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Multicriteria Decision Making Methods for Supplier Selection Problems in Construction

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Abstract

Estimates for materials costs create significant variability in the final 'as built' cost of construction. Getting estimates close to accurate from the beginning of a project reduces conflict, litigation and additional financing costs. Furthermore, accurate cost estimates go a long way towards ensuring the client is ultimately satisfied with the project on hand over. Consequently, the task of identifying "best" supplier(s) of materials is central to construction procurement decision making. The construction team needs to know who is most able to supply materials at the right cost, quantity, quality as well as with a high degree of certainty of delivery in order to achieve success. Supplier selection is therefore a multiple criteria decision making (MCDM) problem. This study utilizes a five step research process; (i) to identify a comprehensive set of supplier selection criteria (SSC) by conducting a wide ranging literature review, (ii) to determine 'vital SSC' by applying 'Pareto analysis', (iii) to apply integrated AHP (Analytical Hierarchy Process) -BWM (define BWM) methods for understanding 'best versus worst SSC', from the given set of 'Vital SSC' by applying an AHP method to establish optimal weightings for each 'Vital SSC', (iv) to determine optimal weights for a given set of suppliers around each 'Vital SSC' using the AHP-BWM method, and (v) establish rankings for suppliers. The proposed five step process is demonstrated by collecting the required pairwise importance score for the set of 'Vital SSC' and suppliers from 10 experts. The novelty of this study is to combine the MCDM methods: AHP and BWM in order to enhance the decision-making process and provide a more robust and comprehensive approach for SSP in construction projects.

Keywords
Construction Industry, Supplier Selection Problem, Vital Supply Selection Criteria, MCDM Method, AHP, BWM.

1. Introduction
The rapidly expanding population and the race of urbanization have led to a rapid development in the construction industry (CI). The CI is highly dependent on a substantial number of resources and energy for the development and operation of its projects (Karamoozian et al. (2023)). The total construction cost of any construction project can be classified into cost associated with (a) materials, (b) labor, and (c) overhead. Out of these three costs, the material cost is accounted for about 40% to 45% of the total cost in any constriction project (Agapiou et al. (1998)). By and large, the labor cost in construction industry is generally based on the availability of workers within the proximity. Further, the materials cost is the one that could provide the required flexibility in minimizing the cost of any construction project (Ng and Li (2006)). These indicates that identification of "best" supplier(s) of construction materials - who will be able to supply the construction materials at the right cost, in the right quantity, with the right quality at the right time - has a critical impact among various decision issues involved in construction industry (Onesime et al. (2004)).

The decision making on supplier selection problem (SSP) in general and particularly in construction industry has many studies. Basically, the SSP is a multiple criteria decision making (MCDM) problem. Many follow a three-stage process to address the SSP. In the first stage, list of supplier selection criteria (SSC) for supplier selection needs to be identified, importance/weights need to be obtained in the second stage, and in the third stage supplier is selected considering different selection method(s).

This study attempts to (a) identify a set of supplier selection criteria (SSC) and (b) apply an integrated MCDM methods for obtaining (i) best and worst criteria from the set of identified SSC – using Analytical Hierarchy Process (AHP) method, and (ii) optimal weight/importance for each of the identified SSC (considering the best and worst SSC obtained using AHP method) – using Best-Worst Method (BWM). The novelty of this study is to combine the MCDM methods: AHP and BWM in order to enhance the decision-making process and provide a more robust and comprehensive approach for SSP in construction projects.

2. Literature Review

The SSP is one of the classical problems which requires MCDM approaches. So many researchers used MCDM method(s) for addressing SSP in the context of CI. A brief review of the same is presented here.

Prior to 2006, the use of MCDM techniques for SSP in the CI was not so common. Hadikusumo et al. (2005) proposed a decentralized database system supported with electronic agents for identification of the right set of suppliers. The authors proved their system to be beneficial in reducing the time required for supplier selection and cutting down costs. Similarly, Ng and Li (2006) developed a parallel bargaining protocol to analyze the characteristics of the process for sourcing suppliers. However, the authors addressed the immediate limitation of the protocol being biased towards the contractors, placing the suppliers at a disadvantage.

Since 2006, researchers started exploring the usage of MCDM techniques to evaluate the choice of suppliers for the CI. Bayazit et al. (2006) aimed to identify the SSP criteria for a real-world case using a Turkish construction company. The authors considered three main criteria namely – logistical performance, commercial structure and production. Lam et al. (2010) aimed to study a supplier selection model based on Fuzzy Principal Component Analysis (FPCA) for SSP in the construction perspective. The authors defined four fundamental supplier selection criteria (SSC) namely – price, delivery, quality and services following the literature and consultation with the property developers.

Patil and Kumthekar (2016) selected the top suppliers of the bulk materials: cement and steel amongst fifteen suppliers in an Indian construction company by using the traditional AHP. They stated the immediate limitation of the dependence of AHP on human perceptions, which could bear a negative impact on the pairwise comparisons. This limitation was addressed by Plebankiewicz and Kubek (2016) who aimed to explore the evaluation of suppliers by using fuzzy AHP. For their research, a committee of three decision-makers was formed.

Basar (2018) used only AHP to effectively evaluate the SSP in the Turkish construction sector. The author categorized eleven SSC under three major headings – suppliers, product performance and service performance. For identification of the said SSC, interviews were conducted with the procurement officers in the white goods sector in Turkey. The study mentioned this as a limitation since these officers were the only selected individuals to be interviewed in the construction sector of Turkey. Hence, the author suggested to use a larger sampling group for future research aspect. Along the same lines, Zhao et al. (2019) used AHP to determine the importance of all the SSC and sub-SSC. The authors proposed a three-step methodology and applied their proposed methodology to a real-life fabrication project. Asaad and Sayegh (2021) aimed to identify the key SSC necessary for evaluation of green suppliers for the CI in UAE. Based on an extensive review of literature, the authors identified twenty SSC and categorized them under four heads – technical and commercial bid, company characteristics, environmental and socio-economic. The authors then employed AHP to perform pairwise comparison amongst the identified SSC. Their results indicated that the SSC under technical and commercial bid category obtained the highest weight of 0.338.

For the first time in the available research, the Best-Worst Method (BWM) for SSP in CI was introduced by Hoseini et al. (2021). In the first phase, the authors determined nineteen SSC considering all the three aspects of sustainability. They then developed a fuzzy BWM for a sustainable SSP to compute the SSC weights and simulate suppliers' performance simultaneously. They concluded that their approach resulted in a more practical and efficient model in real-life cases, unlike other MCDM techniques, which additionally posed computational difficulties.

Similarly, Singh et al. (2023) adopted the BWM method to prioritize SSC according to their level of significance for a sustainable SSP in the Indian construction sector. The authors identified a total of twenty-seven SSC addressing the three dimensions of the triple bottom line paradigm. Their findings highlighted that SSC related to environmental were the most important for sustainable SSP followed by SSC related to economic. The advantage of BWM method was that it included less pairwise comparisons and gave good consistency. At the same time, the authors mentioned the inherent limitation of their technique to deal with ordinal consistency and therefore emphasized the importance of integrating BWM with other MCDM methods.

From the analysis of the closely related studies on SSP in CI, various researchers have studied the SSP in CI considering multiple SSC with multiple perspectives such as SSC w.r.t. economic perspective, environmental perspective, social perspective or a combination of all the three perspectives. Considering the difficulties in handling more number SSC and due to the time constraint of this study, it is proposed to consider the SSP criteria only from an economic perspective. With this assumption, we have considered Tushar et al. (2022) as the base paper and identified 10 SSC, which are used in various studies with different subsets of these 10 identified SSC.

3. Research Objectives, Scope and Methodology

In this section, the research objectives defined for the research problem considered in this study, scope of the study and the objective wise the proposed research methodology are presented as follows:

3.1 Objectives of the Study

- To identify SSC for SS in CI
- To apply of Pareto concept and sorting the identified SSC in descending order according to the frequencies of their occurrences and to decide vital SSC for SS in CI
- To identify best and worst SSC from among the identified vital SSC for SS in CI
- To obtain optimal weight/importance of each of the identified vital SSC for SS in CI
- To obtain the weight of each of the given supplier considering each of identified vital SSC
- To select the best supplier considering the obtained (a) optimal weight of each of the identified vital SSC for SS in CI and (b) the weight of each of the supplier w.r.t. each of the identified vital SSC.

3.2 Scope of the Study

The online databases were considered to identify the closely related research papers, published in referred journal, on SSP in CI. It appears that since 2006, researchers started exploring the usage of MCDM techniques to evaluate the choice of suppliers for the CI (Bayazit et al., 2006). The search on the closely related research papers was limited to the period between 2006 and 2023. The primary data required for applying AHP, in this study, x number of respondents will be chosen based on the criteria: (a) 50 percent of respondents are from construction industry domain, (b) 25 percent of respondents are basically civil engineers or architectures, and (c) remaining 25 percent of respondents are not related to construction industry or civil engineer or architecture.

3.3 Research Methodology

The research objective wise the research methodology followed is as follows (Table 1):

Table 1. Research objective

No.	Objective	Research Methodology
1	To identify SSC for SS in C	Descriptive research by analyzing the existing closely related literature
2	To apply of Pareto concept and sorting the identified SSC in descending order according to the frequencies of their occurrences and to decide vital SSC for SS in CI	Descriptive research by following Pareto 80:20 Rule
3	To identify best and worst SSC from among the identified vital SSC for SS in CI	Experimental Research by following Analytical Hierarchy Process (AHP) Method
4	To obtain optimal weight/importance of each of the identified vital SSC for SS in CI	Experimental Research by following Best-Worst Method (BWM)
5	To obtain the weight of each of the given supplier considering each of identified vital SSC	Experimental Research by following Analytical Hierarchy Process (AHP) Method
6	To select the best supplier considering the obtained (a) optimal weight of each of the identified vital SSC for SS in CI and (b) the weight of each of the supplier w.r.t. each of the identified vital SSC.	Experimental Research by following simple average method

4. Proposed Solution Framework for SSP in CI

The proposed solution framework given in Figure 1 is followed to address the problem considered in this study. In the proposed solution framework, it is assumed that there is no interdependence of the SSC to be identified and used for addressing the SSP considered in this study. Accordingly, the details and the purposes of (i) Pareto 80-20 rule, (ii) AHP method, and (iii) BWM method are presented in the following section.

4.1 Pareto Analysis on the Identified SSC for SSP in CI

One of the quality controls (QC) tools is 'Pareto Analysis'. Pareto analysis, which is termed as Pareto 80/20 rule in the literature, ranks the data classifications (here the SSC appeared in various studies) in the descending order from the highest frequency of occurrences to the lowest frequency of occurrences. The total frequency is equated 100 percent. Applying 80/20 rule in any application perspective, Svensson and Wood (2006) stated that it is a theory where "a small percentage of total is responsible for a large proportion of total outcome" [example – 80 percentage of total revenues comes from 20 percent of the product range].

In general, Pareto 80/20 rule helps to classify between "Vital few" from the "Useful many" (Fotopoulos et al. (2011)). That is, the 'vital few' items occupy 80 percent of the cumulative percentage of occurrences and the 'useful many' occupy the remaining 20 percent of occurrences. Though there are some weaknesses of Pareto analysis (Fotopoulos et al. (2011)), in various fields Pareto analysis is commonly practiced such as enterprise resource planning (Garg and Garg (2013)), food safety assurance system (Fotopoulos et. (2011)), and total quality management (Karuppusami and Gandhinathan (2006)). However, it appears that scant treatment has been given to use Pareto analysis in determining criteria for supplier selection in general, particularly supplier selection in CI.

In this study, to carry out the required Pareto analysis the frequency distribution table on SSC is constructed based on 34 studies addressing the SSP in construction industry scenario and the same is presented in Table 2. Further a Pareto diagram has been constructed using the data presented in Table 2 and the same is presented in Figure 2. In this study, we use the assumption of Pareto analysis where the "Vital few" SSC accounted for 80 percent of the occurrence percentage and the "Useful many: SSC accounted for 20 percent of the occurrence percentage. Accordingly, from the Figure 2, 5 SSC [Cost/Price, Delivery/Service, Quality, Capacity Technical Characteristics/Assurance of Supply, and Reputation/Past Performance/Buyer-Supplier Relationship] were classified under the "Vital few" SSC [which is accounting 72.9 percentage] and the remaining 5 SSC [Payment Terms, Flexibility, Reliability, Location, and Environment & Circular (ECR)] were classified under "Useful many" SSC [which is accounting 27.1 Percentage]

4.2 Demonstration of the Proposed Solution Framework for SSP in CI

This study utilizes the Analytic Hierarchy Process (AHP), introduced by Saaty in 1980, to reduce subjectivity in decision-making by considering human factors and addressing data inconsistencies. However, AHP requires a substantial amount of initial data. On the other hand, the Best Worst Method (BWM), proposed by Rezaei in 2015, is an effective decision-making methodology that yields consistent results with a fewer pairwise comparisons compared to AHP. Consequently, in our study, both AHP and BWM are employed to prioritize factors influencing SSP in the context of CI. To illustrate this, the step-by-step procedures for these MCDM methods in prioritizing the suppliers are detailed in the following section.

4.2.1. Step-by-Step Procedure for effective SSP in CI using AHP

Step 1: Defining the goal: In this context, the aim of AHP is to determine the relative significance or precedence among five distinct factors that impact SS in CI.

Step 2: Decomposing the goal: The vital few identified SSC are C*1 – Cost/Price, C2 – Delivery/Service, C3 – Quality, C4 – Capacity Technical Characteristics/Assurance of Supply, and C5 – Reputation/Past Performance/Buyer-Supplier Relationship.*

Step 3: Performing pair-wise comparison: Each of the respondents independently evaluates the relative importance or priority of each criterion in comparison to others. This is done through a total of 10 pairwise comparisons for the 5 SSC (where N(N-1)/2 calculations are made for N=5), using a scale ranging from 1 to 9 as specified by Saaty in 1980. In essence, a pairwise comparison matrix (PCM) is created, where a_{ij} represents the average preference value of all respondents for SSC C_i over criterion S_j. Additionally, aji is calculated as the reciprocal of a_{ij} for matrix A. This results in the pairwise comparison matrix, as shown in Table 3.

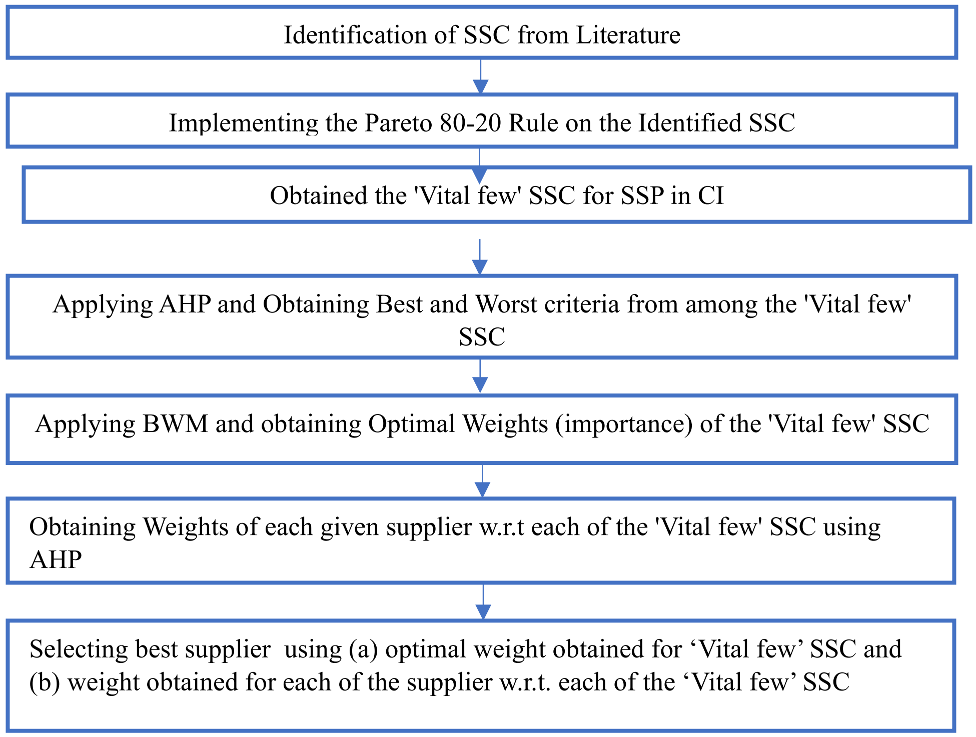

Figure 1. Proposed Solution Framework for obtaining the weightage/importance of SSC

Table 2. Details on the Identified SSC wise the Frequency

Identified Supplier Selection Criteria	Occurrences	Percentage of Occurrence	Cumulative Percentage of Occurrences
Cost / Price	33	17.6	17.6
Delivery / Service	28	14.9	32.4
Quality	28	14.9	47.3
Capacity / Technical Characteristics / Assurance of Supply	24	12.8	60.1
Reputation / Past Performance / Buyer-supplier relationship (BSR)	24	12.8	72.9
Flexibility	15	8.0	80.9
Environment and Circular (ECR)	14	7.4	88.3
Payment Terms	8	4.3	92.6
Reliability	9	4.8	97.3
Location	5	2.7	100.0

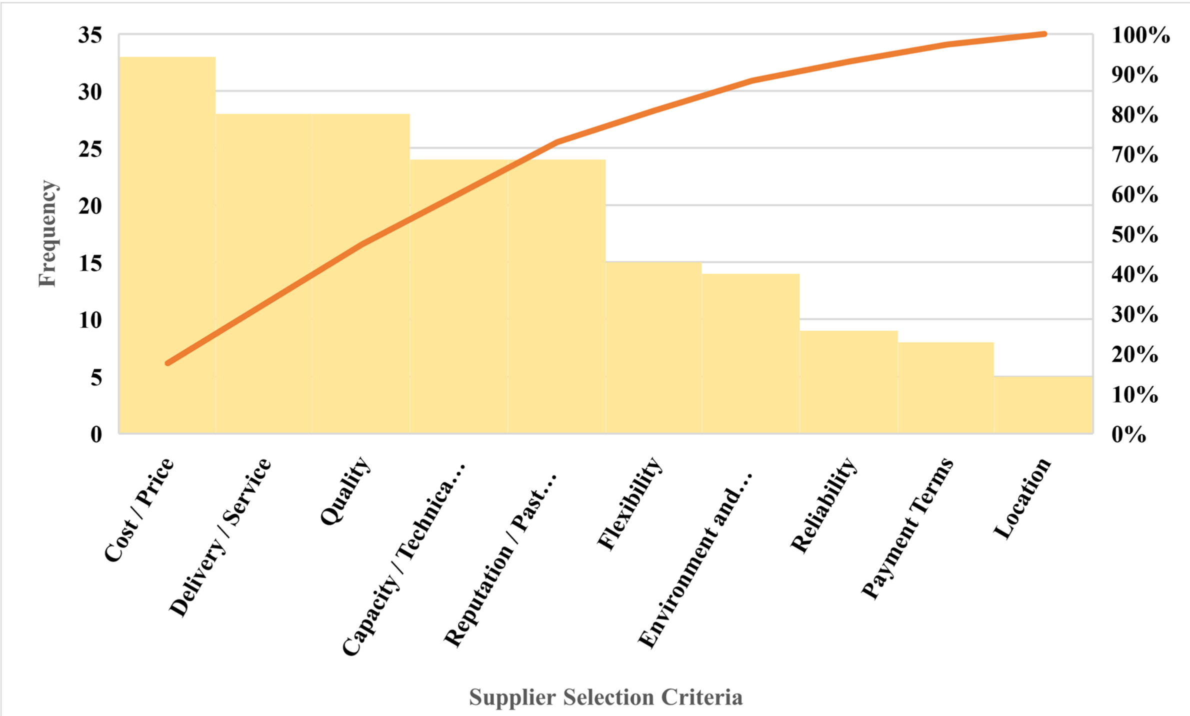

Figure 2. Pareto 80:20 Rule Diagram w.r.t. the identified SSC for SSP in CI

Table 3. Pairwise Comparison Matrix for SSC using AHP

SSC	C1	C2	C3	C4	C5
Cost/Price (C1)	1	0.25	0.13	0.33	3
Delivery/Service (C2)	4	1	0.33	3	2
Quality (C3)	8	3	1	3	6
Capacity Technical Characteristics/Assurance of Supply (C4)	3	0.33	0.33	1	5
Reputation/Past Performance/Buyer-Supplier Relationship (C5)	0.33	0.50	0.17	0.20	1

Step 4: Normalizing the PCM and deriving AHP weights: The pairwise comparison matrix (PCM) is adjusted to ensure that each entry in a column of the pairwise comparison matrix (Table 2) is divided by the total of all the entries within that specific column. This process results in a normalized matrix, which is shown in Table 3. Additionally, the priority weight for each SSC is determined by averaging all the values in the corresponding row. Subsequently, the criteria are ranked in descending order based on their calculated priority weights. Thus, both the computed priority weights and the ranking of the SSC are presented in Table 4.

Table 4. Normalized Matrix for SSC using AHP

SSC	C1	C2	C3	C4	C5	AHP Weights	Ranks
C1	0.061224	0.04918	0.06383	0.04424	0.17647	0.07899	3
C2	0.244898	0.19672	0.17021	0.39823	0.11764	0.22554	4
C3	0.489796	0.59016	0.51063	0.39823	0.35294	0.46835	1
C4	0.183673	0.06557	0.17021	0.13274	0.29411	0.16926	2
C5	0.020408	0.09836	0.08510	0.02654	0.05882	0.05785	5

Step 5: Computing the Consistency Ratio: The Consistency Ratio serves as an indicator of the reliability of pairwise comparisons. Given that human errors can introduce inconsistencies into these comparisons, AHP addresses this issue

by setting an upper limit for the consistency ratio at 0.1. To calculate the consistency ratio, the following sub-steps are undertaken:

Table 5. Calculating the Delta Vector (δ) and Eigen Vector (**λ**):

(a) Calculating the Delta Vector (δ): It is obtained by multiplying the PCM with AHP weights matrix.

$$\underbrace{\begin{vmatrix} 1 & 0.25 & 0.13 & 0.33 & 3 \\ 4 & 1 & 0.33 & 3 & 2 \\ 8 & 3 & 1 & 3 & 6 \\ 3 & 0.33 & 0.33 & 1 & 5 \\ 0.33 & 0.50 & 0.17 & 0.20 & 1 \end{vmatrix}}_{\textbf{PCM}} * \underbrace{\begin{vmatrix} 0.07899 \\ 0.22554 \\ 0.46835 \\ 0.16926 \\ 0.05785 \end{vmatrix}}_{\textbf{AHP Weights}} = \begin{vmatrix} \mathbf{0.42389} \\ \mathbf{1.32111} \\ \mathbf{2.63179} \\ \mathbf{0.92678} \\ \mathbf{0.30886} \end{vmatrix}$$

(b) Calculating the Eigen Vector (**λ**): It is obtained by dividing the Delta vector by the AHP weights.

SSC	δ	AHP Weights	λ
Cost/Price (C1)	0.42389	0.07899	5.36634
Delivery/Service (C2)	1.32111	0.22554	5.85751
Quality (C3)	2.63179	0.46835	5.61924
Capacity Technical Characteristics/Assurance of Supply (C4)	0.92678	0.16926	5.47536
Reputation/Past Performance/Buyer-Supplier Relationship (C5)	0.30886	0.05785	5.33907
Average Value of Eigen Vector			5.53150

(c) **Consistency Index (CI)** and **Consistency Ratio (CR)** is calculated using equations 1 and 2.

$$CI = (\lambda_{avg} - N)/(N-1)$$
$$CR = CI/(Random\ Index)$$

As per Saaty (1980), for a matrix size of 5, Random Index = 1.12. In this case, λ_{avg} = 5.5315, thus leading to CR (consistency ratio) as 0.1, which is acceptable. Therefore, we can conclude that the pairwise comparisons among the SSC exhibit consistency, and the resulting rankings are appropriate for decision-making purposes.

4.2.2. Step-by-Step Procedure for effective SSP in CI using BWM

Step 1: Determining the best and worst SSC: From Section 4.2.1 using AHP, the best SSC is S3 – Quality and the worst SSC is S5 – Reputation/Past Performance/ Buyer-Supplier Relationship.

Step 2: Determining the Best-to-Others (BO) and Others-to-Worst (OW) vector: The preference of the best criterion over all the other criteria is taken from the original PCM (highlighted in Table 5). Accordingly, the preference of all the other criteria over the worst criterion is taken from the original PCM (highlighted in Table 5).

Step 3: Obtaining Optimal Weights: This is obtained from the linear programming (LP) model where the objective is to minimize the consistency rate. The Consistency Rate serves as an indicator of the reliability of pairwise comparisons. A lower Consistency Rate value indicates more dependable pairwise comparisons. Therefore, the desired value for $\xi\ i$ should be close to 0. Set of constraints (1) ensures that the absolute difference between the weight of the best SSC and the product of the 'best to other score for a SSC j' and the 'weight of SSC j' is less than the Consistency Rate for all SSC. Meanwhile, set of constraints (2) guarantees that the absolute difference between the weight of SSC j and the product of the 'others to worst score for a SSC j' and the 'weight of worst SSC' is also less than the Consistency Rate for all SSC. Constraints (3) ensure that the sum of weights for all SSC equals 1, and Constraint (4) imposes non-negativity constraints.

The LP model is generated by developing suitable LINGO set code (given in Annexure 1). The optimal solution obtained is shown in Table 6. After obtaining the optimal weights, the consistency index of the model is obtained by dividing the consistency rate (CR) by consistency index (CI). As per Saaty (1980), CI = 2.3 as N = 5.

Table 6. Optimal weights for SSC as per BWM

SSC	Weights
Cost/Price (C1)	0.0732
Delivery/Service (C2)	0.1951
Quality (C3)	0.4756
Capacity Technical Characteristics/Assurance of Supply (C4)	0.1951
Reputation/Past Performance/Buyer-Supplier Relationship (C5)	0.0610
Consistency rate (Objective function) = 0.10975	
Consistency ratio = 0.0477	

4.2.3. Obtaining weights of each supplier w.r.t. each of the 'Vital Few' SSC using AHP

Three suppliers (S1, S2 and S3) are considered to select best-supplier using AHP considering the identified 'Vital Few' SSC and its weights. Accordingly, pairwise input was collected w.r.t. each of the 'Vital Few' SSC considering the 3 suppliers and presented in Table 7. These pairwise inputs were given as input to AHP and the weights of each supplier w.r.t. each of the 'vital few' SSC are obtained and presented in Table 7.

Table 7: Pairwise input for the given 3 suppliers w.r.t. each of the SSC and Weight obtained using AHP

C1	S1	S2	S3	**Weights**
S1	1	0.33	3	0.2605
S2	3	1	5	0.6333
S3	0.33	0.2	1	0.1062

C2	S1	S2	S3	**Weights**
S1	1	1	5	0.4545
S2	1	1	5	0.4545
S3	0.2	0.2	1	0.0909

C3	S1	S2	S3	**Weights**
S1	1	1	8	0.4706
S2	1	1	8	0.4706
S3	0.13	0.13	1	0.0588

C4	S1	S2	S3	**Weights**
S1	1	5	8	0.6996
S2	0.2	1	6	0.2377
S3	0.13	0.16	1	0.0627

C5	S1	S2	S3	**Weights**
S1	1	0.3	7	0.3025
S2	3	1	8	0.6366
S3	0.14	0.13	1	0.0609

4.2.4. Selection of the Best Supplier

The aggregated weight of each supplier can be calculated using the formula defined by Hruska et al. (2014) and the best supplier is selected based on the maximum aggregated weight. The computation details of aggregated weight of each supplier are as follows:

$$wS_i = \sum_{j=1}^{k} wK_j \times u_{ij}$$

where,

wS_i: aggregated weight of the ith supplier,

wK_j: aggregated weight of the jth criterion for selection of ith supplier [wK_j = (0.0732; 0.1951; 0.4756; 0.1951; 0.0610)], and

u_{ij}: weight of the ith supplier in relation to the jth criterion

Hence $\boldsymbol{wS_1} = (0.0732 \times 0.2605) + (0.1951 \times 0.4545) + (0.4756 \times 0.4706) + (0.1951 \times 0.6996) + (0.0610 \times 0.3025) = 0.4865$

Similarly, $\boldsymbol{wS_2}$ = 0.4440 and $\boldsymbol{wS_3} = 0.0695$

Based on the computed aggregate weight of each supplier the Max wS_i = Max {0.4865, 0.4440, 0.0695} = 0.4865 and this indicates that the supplier S1 should be selected as the best supplier.

5. Conclusion

In this study, we initially examined the use of MCDM (Multi-Criteria Decision-Making) techniques in the context of construction industry. From the various available MCDM methods, we specifically selected AHP (Analytical Hierarchy Process) and the Best Worst Method (BWM) to determine the prioritization of factors influencing supplier selection in the construction industry. Our aim was to triangulate the results by using both of these methods.

It is observed from the results that: the ***most important supplier selection criterion (SSC)*** in the construction industry is Quality (S3). It is also observed that the ***least important criterion*** is the reputation/past performance/buyer-supplier relationship (S5). Further, three suppliers were selected and evaluated on the basis of the 'vital few' SSC. Based on the optimal weights of the 'vital few' SSC obtained from AHP and weights obtained for each supplier w.r.t the 'vital few' SSC, the best supplier was identified.

Annexure I:

Formulation of mathematical model for BWM

Sets:
S SSC
Index:
j 1 to N SSC
Parameters (Independent Variables):
BST: Best SSC
WST: Worst SSC
bo_{Bj} *: Best to others comparison score between best criterion BST and all other SSC from 1 to j*
ow_{jW}*: Others to worst comparison score between other SSC from 1 to j with worst criterion WST*
Decision (Dependent)Variables:
Wj : Weight of the SSC 1 to j
ξ *: Consistency Rate*
Objective function:
$\boldsymbol{min\ \xi}$
Subject To:
Constraints for comparing other SSC with the best SSC BST
$| w_{BST} - bo_{Bj}\, w_j | \leq \xi \quad \forall j$ *= 1, 2… N (=5)* *(1)*
Constraints for comparing the worst SSC WST with other SSC
$| w_j - ow_{jW} w_{WST} | \leq \xi \quad \forall j$ *= 1, 2… N (=5)* *(2)*
Constraint for sum of weights for SSC
$\sum_j w_j = 1$ *j = 1, 2… N (=5)* *(3)*
Constraints for non-negativity
$w_j \geq 0\ \forall j$ *= 1, 2… N (=5)* *(4)*

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