model categorises the uncertainties to accurately allocate resources in a systematic manner. The proposed model helps managers ensure that the project will be successfully completed by recognising the root causes of uncertainties. A case study is illustrated to show the effectiveness of the proposed model. The results demonstrate that the model can identify and prioritise the most important uncertain challenges. The results show that delays (C11) with the value of 0.10 is the most important uncertain source; whereas, project team conflict (C33) with the value of 0.01 is the least important one. However, the process employed by the proposed model is time-consuming, known as the main limitation of the model.

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