Automation in Construction 84 (2017) 356–366

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

A type-2 fuzzy set model for contractor prequalification

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ARTICLE INFO

Keywords:
Contractor prequalification
Multi-criteria decision making
Uncertainty
Interval type-2 fuzzy set

ABSTRACT

Prequalification helps decision makers find the right contractor for the job, which is key to the successful delivery of a construction project. The procedure involves judging the suitability, capability and competency of the contractor on various criteria, using both anecdotal and empirical evidence. The evidence used is often imprecise and subjective, and so is the evaluation and decision making procedure. Type-1 fuzzy sets have been used in the prequalification procedure to handle uncertain information. However, type-1 fuzzy sets are unable to reflect the differences in opinion among experts involved in group decision making. The purpose of this paper is to propose a practical prequalification procedure that uses interval type-2 fuzzy sets to address both linguistic imprecision and differences of opinion. A numerical example shows how the proposed procedure is carried out and the benefits that result compared to a similar procedure using type-1 fuzzy sets.

1. Introduction

1.1. Need for contractor prequalification

Finding the 'right' contractor for a job is important to gain the maximum assurance that the contractor can deliver the project, meet expectations of quality, cost, time, as well as obligations on safety, social and environmental responsibility. The 'right' contractor is defined in terms of its capability – the resources, equipment, work methods and processes to perform certain types of work, and competency – the skill at applying capability to a task/problem to obtain a successful outcome. Prequalification enables the decision maker to find the contractor(s) with the right capability and competency for the project based on evidence. The purpose of prequalifying contractors is to filter from a potentially long list of candidates down to a shorter list, where members of the latter list have the best potential of bidding, undertaking and completing the project. However, prequalification is carried out at the early stage of the project development cycle when information about the project is not fully detailed or precise, and there are many alternative candidates for the right candidate. Furthermore, prequalification is often done under tight constraints of time and resources. Still, it is important for the owner to narrow the field of candidates and focus the search on a few strong prospects even on the basis of imprecise information. It may also be required to rank the contractors based on how well they meet the selection criteria.

1.2. Contractor prequalification as a MCDM problem

Prequalification can be characterized as a Multi-criteria Decision Making (MCDM) problem. This problem has been addressed from different perspectives, using different computational methods. Holt [1] published a review of 'contractor selection' models described in the research literature over two decades. It was found that most of the models were deterministic in nature, i.e. information uncertainty was not explicitly accounted for. Preferred methods of research included `system interrogation`, rank order analysis and the use of Likert scales. This indicates that relatively coarse methods are used to encode expert knowledge and preferences. The study also called into question the reliability and longevity of the selection criteria used, as well as the usefulness of the models proposed due to their complexity. Nevertheless, the quest for better models that are easy to use and maintain must continue. We review a few key papers, each representative of a particular approach to the derivation of a MCDM model for contractor prequalification. The purpose is to illustrate some of the prominent approaches, and highlight the way in which key issues are addressed.

Russell and Skibniewski [2] proposed the logic of a general procedure involving selection criteria, the purpose of which was to rank contractors on their suitability for the project. Russell and Skibniewski [3] later proposed a computerized program, namely Qualifier-1 to facilitate the prequalification decision making. However, in this model, a user was required to have the expertise to do a subjective evaluation of the contractor based on a scale from 1 to 10. The subjectivity of this evaluation was addressed by further development in Qualifier-2 [4]

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http://dx.doi.org/10.1016/j.autcon.2017.10.003
Received 11 January 2016; Received in revised form 12 May 2017; Accepted 1 October 2017
Available online 06 October 2017
0926-5805/

where the MCDM procedure was presented as a hierarchical tree of composite and (elemental) decision factors, with the use of heuristic rules involving the decision factors to address the prequalification problem.

Another notable approach for the contractor prequalification problem is the use of Artificial Neural Networks [5] to learn the association between the data presented as selection criteria and the binary outcome of the prequalification decision. If data is plentiful, the ANN-based decision model can learn the non-linear mapping between criteria and decision, even in the face of uncertainty associated with the input data. Ng [6] encoded the experience on past prequalification decisions directly using Case-based Reasoning (CBR). Exemplar cases can capture more concisely the association between the performance on selection criteria, and the prequalification decision. There is no need to compile a large amount of training data, unlike the case with ANNs.

Sönmez et al. [7] approached the contractor prequalification problem as one involving reasoning from evidence. Rather than being a drawback, they combined partial evidence to derive reasonable and plausible conclusions using Dempster-Shafer Theory. One of the advantages of this model was that it could handle both quantitative and qualitative evidence within the same reasoning framework. Ever since their introduction by Zadeh [8], fuzzy sets have proven to be a popular approach to encode and compute with uncertain data, whether arising from measurement error, lack of details, or the use of imprecise linguistic terms in the decision rules. Lam et al. [9] describe the use of fuzzy sets to encode fuzzy rules for a Fuzzy Neural Network in order to solve the contractor prequalification problem. It was found that the use of fuzzy sets improves both the model efficiency (as measured by the R^2 error) and the mean absolute percentage error, compared to a general feedforward neural network trained on the same data.

Group decision making and uncertainty are taken into account by modelling the inherent uncertainty involved when different experts are involved. Each expert in the group has to evaluate both the importance (weights) of the different criteria, and the performance of a contractor on the criteria. Fuzzy sets were used to model the uncertainty in both the criteria weights and the performance scores. Nguyen [10], for the first time, used these sets in order to build a contractor selection model. In the proposed model, three major criteria: - cost, presentation of bid information, and past experience were included. Plebankiewicz [11] presented a prequalification procedure based on fuzzy sets in which different objectives of owner such as time, cost and quality of works were considered. Imprecision and ambiguity in the prequalification procedure was addressed by the use of linguistic variables in the contractor prequalification model [12].

Jaskowski et al. [13] describe a model in which the decision for contractor prequalification is made by making pairwise comparisons between the candidates using the Analytic Hierarchy Process (AHP) in a group decision making procedure. Fuzzy sets were used to define the criteria weights elicited by aggregating the judgment of several decision makers. It was found that the fuzzy approach resulted in improved quality of criteria prioritization. Hosny et al. [14] propose the use of fuzzy sets in the pairwise comparison stage of the AHP when attempting to assess the relative importance of the criteria for contractor prequalification. Nasab [15] also advocated the use of fuzzy sets and the AHP procedure to elicit the relative importance of the prequalification criteria. The weighted criteria are then used in a TOPSIS-like procedure to determine the candidate closest to the ideal solution. Nieto-Morote and Ruz-Vila [16] also proposed the use of fuzzy sets and linguistic terms in a TOPSIS-like procedure for prequalifying contractors, and proposed a way to handle inconsistencies in the preference relationship between pairs of alternatives.

Plebankiewicz [17] presented a statistical survey of the methods and criteria of contractor selection used by public and private clients in the Polish building industry. The results indicated that public clients were using only one criterion in most of the restricted tenders in order to qualify the contractors; a significant percentage of private clients did not have a prequalification procedure.

Plebankiewicz [18] suggests a pre-evaluation screening step in the prequalification procedure where: (1) minimum thresholds are defined for some key criteria (especially financial and technical capability); (2) any contractor that fails to meet the minimum threshold is immediately eliminated from further consideration. Those that pass this screening step are evaluated in more detail to determine a suitability score with which they can be ranked. Plebankiewicz [19] modeled decision-making processes of contractor and client in bidding procedures using fuzzy sets. Alhumaidi [20] formulated a model which allowed group decision making in the prequalification problem. Data was encoded using fuzzy sets, and the fuzzy weighted average of the responses of the different experts was used to determine the final contractor suitability and ranking.

From the review of the literature discussed above, it is concluded that the use of fuzzy sets to encode information uncertainty in a MCDM model generally improves the performance of the model. It makes the application of human expert knowledge easier since linguistic terms are used. However, much of the research using fuzzy sets cited above is based on Type-1 Fuzzy Sets (T1FSs) with crisp membership functions. Although a piece of measured data can belong to more than one fuzzy set (with different degrees of membership for each set), T1FSs cannot accommodate the situation when the membership value of the data itself is uncertain. This situation arises when the evaluation and the decision are made by a group rather than a single person (group MCDM). Thus, the results obtained from using T1FSs for a group MCDM problem like contractor prequalification can be unreliable. Also, there is uncertainty about the setting of thresholds for concepts and the activation of rules as more than one rule (and consequence) could be applicable. These new sources of information uncertainty can be more efficiently represented using a higher-level type-2 fuzzy set (described in more detail later). In spite of the widespread use of T1FSs in MCDM, the use of general type-2 fuzzy sets is not as common. Previously, it had been computationally onerous to maintain the many degrees of possibility associated with maintaining this level of information using T2FSs. However, with the introduction of a special type-2 fuzzy set, namely Interval Type-2 Fuzzy Sets (IT2FSs), such computations are now possible, even using software run on general purpose desktop computers. Therefore, it is not necessary to sacrifice information content for computational expediency. It is the intention of this paper to present a group MCDM model which incorporates the use of IT2FSs to encode information uncertainty. IT2FSs efficiently model the uncertainties inherent in group decision making for the contractor prequalification problem, and requires less computational effort than general type-2 fuzzy sets. A numerical example demonstrates its application and offers a comparison with the result from T1FSs. Also, Interval Weighted Average (IWA) method is used as a MCDM method. Since hybridization of IT2FSs with any MCDM method increases the complexity of the calculations, the IWA approach, which is simpler and needs less calculation than other approaches such as AHP, TOPSIS, etc., makes it computationally tractable to compute with T2FSs for the prequalification problem. In summary, the paper describes how to encode uncertainty in a group decision making problem like contractor prequalification using IT2FS, and to efficiently compute results without sacrificing information along the way.

2. The role of information in contractor prequalification

In the contractor prequalification problem, information about the problem is collected about: (1) the requirements of the project, and owner; (2) evidence on the characteristics of the contractor relevant to the different criteria used in the prequalification exercise; (3) the importance (weight) of the criteria; (4) rubrics and scales used to evaluate performance based on the evidence; and (5) rules to draw implications from the evidence.

Many studies have presented lists of criteria that can be used to