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A FUZZY FRAMEWORK FOR CONTRACTOR SELECTION ON IPD PROJECTS

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ABSTRACT

The construction industry is characterized by complexity, budget and schedule overruns, quality and safety problems, and increased claims and disputes. To successfully manage the inherent complexity of construction projects, optimal contractor selection is integral for project success. Choosing the best-fit contractor is especially important in Integrated Project Delivery (IPD), since this procurement route relies heavily on the efficient collaboration of project stakeholders and necessitates trust to guarantee successful outcomes. However, the numerous methods and tools for contractor selection in the literature target traditional delivery routes and are unsuitable for IPD, considering the latter's distinct features and stakeholder roles. As such, owners transitioning to IPD do not fully understand the requirements for optimal contractor selection, which jeopardizes the success of IPD projects. To address this need, this paper conducts a comprehensive literature review and investigates twelve unique IPD case studies to identify contractor selection criteria important to IPD. The paper presents a decision-making framework for contractor selection in IPD projects, using the Fuzzy Inference System (FIS), that provides an indication of the best-fit contractor for the IPD project. This research fills a significant gap in the literature by providing a tool to assist IPD practitioners to select the right contractor.

KEYWORDS

Contractor selection, fuzzy inference system (FIS), integrated project delivery (IPD), qualification-based selection, multi-criteria decision-making (MCDM) tool

INTRODUCTION

The construction industry is characterized by complexity, budget and schedule overruns, quality and safety problems, and increased claims and disputes (Singh and Tiong, 2005). Since construction projects heavily rely on the interaction and collaboration of different parties (El-Sayegh et al., 2021), and since contractors play a major role on such projects, it is widely agreed that optimal contractor selection is integral to manage the inherent complexity of these projects (Mousakhani et al., 2018). Accordingly, having the right contractor on board is critical to determining project success or failure (Vardin et al., 2021) as appointing the most suitable contractor is a prerequisite for successful project outcomes (Fong and Choi, 2000; Jafari, 2013;

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Zhang et al., 2016). Furthermore, Kog and Yaman (2014) underline the importance of having a strong and steady relationship between the client and the contractor to achieve project goals. On the other hand, inappropriate contractor selection leads to bad quality works (Alptekin and Alptekin, 2017), delays, cost overruns, poor performance, accidents, bankruptcy, disputes (Abdul Razak et al., 2021), and project failure in terms of quality, cost, and time (Mousakhani et al., 2018).

"Integrated Project Delivery (IPD) is a project delivery approach that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to optimize project results, increase value to the owner, reduce waste, and maximize efficiency through all phases of design, fabrication, and construction" (AIA, 2007). Considering the unique characteristics of IPD and its reliance on the efficient integration and collaboration of project stakeholders, it is crucial to select suitable project participants with shared goals and established trust and cooperation to guarantee the successful implementation of integrated projects (Zhang et al., 2016). In this regard, selecting a project team that collaborates efficiently has been identified as a prerequisite to effective IPD implementation (Townes et al., 2015). Therefore, it can be argued that appropriate contractor selection for IPD projects is of even greater importance than for other traditional project delivery routes.

While numerous studies in the literature attempt to propose methods for contractor selection for traditional delivery routes, these traditional practices and selection methods are not suitable for IPD projects (Zhang et al., 2016; Townes et al., 2015). Zhang et al. (2016) emphasize that different criteria and techniques must be considered when selecting contractors for IPD projects, since this delivery route has distinct features and imposes different roles and obligations on the participants. Nevertheless, there is a lack of studies on IPD party selection, and the existing literature fails to sufficiently investigate how IPD contractors should be assessed and compared (Townes et al., 2015). Furthermore, an investigation of the contractor selection process in twelve IPD projects published by the AIA "IPD Case Study Matrix" in 2012 reveals that, while certain IPD-related criteria are considered, there is no standardized or published decision-making framework utilized for this process. Due to the present state of knowledge, project owners transitioning to IPD do not fully understand the requirements for selecting an optimal contractor for this delivery route, which jeopardizes project success (Townes et al., 2015). Therefore, considering the established importance of appropriate contractor selection for construction projects in general, and IPD in specific, and considering that the traditional selection methods and criteria are not suitable for IPD, there is a clear need to establish a framework for contractor selection on IPD projects.

This paper conducts a comprehensive literature review to identify the criteria used for the assessment and selection of contractors for construction projects. In addition, the paper further investigates twelve unique cases of IPD projects, published by the AIA, to identify IPD-specific criteria utilized in this process. Ultimately, the objective of the paper is to develop a decision-making framework for contractor selection in IPD projects that utilizes the user's rating of the identified criteria as inputs and provides, as an output, an indication of the best-fit contractor for the IPD project at hand. This research fills a significant gap in the literature by providing criteria and a framework for evaluating and selecting contractors on IPD projects. The proposed framework can be customized according to the stakeholders' needs and preferences on the specific project it is applied to. This decision-making tool will assist practitioners entering IPD projects in selecting the right contractor to optimize the chances of project success.

METHODOLOGY

The methodology of the paper followed the below 5 steps.

1. Identification of Contractor Selection Criteria for Construction Projects: A systematic literature review was conducted, based on the guidelines by Hong et al. (2012), to identify the criteria for contractor selection on construction projects, with a specific focus on IPD projects. Accordingly, the authors performed a selective search to find articles with the following phrases in subjects, titles, keywords or abstracts: contractor selection “and/or” criteria, factors, frameworks, IPD, and methods. The abstracts of the articles were then reviewed in detail to assess their relevance and criteria were identified from the research.
2. Identification of Contractor Selection Criteria for IPD Projects: Subsequently, the authors studied and analyzed twelve cases of IPD projects published by AIA IPD Case Study Matrix (2012) to establish a stronger understanding of the process of contractor selection in real IPD projects. From these cases, further criteria relevant to contractor selection were identified.
3. Filtering, Sorting, and Grouping the Established Criteria: Next, the factors identified from the first two steps were analyzed, filtered by removing redundancies, grouped into sub-factors, and organized under a hierarchy to prepare for the execution of the FIS modeling.
4. Constructing the Rubric for Measuring the Factor Input: A rubric was developed to maintain consistency in rating the metrics. The rubric describes the input degrees of each factor in practical terms.
5. Modeling Using Fuzzy Inference Systems (FIS): The framework is constructed using FIS, which was chosen due to (1) its ability to manage and represent qualitative factors, considering that certain factors identified for IPD contractor selection are qualitative in nature, and (2) its capacity to account for the vagueness and uncertainty of decision-makers (Hellmann 2001). The MATLAB Fuzzy Logic Designer Toolbox is used to construct the model and the Mamdani style is adopted for “being intuitive, having widespread acceptance, and well-suited to human input” (Gunduz et al. 2015). Using the Mamdani style, membership functions are assigned trapezoidal and triangular shapes, ‘if … then’ rules are applied, and the output is evaluated by calculating the centroid of the aggregated shape. For simplicity, the authors assumed a set of base rules and a standard template for the membership function applied to all factors, based on the model proposed by ElBeltagi et al. (2011). Nevertheless, when applying the tool to a specific case study, the rules and functions can be easily calibrated based on the expert opinions of the project stakeholders, which can be obtained through surveys or interviews. The FIS involves 3 stages, Fuzzification, Fuzzy Inference, and Defuzzification and follows the below steps:
    1. The user provides a crisp input by choosing a rating between 0 and 10 as per the rubric developed in Step 4.
    2. Fuzzification: Using membership functions, the input is converted to fuzzy sets.
    3. Fuzzy Inference: The fuzzy inference or the rules that determine the outcome of the outputs are applied. Each rule generates a fuzzy set which is then aggregated for the next step.
    4. Defuzzification: Using output membership functions, the sets are defuzzified after aggregating the fuzzy sets.
    5. The user then receives the final output which is a crisp result. This is an indicator of the “contractor score” on the IPD project.

LITERATURE REVIEW

The selection of the optimal construction contractor is considered the most important responsibility of the owner as this decision directly impacts project performance and outcomes

(Mousakhani et al., 2018). While, traditionally, contractors were selected on a lowest-bid basis, studies have found this method to detrimentally affect project outcomes in terms of time, cost, quality, and disputes (Cheaitou et al., 2019). Therefore, contractor selection methods were developed to include multiple criteria additional to cost and utilized various multi-criteria decision-making (MCDM) techniques (Cheng et al., 2020). To this end, Sigh and Tiong (2005) presented a fuzzy model to assess the contractor's capacity to deliver a project meeting the owner's requirements and applied the tool to choose between 4 contractors. Doloi (2009) analyzed contractor prequalification criteria to determine their influence on project success. The author performed a factor analysis on 43 influencing technical attributes and extracted 7 factors that impact performance. The results show that project success in terms of cost, quality, and time is significantly influenced by a number of factors, including time in business, technical proficiency, history of success, working capital, and work methods. Jafari (2013) used the quality function deployment (QFD) method for contractor prequalification, considering both the owner's requirements and the contractor's qualifications. Marzouk et al. (2013) categorized factors influencing contractor selection into 10 main criteria and 46 sub-criteria, including cost, experience, time, safety, insurance, disputes, and risk avoidance, among others, and isolated the most important ones based on statistical analysis using surveys. Moreover, Kog and Yaman (2014) developed a multiagent system-based model to prequalify contractors. However, this was only suitable for traditional design-bid-build projects and excluded other delivery routes. Liu et al. (2015) identified several essential criteria to consider in assessing contractors, based on two-stage partial least squares path modeling. In their contractor selection method research, Mousakhani et al. (2018) used a risk-oriented approach to identify contractor selection factors and evaluated them using AHP. To select the best contractor for public construction projects, Cheng et al. (2020) proposed a Bayesian fuzzy prospect model, based on probability and utility multiplied relation. Further, to overcome the deficits of lowest bid selection, Vardin et al. (2021) used Fuzzy-VIKOR and the best-worst method to develop a contractor selection framework.

While these studies, in their selection of criteria and development of decision-making models, appear to be comprehensive, they are all related to traditional procurement routes and are not sufficient for IPD. In fact, existing studies do not adequately investigate how IPD contractors should be compared and selected (Townes et al., 2015). Nevertheless, certain researchers attempted to reduce this gap by providing insight and recommendations on the matter. As such, Rahman and Kumaraswamy's (2005) recommended pre-selection workshops for short-listed teams to select relationally integrated teams. Similarly, Dossick et al. (2013) described the adoption of 2-hour workshops in an IPD case study that involved 4 shortlisted teams who engaged in a unique proposal process. Townes et al. (2015) investigated a case study to comprehend the means and process of contractor selection on IPD projects, and detailed the different stages that took place, including the submission of proposals prepared by self-selected multidisciplinary teams and the use of pre-selection workshops for team evaluation. They described that the owner's assessment of the shortlisted teams relied on the IPD workshops and interviews conducted, which were useful for the observance and evaluation of IPD team selection criteria, including intangibles qualifications, such as collaborative performance. However, they did not provide the method for rating the criteria nor the decision-making tool used to this end. On the other hand, based on the inter-organizational transactive memory system (I-TMS), which is "a collaborative cognition division system that forms when multiple organizations cooperate with each other", Zhang et al. (2016) developed a method for selecting IPD contractors. Using this system, all IPD stakeholders rate the transactive memory of others across three main factors: specialization, credibility, and coordination, and the appropriate combination of IPD parties is evaluated using social network analysis (SNA). This technique is a relational-based framework that considers trust and collaboration, being factors integral to IPD. Nevertheless, a strict prerequisite to its adoption is that project participants possess previous, shared memories or experiences of cooperation, which limits the application of the framework. Accordingly, there remains a need to propose an objective MCDM framework to evaluate contractors on IPD projects without the limitation of previous relationships between the parties, which is the main contribution of this paper.

CASE STUDY ANALYSIS

The 2012 AIA IPD Case Study Matrix provides detailed project information and firm selection strategies for 12 unique IPD projects (AIA 2012). Figure 1 presents the contractor and/or subcontractor selection processes and methods used in those case studies. Two out of the twelve case studies had no published information on the party selection processes and therefore were excluded.

1 [Cathedral Hill Hospital]

- The Contractor was selected based on (1) familiarity with IPD and lean construction and (2) previous history/relationship with the owner, who was also keen on IPD.
- Subcontractors were pre-qualified, then pre-qualified firms submitted RFP, then shortlisted firms were interviewed. Among the considered criteria for subcontractor selection were (1) experience with IPD and (2) willingness to be part of IPD and (3) willingness to collaborate.

2 [MERCY Master Plan Facility Remodel]

- RFQ were sent to contractors and considered the following criteria: general company information, regional experience, healthcare experience, and IPD knowledge and experience. A scorecard was used to evaluate RFQ to shortlist firms, who were then interviewed on subjects, including: relational aspects of project delivery, budgeting process, and logistical strategies specific to healthcare and IPD environments. The selected contractor had shared project experience with the architect.
- Subcontractors were pre-qualified based on positive past work experience with the contractor. Then pre-qualified firms submitted RFP on experience with IPD, experience with other technologies that would be used on the project, and financial background. Finally, shortlisted firms were interviewed.

3 [Lawrence and Schiller Remodel]

- Contractor selection was based on (1) previous relationship with owner and (2) interest in IPD.
- Subcontractor selection was based on expertise, past experience, and trust.

4 [Edith Green Wendell Wyatt Federal Building]

- Public RFP were sent to contractors inviting them to attend a project workshop. Then, 13 contractors met with owner in "Early Exchange Meetings" to discuss project requirements, including project history, design aims, and constraints regarding time, cost, and site. The IPD process was a main topic discussed as applicants were made aware of the necessity to support a collaborative approach. Final contractor selection relied on their qualifications, past performance, key personnel, conceptual cost estimate and pricing for design phase services.

5 [Autodesk Inc.]

- RFP were issued to select an already established team of architect and contractor. The RFP expressed the owner's targets regarding scope, cost, sustainability, and type of agreement. The architect and contractor were selected on the basis of qualifications, understanding of the local market, BIM and LEED experience, and willingness to abide by a "true" IPD agreement.

6 [Sutter Health Fairfield Medical Office Building]

- At the owner's request, the architect met with the contractor to investigate the fit and alignment of their cultures. They met and found it was a good fit. The companies had past experience working together on traditional projects in the Midwest.

7 [Cardinal Glennon Children Hospital]

- The owner decided to adopt IPD after the commencement of the design stage, once the architect, engineer, and contractor were on board. The owner, architect and contractor had previous work experience and relationships.

8 [Encircle Health Ambulatory Care Center]

- Selected the contractor based on (1) the owner's previous experience with the contractor and the (2) the contractor's previous experience with IPD.
- Subcontractor selection was based on price, personnel qualifications, and previous work with the contractor.

9 [Walter Cronkite School of Journalism]

- Public RFQ were issued to select an already established team of architect and contractor, purely based on qualifications. Around 15 responses were received and 3 teams were shortlisted, based on past experience with public entities, familiarity with the type of project, and the prospect of working well together.

10 [USCF Mission Bay Medical Center]

- The owner adopted a best value selection process, developing a questionnaire that allows the selection of contractors based on experience and expertise and not on the lowest price.
- Subcontractor selection followed best value selection based on the quality of experience. The expectations for teams, relative to IPD principles, were listed as part of the bid documents. Criteria were specified to support IPD goals, whereby heavy weight was given to collaborative experience.

Figure 1: Contractor and Subcontractor Selection Processes and Criteria in 12 IPD Case Studies

Analyzing the selection methods on these projects, it is apparent that most projects adopted requirements particular to the IPD procurement route. For instance, on projects 1,2,8, and 10, owners focused on the contractors' knowledge and experience with IPD as a criterion in the selection process. Moreover, on projects 1,3,4, and 5, all bidders were made aware of the IPD form of delivery and contract to be signed and therefore the selected bidder would have expressed their willingness to sign and take part in a "true" IPD agreement. Additionally, on certain projects, bidders' experience with implementing lean (project 1) and Revit/BIM (projects 2 and 5), which are operational principles and systems integral to IPD, were specified. It is worth noting that a recurrent factor adopted across several projects was the previous relationships of the parties, owner, architect, and contractor, be it on IPD or traditional projects (projects 1,2,3,7, and 8). Finally, another unique criterion in selecting contractors for IPD was the contractor's compatibility with the architect and the prospect of positive collaboration between the parties (projects 5,6, and 9). In fact, this is not usually considered in traditional delivery routes but is especially important in IPD in the presence of a multi-party agreement establishing an official relationship between the contractor and the architect and with the requirement for high levels of communication and collaboration between those two parties on IPD projects. From these studies, the authors well able to identify and translate certain factors of importance in contractor selection used in the above IPD projects into IPD-specific criteria to be included in the proposed decision-making tool, as presented in Table 1.

Table 1: Criteria obtained from IPD Case Studies

No	Criterion	Case Study
1	Previous implementation of lean in contractor's organization	1
2	Knowledge and experience with IPD	1-2-8-10
3	Willingness to be part of IPD and sign "true" IPD agreement	1-3-4-5
4	Systems and technologies that are integral to IPD (e.g. BIM, Revit)	2-5
5	Successful previous relationship with owner/architect/contractor	1-2-3-7-8
6	Compatibility of contractor and architect	5-6-9

Notwithstanding, it is apparent that none of the case studies present a comprehensive contractor selection procedure specific to IPD nor an official decision-making tool for choosing the most appropriate contractor based on a scientific method and an inclusive list of criteria. Rather, it would appear that criteria for qualification-based contractor selection in traditional delivery routes were considered, while adding certain requirements related to IPD. Moreover, the majority of the projects adopted an interview process whereby the bidders' compatibility with IPD was assessed, but again without providing the method for evaluating and ranking the bidders. In any case, if any decision-making tool was used, there are no official publications in the literature detailing the basis of the same to advise on the optimum process for IPD contractor selection.

RESULTS AND DISCUSSION

PRESENTATION OF THE IDENTIFIED FACTORS

After conducting the systematic review, a total of 42 factors were identified, filtered, and organized into four categories: Technical Qualifications (14), Past Experience and History (16), Financial Qualifications (5), and IPD Qualifications (7).

PRESENTATION OF FINAL HIERARCHY OF CRITERIA

Subsequently, the 42 identified factors are organized under the four-level hierarchy presented in Figure 2 below.

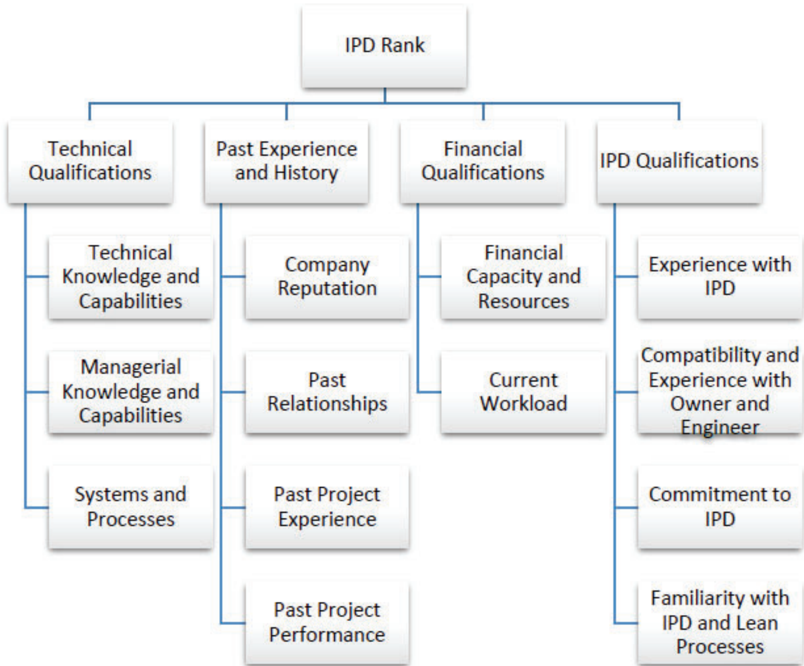

Figure 2: Hierarchy of Factors

PRESENTATION OF THE FUZZY DECISION-MAKING TOOL AND RUBRIC

The development of the fuzzy inference system relies on specifying the inputs and outputs of the model. In this paper, the output is the IPD rank, and the inputs are several factors that contribute to this rank. A membership function must be defined for every factor. After identifying those membership functions, the factors of the lowest level are rated by the user, using the rubric, to identify the final output score, representing the contractor's IPD rank. The forthcoming sections will discuss the developed model in detail.

Using the developed rubric, the users input a rating from '0' to '10' of each lower-level factor, where '0' represents a minimum rating and '10' represents a maximum rating.

Input and Output Factors

The model is a multi-level hierarchy, where the first level in the hierarchy is the major goal itself, the IPD Rank. The second level presents the main categories that contribute to the score of the IPD Rank. Finally, the third level, which is the lowest level, defines the sub-factors.

To use the tool, the following steps are followed: (1) the user inputs the rating of the third-level factors using the developed rubric (2) next, fuzzy calculations are applied in order to obtain the ratings for the level 2 factors, which will be the outputs from the level 3 calculations and (3) finally, the ratings of the level 2 factors are used as input to calculate the rating of the level 1 factor, which represents the IPD rank. As such, this model could be described as an aggregated tree, in which the output of a function is used as an input of another function to get the output of the final goal.

Membership Functions and Rules

After conducting an extensive literature review, the authors implemented the most commonly utilized membership functions: low, medium, and high. Furthermore, the membership functions were represented by trapezoidal and triangular functions, trapezoidal functions for both low and high membership functions and the triangular function for the medium membership functions. Fuzzy logic allows the overlapping between different functions so that each score/rating might be represented by membership in two functions, which is the core benefit behind choosing this method. The parameters of the membership functions have been set with the following values, representing the span of the functions, low [0 0 2 4], medium [2 5 8], and high [6 9 10 10].

The subsequent step is identifying the different scenarios, or rules, that might occur in evaluating the output. The number of different scenarios is based on the number of factors and the number of membership functions. So, in the case of a category that has 4 sub-factors, each having 3 membership functions, the total number of rules required is MF^SF (i.e., 4^3=64 rules). Overall, 227 rules were defined for the entire model.

CONCLUSION AND FUTURE RESEARCH

This research provides a practical tool for owners to select the most suitable contractor for an IPD project. This research adds to the body of knowledge by providing a metric to the decision maker so that he/she can have a better understanding of the requirements for contractor selection in IPD to optimize successful project outcomes. The developed framework facilitates the selection of the appropriate contractor for the IPD project at hand, considering a rounded classification of criteria along IPD-specific requirements. The benefit of the tool is in its flexibility, as it is suitable for use on any project since its main membership functions and rules can be adjusted as required using the input of project stakeholders. Nevertheless, it was apparent from the investigated IPD case studies that an interview process is essential, whereby the owner and the architect met with the bidders to assess several qualitative factors such as the “willingness to collaborate”, “team chemistry” and the “compatibility of the cultures”. Therefore, the authors suggest that this tool be used not as a replacement but rather to supplement the interview process. For instance, one potential application is applying the tool as a pre-qualification step to filter contractors prior to the interview process. For future work, a more comprehensive model can be developed that considers additional factors, which would benefit from the input of construction professionals in validating the identified factors and contributing to the development of new factors. Another opportunity is the framework’s application to a case study after calibrating the membership functions and rules through input gathered from project stakeholders and experts.

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