Project Delivery System Selection using the AHP Multi-Criteria Decision Making Method

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ABSTRACT

This study aims to select the most suitable project delivery method for the implementation of construction projects in Iraq. The descriptive analytical approach was used to determine the importance of the criteria considered in this study, namely cost, project duration, and quality, according to owners, contractors, and consultants. A field study was used utilizing questionnaire survey and interviews to determine the degree of importance of these criteria. Then, data regarding 28 projects for the period from 2022 to 2024 were was collected to measure the performance of these criteria. Univariate data analyses were performed to assess the performance of Integrated Project Delivery (IPD) along with the deriving priority scales based on the Analytic Hierarchy Process (AHP) theory. The results of the AHP indicate that the IPD system ranked first with a preference rate of 34.5%.

Keywords-integrated project delivery system; AHP; MCDM

I. INTRODUCTION

A Project Delivery System (PDS) is used for organizing and financing design, construction, operations, and maintenance services for a structure or facility by entering into legal agreements with one or more entities or parties [1]. Choosing a project delivery method is one of the fundamental decisions owners (users) make at an early stage of the project [2]. At an early stage the owners have to think about which delivery method is best suitable for their project. The main challenge is that there are many different delivery methods. So, the owners need to involve a project manager or consultant for support and for finding the most suitable delivery method [3].

Iraq has recently witnessed an expansion in the field of infrastructure development projects and increasing investments that encourage local partnerships and seek to develop their own delivery strategy, thus creating a wide potential market at the international and local levels. As a result, local project management needs to innovate methods and develop new management techniques, such as BIM technology. The main purpose of a Project Delivery System (PDS) is to transform the owner's purposes and objectives into completed facilities. It also includes the mechanism through which the relationships and interactions between project participants are determined [4]. The PDS defines the liability of each project party, the scope of delivery, the project risk distribution, the payment method, and the relationship among essential participants, while it provides the administrative and technical framework for project execution. The PDS confirms the relationship among stakeholders and the appropriate timing of their participation in the different project stages [5]. However, determining the appropriate PDS has a significant impact on contract management, cost, quality, and schedule, and thus the success of the engineering project [6, 7]. This research focuses on the importance of adopting a multi-criteria approach to select the appropriate project delivery method according to the opinion of experts in Iraqi projects.

II. LITERATURE REVIEW

PDSs followed by owners vary, including traditional delivery Design-Bid-Build (DBB), Construction Management-at-Risk (CMR), Integrated Project Delivery (IPD), Design-Build (DB), Engineering, Procurement, and Construction (EPC) or General Contractor (GC) [8]. The first two are the most prevalent in Iraqi projects. In practice, the use of different PDSs in engineering projects tends to cause significant variation in the economic and technical impacts of large and medium-sized projects in particular [9]. The recent studies mainly focus on fuzzy decision evaluation methods, AHP, and multiple regression analysis for PDS selection. By consulting academic experts and reviewing the literature, authors in [10] collected data through a survey questionnaire to identify and refine 14 influencing factors. After filtering the data, factor analysis was used to reduce them to four components. Logistic regression analysis was used to examine the relationship between project cost performance and the four main components. The results indicate that there is a large disparity in the influencing factors to determine the extent of matching project cost performance criteria between IPD, DB, and DBB projects. The determination of the extent of cost overrun of DBB projects depends on the owner team's capabilities, resource diversity and experience [11]. In contrast, contractor capabilities are an important determinant of cost performance evaluation in projects, including contractor experience, contractor financing, and contractor team capabilities for DB projects. Authors in [12] presented an integrated fuzzy AHP approach for multi-criteria group decision making based on the opinions of a heterogeneous group of experts. The proposed methodology was applied to a hydropower project based on a case study of a real dam. The results of the proposed methodology helped to select the best PDS option with high efficiency. Authors in [13] used the AHP approach to develop a decision-making model as a means to assist owners in selecting alternative project delivery methods by prioritizing project time slots, along with the concepts of approximation. This model appears to have the ability to analyze owner and expert opinions and adopt criteria results to rank alternative delivery systems. Extensive studies have been conducted to develop prediction models using deep learning methodology such as Artificial Neural Networks (ANNs) as well as statistical analysis methods. Authors in [14] studied five projects and analyzed the collected data to build a model based on ANNs to predict project performance and its impact on the type of adopted PDS [15].

Many project owners have realized that the success of any construction project depends on many factors [16], the most important of which is choosing the appropriate building plan. Moreover, choosing the appropriate building plan is crucial to help project owners make their decisions more scientific and objective, so identifying the main criteria they should consider when choosing PDS and the importance of these criteria is a fundamental issue that must be addressed. Therefore, this study contributes to providing a clearer methodology by deepening the research and expanding the content. In addition to providing valuable results to project owners to help them adopt the Multiple Criteria Decision Method (MCDM) to choose an accurate and reasonable building plan, which ultimately leads to improved project management and reduced additional costs.

III. RESEARCH METHODOLOGY

This research adopts the following methodology (Figure 1):

- Study and provide a brief review of commonly used PDSs.
- Conduct field study and collect data for the considered criteria and use them to compare the candidate PDSs.
- Use the AHP to select the best among project delivery systems according to priorities.

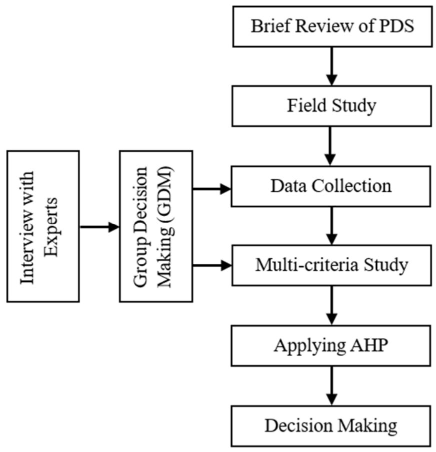

Fig. 1. Research methodology.

IV. DATA COLLECTION

Information for the period from 2022 to 2024 was collected from 20 project management experts. They were asked to provide information related to project delivery methods according to criteria (cost, duration, quality) based on previous studies. Data were extracted by filling out a questionnaire dealing with project delivery methods, where they choose one of Saaty's Five-point scale judgment preferences as shown in Table I. The considered PDSs were the Traditional Delivery (TM), CMR, and IPD. The questionnaire and the summary of the answers are given in the Appendix.

TABLE I. SAATY'S FIVE-POINT SCALE JUDGMENT

Relative Importance	Definition
1	No effect
2	Low effect
3	Moderate effect
4	Strongly effect
5	Extremely effect

V. ANALYTIC HIERARCHY PROCESS (AHP)

AHP is able to solve the most complicated problems which may include complex structures, multiple levels, and many criteria, using pairwise comparison [17]. AHP can be enhanced with the help of a group of project experts for Group Decision Making (GDM). The use of GDM will lead to the best diagnosis of the problem and improve the accuracy of decision-making. Usually, more DMs are used by the GDM to solve a specific decision problem, thus arriving at a single comprehensive, meaningful, and robust decision solution to that problem. The AHP-GDM process is explained in detail below.

A. Step 1

Pairwise comparison is used in the AHP method to assign scores for each alternative according to each criterion. Decision makers compare the alternatives according to each criterion individually using the preference scale that experts have determined according to the AHP method to be a rational basis for the comparison between the alternatives [18]. A degree of inconsistency is to be expected when applying the AHP methodology. So the Pairwise Comparison Matrix (PCM) needs to define the allowable level of inconsistency, and therefore we need to develop an indicator to quantitatively find the consistency value. A as a consistent matrix yields a normal matrix N in which all columns are congruent:

$$N = \begin{pmatrix} W1 & W1 & W1 \\ W2 & W2 & W2 \\ Wn & Wn & Wn \end{pmatrix}$$

Using the inverse operation by dividing the elements of the column is the proper way to find the determination of the original comparison matrix A of N:

$$A = \begin{pmatrix} 1 & \frac{W1}{W2} & \frac{W1}{Wn} \\ \frac{W2}{W1} & 1 & \frac{W2}{Wn} \\ \frac{Wn}{W1} & \frac{Wn}{W2} & 1 \end{pmatrix}$$

Post-multiplying A by $W = (w_1, w_2, \ldots, w_n)^T$, we get:

$$\begin{pmatrix} 1 & \frac{W1}{W2} & \frac{W1}{Wn} \\ \frac{W2}{W1} & 1 & \frac{W2}{Wn} \\ \frac{Wn}{W1} & \frac{Wn}{W2} & 1 \end{pmatrix} \begin{pmatrix} W1 \\ W2 \\ Wn \end{pmatrix} = \begin{pmatrix} nW1 \\ nW2 \\ nWn \end{pmatrix} = n \begin{pmatrix} W1 \\ W2 \\ Wn \end{pmatrix}$$

Hence, A is consistent if, $AW = nW$

B. Step 2

The main element in the decision-making process is the pairwise judgment for each project manager or expert to reach the decision matrix. The pairwise decisions are counted for each Geometric Mean (GM), and the Priority Vector (PV) and the PCM are calculated.

C. Step 3

When the PCM is fixed, the sum of the items in each column is calculated and multiplied by the standard value of the corresponding row and the results for all columns are summed. On the other hand, if the judgments are contradictory, this value, known as Eigenvalue (λ_{max}) is obtained from (1):

$$\lambda_{max} = \sum_{i,j=1}^{k} C_j PV_i \quad (1)$$

where C_j is the column vector sum.

D. Step 4

Decision consistency is the main criterion for accepting decisions. So, it becomes necessary to calculate the Consistency Index (CI) based on the derived PDM to check the consistency of the decision:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} \quad (2)$$

where n is the matrix element number.

E. Step 5

After obtaining the CI, it must be compared with the Random Index (RI) in order to identify the Consistency Ratio (CR). RI is defined as:

$$\mathrm{RI} = \frac{1.98\,(n-2)}{n} \quad (3)$$

F. Step 6

The AHP measures the CR to set the overall stability of judgments, which must be 10% or less. CR is obtained by:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (4)$$

The eigenvalue of the PCM with respect to the cost was 3.0167274, the CI was 0.0084, the RI was 1.32, and the CR was equal to 0.006, less than 10% (Table II). The eigenvalue of the PCM with respect to the duration was 3.062074, the CI was 0.031037, the RI was 1.32, and the CR was equal to 0.0235, less than 10% (Table III). The eigenvalue of the PCM with respect to the quality was 3.00785, the CI was 0.0039257, the RI was 1.32, and the CR was equal to 0.003, also less than 10% (Table IV). The above mentioned results were synthesized to obtain the final decision. The eigenvalue of the final results was 3.006, the CI was 0.003, the RI was 1.32, and the CR was equal to 0.002, less than 10%, so the judgment has stability (Table V).

TABLE II. PCM OF COST CRITERION

Budget	IPD	TD	CMR	Priority
IPD	1	1.25	0.9	0.347
TD	0.8	1	1.1	0.320
CMR	1.11	0.9	1	0.333

TABLE III. PCM OF DURATION CRITERION

Delivery Speed	IPD	TD	CMR	Priority
IPD	1	0.95	0.98	0.325
TD	1.05	1	1.08	0.347
CMR	1.02	0.93	1	0.347

TABLE IV. PCM OF QUALITY CRITERION

Quality	IPD	TD	CMR	Priority
IPD	1	1.16	1.11	0.362
TD	0.86	1	1.28	0.343
CMR	0.9	0.78	1	0.295

TABLE V. FINAL RESULTS

PDS	Cost	Duration	Quality	Priority
Cost	1	1.25	0.9	0.345
Duration	0.8	1	0.83	0.290
Quality	1.11	1.2	1	0.365

The results of the AHP after PDS pairwise comparison by looking at the order of priorities of the main elements of the project (budget, quality, and delivery speed) indicate that the IPD system ranked first 34.5%, followed by TD with 33.5%, finally and CMR by 32%, as shown in Figure 2.

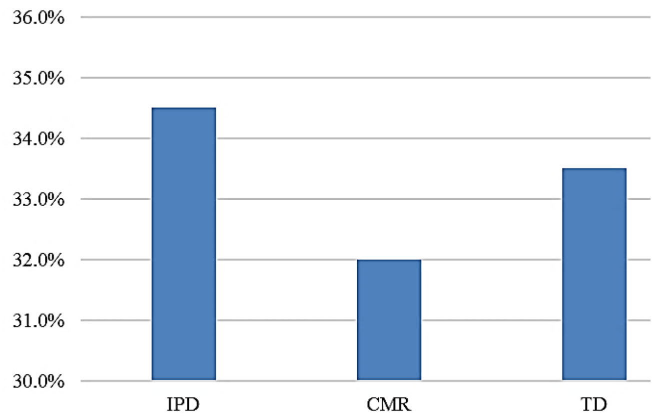

Fig. 2. Final PDS ranking.

VI. CONCLUSIONS

The mechanism used in this study benefits from the the specialized knowledge of experts by using the AHP method in relation to different project delivery systems. Experts working in different environments may arrive at different assessments. Researchers may find it interesting to apply a multi-criteria decision-making approach to prioritization by drawing on specialized knowledge. More specifically, they may benefit from project stakeholders' preferences for any element or constraint that may influence the choice of project delivery system by discussing and solving similar problems and making decisions using the AHP approach. The results of the AHP after the pairwise comparison of the considered project delivery systems indicate that the integrated project delivery system ranked first with 34.5%, followed by traditional delivery systems with 33.5% and CMR with 32%.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of personal relationships or financial interests that could in any way affect the accuracy of the information contained in this paper.

APPENDIX

THE QUESTIONNAIRE

How does the Budget affect the choice of project delivery system among the following:

Budget	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
IPD	0	3	4	3	10
TD	2	3	7	5	3

How does the Budget affect the choice of project delivery system among the following:

Budget	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
IPD	2	4	2	5	7
CMR	0	3	3	6	8

How does the Budget affect the choice of project delivery system among the following:

Budget	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
TD	0	1	4	8	7
CMR	2	2	4	5	7

How does the Delivery Speed affect the choice of project delivery system among the following:

Delivery Speed	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
IPD	1	0	5	5	9
TD	0	1	3	6	10

How does the Delivery Speed affect the choice of project delivery system among the following:

Delivery Speed	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
IPD	1	1	5	5	8
CMR	1	1	5	3	10

How does the Delivery Speed affect the choice of project delivery system among the following:

Delivery Speed	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
TD	1	0	5	5	9
CMR	0	1	7	8	4

How does the Quality Systems affect the choice of project delivery system among the following:

Quality Systems	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
IPD	0	1	2	8	9
TD	0	3	6	6	5

How does the Quality Systems affect the choice of project delivery system among the following:

Quality Systems	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
IPD	0	1	5	6	8
CMR	0	4	5	5	6

How does the Quality Systems affect the choice of project delivery system among the following:

Quality Systems	No effect	Low effect	Moderate effect	Strongly effect	Extremely effect
TD	1	0	1	6	12
CMR	1	3	6	6	4

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