A Multi Agent Systems based Contractor Pre-qualification Model

Faikcan Kog, kog@itu.edu.tr
Istanbul Technical University, Turkey

Hakan Yaman, yamanhak@itu.edu.tr
Istanbul Technical University, Turkey

Abstract

In this study (1) contractor selection and pre-qualification models and systems in the literature are examined and (2) the proposal of a multi agent systems (MAS) based contractor prequalification model in order to support client's decision with the optimal solution in a contractor selection phase are introduced. A meta-classification and analysis study based on a comprehensive literature survey is used to analyse models and approaches available. Three basic tendering processes, which are open, selective limited and negotiated, were studied and a prototype program is created to implement the model proposed. In addition, the tender management system is conceptually discussed in the context of the model.

Keywords: Contractor Prequalification, Contractor Selection, Multi Agent Systems, Decision Support Systems, Criteria Evaluation

1 Introduction

In the construction industry, selecting a right contractor is a major problem that clients have to face at the beginning of every project. It is well known fact that construction projects consist of various uncertainties and risks and the success of construction projects depends on effective and efficient use of resources. In addition, construction projects be composed of commonly unique and complicated tasks that the participants have to be dealt with in order to achieve to the success. Therefore a strong and consistent relationship between client and contractor, who are the two main participants of construction projects, is expected for objectives (Kog & Yaman 2014a).

Contractor pre-qualification (CP) is the most effective way to support client's decision in order to select contractors from the short list of qualified contractors. In practices, "bid price" is the dominant and significant factor that affects the result of tenders directly. However, many researches has exposed that bid price cannot be criterion alone in order to take decision (Latham 1994). Therefore, in order to support decision on contractor selection (CS) of clients, several contractor pre-qualification criteria were determined and used within the decision support methods to qualify contactors. Despite various proposals and models to evaluate those criteria in literature, it is observed that there will always be missing points in the evaluation of criteria and in the simulation of tendering process with being human interference.

In this paper, contractor selection and pre-qualification models are examined. A meta-classification and analysis study based on a comprehensive literature survey, is used to analyse existing models and approaches to date. A multi agent systems based contractor prequalification model is proposed to support client's contractor selection decision. Contractor prequalification model works in the context of a new tender management system, which is also introduced briefly. Three basic tendering processes, which are open, selective limited and negotiated tendering, were studied and a prototype program is created to implement the model proposed. A simulation model for the proposed pre-qualification model is given conceptually.

This paper is structured as follows: the problem and the objectives of the study are clarified in the background section. Research methodology and classification is overviewed in approach section. A prototype CS program is introduced and a case study is given in order to present initial results of proposed CP model in the fourth section. And in last section the results are discussed and the paper is concluded with the suggestions of further studies.

2 Background

Contractor selection problem in construction industry must be handled in two directions as contractor selection and contractor pre-qualification. Pre-qualification process provides contractors with the opportunity to differentiate themselves from their competitors and to impress clients and their advisors to have place on their tender lists (Tarawneh, 2004).

Despite the attractive impacts of "bid price" in construction tenders, selecting a right contractor is not a decision, which could only depend on one criterion. The details such as character of client, type of tendering or nature of project cause to consideration of dominance of "bid price" criterion and underlie the CP criteria. Many researches has exposed that bid price cannot be criterion alone in order to take decision (McCanlis 1967; Latham 1994; Holt et al 1995). Therefore researchers are focused on some issues such as attributions (El-Sawalhi et al 2008) and past performances (Kadefors et al 2007; Holt et al 1994) of contractors. Besides that contractor selection problem is evaluated according to the expectations and objectives of clients (Russell & Skibniewski 1988; Wong et al 2001). As a result non-price criteria are suggested in order to evaluate contractors in pre-tender stages. The holistic study on CS criteria is conducted by Ng & Skitmore (1999) for UK Construction Sector. In this study, a large empirical survey is carried out in UK to indicate significant differences in the perspectives of clients and consultants on CS criteria. In another study, Tarawneh (2004) examines the perceptions of major client from public and private sector on the importance of the pre-qualification criteria. In literature there are many researches, which are conducted on the CP criteria in many countries (Jennings & Holt 1998; Plebankiewicz 2010; Singh & Tiong 2006). Meta classification study of Kog & Yaman (2014a) indicates 65 institutions from 24 countries are dealt with CS and CP problem in last two decades. Moreover several researches are carried out in Turkish construction sector (Arslan et al 2008; Baykasoglu et al 2009; Topcu 2004; Yilmaz & Ergönül 2011).

Determination of the CP criteria has revealed a problem of evaluation of those criteria. Evaluation of many criteria is subjective and ambiguous in meaning and it is also not an easy task to determine one scale of evaluation for all the criteria (Plebankiewicz 2009). One of the most comprehensive studies on CS is conducted by Russell (1992). Russell proposes a decision support system, which consists of financial model, linear model, fuzzy set model, statistical model, knowledge-based model and hybrid model, in order to evaluate contractors. On the other hand there are many other approaches proposed such as linear model using PERT approach by Hatush & Skitmore (1997), fuzzy sets theory based methods by Singh & Tiong (2004), artificial neural network by Lam et al (2000), analytical hierarchy process by Fong & Choi (2000). In last 2 decades, 59 different methods and techniques, which could be grouped as decision theory, statistical methods, neural networks, machine learning and hybrid, are used 220 times in the researches about CS (Kog & Yaman 2014a). Meta classification study indicates that Statistical Methods, which occurred in 36 papers, are mostly preferred ones. Fuzzy Set Theory (Singh & Tiong 2004), Analytical Hierarchy Process (Fong & Choi 2000), Decision Support Systems (Ng & Skitmore 1995), Artificial Neural Networks (Khosrowshahi 1999), Multi Attribute Analysis (Holt et al 1994) are other commonly occurred methods.

The methods in the researches indicate that the CS and CP problem is mostly evaluated as a Multi Criteria Decision Problem (Kangas et al 2008). Although the most preferred methods are statistical methods and decision theory, in recent years there is a tendency to the machine learning and neural networks. This emphasizes that there is an increments in the intelligent systems based solutions of the CS and CP problem. Another increment is observed in the hybrid solutions, which consist of different models and methods. Many researches was established on base of a criteria weighting and omitted the whole tender process. Literature study is indicated that there is still missing point in the automation of selection process and simulation. Watt et al (2010) indicates that the identification of CS and CP criteria, relative importance or effectiveness and weighting of criterion has still unexplored fields.

On the other hand, every construction project is unique and consists of specific and complex tasks, which should be effective on the decision making. CS is a human-driven process between client

and contractors. Therefore, the type of tendering such as open, selective limited and negotiated tendering has also direct influence on the selection of contractor.

The concept of using computer aided tools for decision making was first suggested by Bonini (1963) and growth steadily as decision support systems (Khripunova et al 2013). This study is aimed to propose a multi agent systems based CP model, which is a part of an automated tender management system in the big picture. Multi agent systems (MAS) on the other hand is a selected technology in order to provide an automated and intelligent CP and CS.

3 Approach

3.1 Meta Classification and Analysis

This study is conducted in the scope of a Ph. D thesis namely "Multi Agent System Based Contractor Selection and Prequalification Model". A comprehensive literature study of last two decades (1992-2013) is carried out from the researches on CS and CP in order to classify and analyse CS studies. This survey study is carried out in order to provide the initial parameters of the theoretical CS model. According to the meta-classification analysis of 133 peer-reviewed studies covering the topics of CS, CP and weighting criteria in the last 20-years period are identified and compiled in order to observe perspectives in empirical study. Those are grouped in 5 main criteria as;

A. **Financial Standing**; Financial Stability, Credit Rating, Working Capital, Turnover and Equity.

B. **Management Capability**; Previous Performance and Quality, Quality Control Policy, Quality Management System, Project Management System, Experience of Administrative Personnel, Management Knowledge, Project Delivery Method and Location.

C. **Technical Ability**; Plant and Equipment, Personnel, Usage Level of Technology, Expertise Field, Integrity, Size of Project, Experiences of Technical Personnel and Workload.

D. **Reputation**; Age of firm, Fraudulent Activities, Disqualification Status, Past Failures in Completed Projects, Quality of Construction in Previous Projects, Attitude in Previous Projects, Following the Instructions in Previous Projects, Delays in Previous Projects, Number of Previous Bids, Past Client Relationships, (Reference) and Interoperability.

E. **Health and Security**; Accidents, Health and Security Management System and Insurance Policy (Kog and Yaman, 2014b).

More information on the given meta-classification system and result can be found in (Kog & Yaman 2014a)

3.2 Quantitative Survey

According to these criteria, a quantitative survey is conducted in Turkish construction sector to obtain parameters of the model proposed. The study is aimed to examine and to compare the level of weightiness (Ginevičius & Podvezko 2004) and effectiveness (Srdoc et al 2005) of the contractor selection criteria from the perspective of the Turkish construction sector. The survey is carried out in the major 3 cities of Turkey with the sample of 106 respondents from public and private sectors. The ranked CS criteria and sub-criteria are weighted by relative importance index (RII) as follows in equation 1 (Kometa & Olomolaiye 1997);

$$R = \frac{\sum w}{A_n * N} \qquad (1)$$

Where,
w = weight of given sub-criterion in the range of 1 to n.
A_n = the maximum weight, defined as n.
N= the sample size.

Table 1 indicates the respondents' perspectives on the relative importance and the effective use of the main criteria. The given criterion scores, which are used as initial criteria weighting, are estimated by RII method. According to the both ranking "financial standing" is seen as the most important and effective criterion. On the other hand, the criterion scores of sub-criteria express that the three most important sub-criteria are "quality of construction in previous projects", "past failures in completed projects" and "accidents". Those are sub-criteria of "reputation" and "health and security". Results emphasize that "interoperability of contractor with other firms", "the location of head departments" and "the current workload of the contractor" do not play significant role in the decision of CS. More results on the given quantitative study can be found in (Kog & Yaman 2014b)

Table 1 Ranking Comparison of Weightiness and Effectiveness of Main Criteria

Code	Sub-Criteria	Criterion Score	Weightiness Rank	Effectiveness Rank
A	Financial Standing	0,6868	1	1
B	Management Capability	0,5981	4	5
C	Technical Ability	0,7208	3	2
D	Reputation	0,5528	5	4
E	Health and Security	0,4415	2	3

3.3 Tender Management System

The tender management system introduced consists of 8 phases (Fig. 1).

- The first phase is the selection of tender, which is initiated by client.
- At the end of the application procedures the pre-qualification phase is activated by "call agent" phase, which is introduced in Section 3.4.
- In contractor pre-qualification phase the ranking results of contractors according to the criteria is expressed. Client can pre-define the pre-qualification rules such as short listing the contractor with a constant number of bidders or threshold value.
- After listing the contractors, who are eligible to bid, bidding type selection phase occurs. Considering the tender type of open, selective limited or negotiated tendering, there are two type of bidding methodology defined, which are auction and negotiation (introduced briefly in Section 3.4).
- After selecting the bidding type "call agent" is activated to perform negotiation or auction process and suggest agent offers.
- The suggested offers are presented in next step with the detailed MAS process view as system log view.
- The next phase is the approval of the suggested offers as the latest biddings of contractors.
- At the end system turns out the last ranking by the calculation of initial ranking scores and latest biddings.
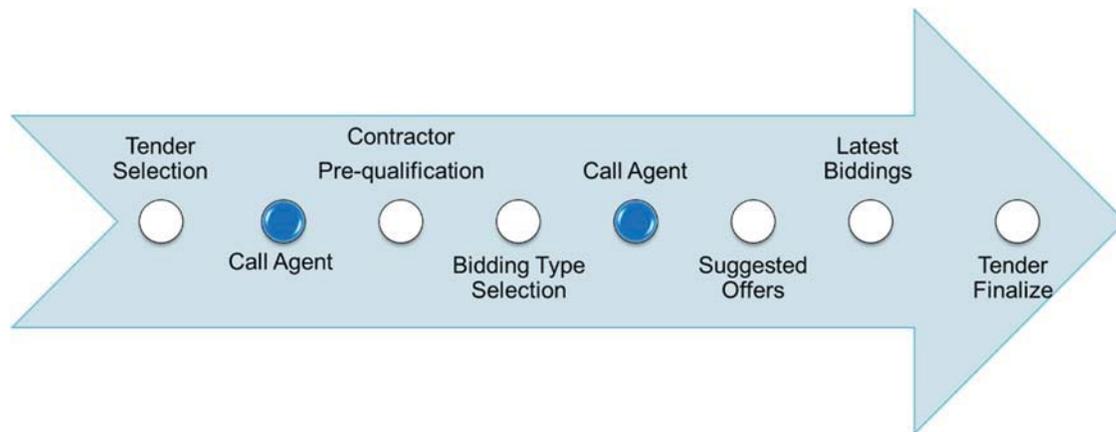
Figure 1 The approach of Multi Agent System (MAS) based Tender Management System
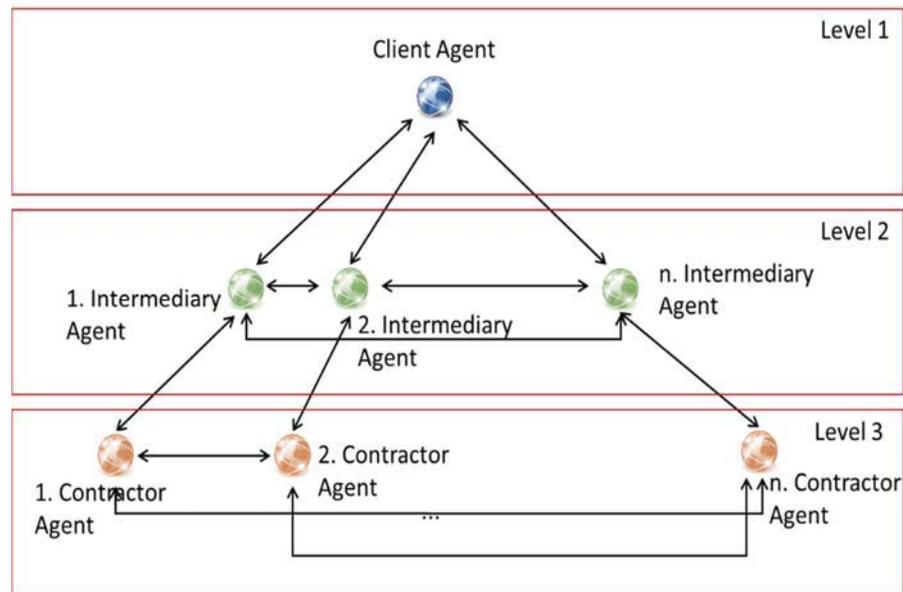
3.4 Multi Agent Systems based Contractor Pre-qualification Model (Call Agent)

Multi agent systems (Maes et al 1999), which are the next generation knowledge based systems (Miles and Moore, 1994), are selected methodology in order to automate CS process and to suggest intelligent solution. Intelligent agents (Kirn et al 2006), which are an autonomous system situated within an environment, are form a basis for the MAS. Agent interacts with its environment, learns upon obtaining new data and acquire some knowledge. It acts in pursuit of its own agenda to achieve its goals, possibly influencing the environment. (Arciszewski et al 2005) The emphasized features of the agents are the ability of synchronous evaluation of stored and immediate data, the ability of updating stored data and improving oneself with the competence of learning.

In this study, agents are first used to store initial weighting of criteria. It is aimed that the agents could be specialized in updating criteria weighting, according to the subject and type of tender and observing recorded contractors in the proposed system. In the competitive construction industry, it is very important for clients and contractors to develop a strategy. In the open type of tender, contractors should be estimated not only the strategies of client, but also the competitors.

In literature there are various agent based solutions for the negotiation processes of clients and contractors with or without considering agent's learning. Vahidov (2007) proposed an agent-based architecture for managing multiple negotiations. Hsieh (2005) used agents to automate negotiation process in the electronic market contracts. Dereli & Altun (2012) proposed a modified method considering the influence of fixed performance on the bargaining issues. Ren et al (2002) are used MAS in order to automate construction claim negotiation by MAS. In this study Zeuthen's bargaining model was integrated with Bayesian learning mechanism in order to develop high level MAS architecture for the claims negotiation between client's engineer and contractor (MASCOT, Ren et al 2003). MASCOT is the inspiration of this proposed MAS based tender management system.

MAS based CP and CS approach is shown in Figure 2. The model consists of 3 levels as client agent, intermediary agents and contractor agents. Client agent controls the system inputs and outputs and updating data with its learning mechanism. It retrieves data of contractors from intermediary agents and performs regression analysis (Aibinu & Pasco 2009) as learning mechanism for every criterion. It estimates the contractor's criterion score (between 0 and 1) according to weighting of criterion and regression analysis of given criterion of all contractors. This interval estimation, which is defined in the system as Bayesian interval estimation (Severini, 1993), performs many times for all criteria until the constancy of ten thousands decimal digit of both side of the interval. At the end of process client agent use the last scores to calculate the ranking point of contractor by normalizing the latest results. This interaction between the first level and second level constitute the CP phase of the model, which is also shown in the Figure 1 as first "call agent" phase.

Figure 2 The Agent Interaction Levels of the Multi-Agent System based Contractor Pre-qualification and Selection Model

In the second call agent action, there are interactions between the agent of level 2 and level 3 in both vertical and horizontal layers. Negotiation and auction based bidding types are selected as the two methods in this phase to perform agents. In this study second call agent action is given conceptually. However, in order to perform a case study and to indicate system results a negotiation based bidding type is used. Negotiation based bidding depends on the MASCOT model. However in MASCOT model there is only one to one negotiation between client engineer and contractor. In this study an approach is developed to perform negotiations in the one to many relation level.

4 Case Study

In order to make the tender management system as a user friendly platform, a Hypertext Preprocessor (PHP 2015) based web application is built as prototype into a virtual server with database. Java programming language (Arnold et al 1996) is used to create a multi-agent system. These programs are integrated with virtual server and the other tools.

A real tender process from Turkish construction industry is used as a case. The case is a real tender of a construction work with approximate cost of 5.252.942,81 Turkish Lira. In the case 6 contractors are applied for the tender, however one of them is not eligible to attend tender because of missing documents. Therefore 5 contractors are able to attend tendering process. After interviews with those 5 contractors (are named as contractor a, b, c, d, e) all the information are collected to estimate initial criteria scores and the initial strategies of contractors. Contractors and their initial criteria points in the web based GUI of the tender management system is shown in Figure 3.

Figure 3 Contractors and their criteria points shown in the tender management system GUI .

Criteria points are given as 1-5, where 1 denotes the interval [0-0,2); 2 denotes the interval [0,2-0,4); 3 denotes the interval [0,4-0,6); 4 denotes the interval [0,6-0,8); and 5 denotes the interval [0,8-1].

   The next step is the calling of multi-agent system in order to estimate latest criteria scores of contractors. These scores are used to calculate overall criteria score of contractors and after a normalization (between 0-1) pre-qualification results are shown in Figure 4. The results express that the contractor "d" has the highest and the "b" has the lowest ranking scores. In this phase, negotiation bidding type is selected and the first three contractors ("d, a, e") are accepted to continue bidding process.

Figure 4 The GUI of the multi agent systems based contractor pre-qualification results and selection of bidding type phase in the tender management system.

Then the second call agent process is run and the results of the suggested offers of the contractors are shown in Figure 5. It is possible to control contractor intermediary agents' negotiation process through observing the system logs in GUI. If the suggested offer are accepted as the last offer then finalizing tender procedures is run. Finalize tender client agent uses a ratio for the weighting of criteria and the bid price. This ratio is given to the system according to the type of construction work and its properties. In this case from the quantitative survey (given in Section 3.2) criteria is calculated as %40 and bid price calculated as %60 weighting.

MAS results

Company	Ranking	Optimum	Reservation	Suggested Offer	Offer	Log
dcon	0.28324924742678	6500000	4143750	4442281.254706987	4442281.254706987	log
acon	0.22833032322356	5239721.2505809	4143750	4470641.084811915	4470641.084811915	log
econ	0.2037054655559	4674630.3410944	4143750	4545767.405167445	4545767.405167445	log

Finalize tender

Figure 5 The GUI of the multi agent systems based suggested offers of the contractors' in the tender management system.

Figure 6 shows the last ranking of the contractors with initial rankings and latest offers. It is shown that the contractor "d" with 4.442.281 TL is the optimal offer for the case. The contractor "d" has been the winner of the tender in reality, however the contract has been signed for 4.741.750 TL. It means the client has been lost approximately 300.000 TL (~100.000 €), which is correspondent to %5,7 of the estimated cost by the client.

Final

Company	Initial Ranking	Offer	Last Ranking
dcon	0.28324924742678	4442281.254706987	0.59672193004377
acon	0.22833032322356	4470641.084811915	0.57401011984028
econ	0.2037054655559	4545767.405167445	0.56218865396487

Figure 6 The GUI of the multi agent systems based contractor selection final results in the tender management system.

5 Conclusion

Contractor selection is a major decision process, which effects directly the success of a construction project and it is a kind of multi-criteria problem. Against to the irresistible attraction of the bid price as a key criterion more realistic methods and evaluation techniques should be developed. In this study multi agent system based contractor pre-qualification and selection model is proposed to evaluate contractor pre-qualification criteria in the learning and autonomous nature of the intelligent agents.

This study is carried out in the frame of a new tender management system approach. The main idea is constructing a non-human-driven tendering process for the construction industry. It is thought that it could be a useful tool for an automated contractor pre-qualification and selection process for future works.

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