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Smart Home Subcontractor Selection Using the Integration of AHP and Evidential Reasoning Approaches

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Abstract

Subcontracting is a very common practice in the construction industry. The large portions of actual production work are carried out by subcontractors. Therefore, main contractors have focused on selection of the appropriate subcontractors to increase the performance of their business. Finding the most suitable alternative among these subcontractors is another complex task because assimilating a large number of aspects is not simple without using any selection tools. In order to understand this better, breaking down the problem into smaller parts and building a model is one of the best ways in the selection process. Companies want to make differences to increase buyers' interest; this is to obtain better position in the competitive construction market. Recently, the popularity of smart home and home automation has importantly increased in modern societies in Turkey. This has lead construction companies to import the smart home system into their business investments. This study aims to propose an integrated model for selection of smart home subcontractor. The proposed model integrates Analytic Hierarchy Process (AHP) and Evidential Reasoning (ER) techniques. In this study, AHP is used to find the weights of the criteria that are considered in the smart home subcontractor evaluation process and ER is employed to rank the alternative subcontractors. The proposed approach is applied in a construction company that has completed many projects in Turkey. In the case study, twenty evaluation criteria are considered and eight alternative smart home companies are evaluated. The result of this study demonstrated that the suggested model is applicable.

Keywords: Analytic hierarchy process; case study; evidential reasoning; smart home; subcontractor selection

1. Introduction

A subcontractor can be defined as an individual or a company hired by a main contractor to carry out specific tasks on a construction project and/or supply resources (e.g., laborers, materials, equipment, tools) and designs [1-2]. Subcontracting has become a very common practice, as the main contractors' have been much more willing to sublet a large portion of their work for various reasons (e.g., financial benefits, resource constraints, better efficiency) [3]. According to Hinze and Tracey (1994) [4], indeed, subcontractors are hired to perform 80-90% of the tasks on many construction projects, especially building projects. It should be noted that even though subcontracting is a very common practice, it is also a very risky practice. Having a group of unknown subcontractors which are hired to carry out the majority of the tasks in a project can be a disadvantage in some circumstances. The main contractor may fail to coordinate subcontractors or control the quality and progress of their works [3, 5-9].

Since the main contractor takes prime responsibility for the performance of the subcontractors, the selection of the most appropriate subcontractor is crucial to complete the project successfully in terms of time, cost, and quality [10-14]. Nevertheless, many contracting companies underestimate the risk of not being able to complete the project successfully due to selecting their subcontractors solely based on the lowest bid. This type of selection increases the possibility of selecting unqualified, incompetent, inexperienced, and insufficiently financed subcontractors [11-13, 15-16]. Besides, the consequences of hiring inadequate subcontractors may be severe, such as claims, disputes, litigations, adversarial working conditions, penalties, abandonment of work, bankruptcy. Therefore,

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considering several factors in selection of subcontractors is important for the success of construction companies, rather than only taking bid prices into account when they select their subcontractors.

The selection of smart home subcontractors gained more importance, as the popularity of smart home and home automation has increased in Turkey. The main objective of this study is to propose an approach to provide contracting companies with a tool that will support them overcome the challenge of selecting the most appropriate subcontractor for their projects. In the proposed approach, two multi-criteria-decision-making methods namely, Analytic Hierarchy Process (AHP) and Evidential Reasoning (ER), were integrated. The proposed approach is also applied in a construction company, which is the main contractor of a residential project that consists of smart home systems.

2. Research Methodology

A review of literature shows that there are several studies focused on developing a model for subcontractor selection. However, studies that are focused on selection of smart home subcontractor are very limited. The aim of this study is to propose an integrated approach for selection of smart home subcontractor. For this purpose, the following tasks were performed: (1) determining the factors that have an impact on selection of smart home subcontractor; (2) integrating AHP and ER methods for selection of smart home subcontractor; and (3) applying the integrated approach to solve a smart home subcontractor selection problem of a Turkish construction company. The following sections provide information about AHP and ER methods.

2.1. *The AHP method*

Even though there are various methods to solve multi-criteria-decision-making problems, AHP has become one of the most commonly used methods after it was developed by Thomas Saaty [17]. The main steps of AHP method are as follows: (1) defining the decision problem and determining its goal, (2) development of the decision hierarchy, (3) establishment of the pairwise comparison matrix, (4) calculation of the weights of the criteria, and (5) calculation of the consistency ratio [18-19].

Defining the decision problem and determining its goal is the first step of AHP method, as it is the same for many methods that are used to solve multi-criteria-decision-making-problems. The second step, development of the decision hierarchy, involves the identification of the problem goal, selection of criteria and possible alternatives. If a decision-maker needs to represent the decision hierarchy in details, then he/she can add several levels (i.e., main criteria, sub-criteria, etc.) to the decision hierarchy. In the third step, pairwise comparison matrix is established after developing the decision hierarchy. The comparison of the importance of the selection criteria is done in pairs according to the goal of the decision problem using the nine-point rating scale which is represented in Table 1 [17]. In case of having more than one decision maker, the judgments of the decision-makers in the pairwise comparison matrices should be aggregated using the geometric mean. The next step comprises the calculations of the weights of the criteria. First, each element in the pairwise comparison matrix is divided to the sum of its own column. Then, the arithmetic mean of each row is calculated to obtain the weights of the criteria. In order to measure the consistency of the decision maker's judgements, the Consistency Ratio (CR) in each pairwise comparison matrix calculated in the final step of the AHP method. Any value less than 0.1 indicates that the judgements of the decision maker(s) are consistent. If CR is greater than 0.1, the pairwise comparisons should be repeated by the decision maker(s) until obtaining a value of CR that will be acceptable.

2.2. *The ER method*

Lowrence et al. (1986) developed ER method to solve multi-criteria-decision-making problems by using the evidence and decision theory of Dempster-Schafer [20]. One of the most important advantages of ER method is that it allows to use of both quantitative and qualitative data. In order to model the uncertainties inherent in information related to a problem, belief structure and belief decision matrix are employed in ER method [20-21]. ER method mainly consists of three steps namely, (1) development of the hierarchy, (2) data transformation, and (3) evaluation of alternatives. In the first step, the problem hierarchy is developed by defining the assessment criteria and alternatives. Subsequently, the criteria weight and utility are used to define a belief decision matrix. ER method allow the decision-maker to use different types of data (precise numbers, interval numbers, belief structures, etc.) to evaluate the alternatives according to the assessment criteria. The second step involves the transformation of different types of evaluation data to a common framework in order to make comparison and aggregation. This transformation is done by using rule or utility based information transformation techniques. The final step is based on the aggregation of all type of information thorough the ER algorithm. The weights of the assessment criteria and the evaluations of alternatives according to the criteria are used to rank the alternatives.

3. A numerical application of the proposed approach

A real-life case study is provided where the steps of the proposed approach are used for subcontractor selection. The content of the case study is based on a subcontractor selection of a Turkish construction company. The company is the main contractor of a residential project that consists of smart home systems. The construction company is interested in finding subcontractors, which are specialized in installation of smart home systems. The decision-making team of consists of four experienced engineers, who are assigned to manage the subcontractor selection process. First of all, team members determined the criteria that should be taken into account during the selection of the subcontractor in the case study. They determined eight main criteria namely, “quality of service” (MC-1), “level of experience in different building types” (MC-2), “financial capacity” (MC-3), “cost” (MC-4), “technical capability” (MC-5), “past experience with the company” (MC-6), “quality of the product” (MC-7), and “experience in implementation technique” (MC-8). Five of these main criteria have sub-criteria which are quality of call center service (SC1-1), “qualifications of the employees” (SC1-2), “duration of providing service” (SC1-3), “duration of providing spare parts” (SC1-4), “experience in single house” (SC2-1), “experience in apartments” (SC2-2), “experience in hotels” (SC2-3), “capital cost” (SC4-1), “operational cost” (SC4-2), “maintenance cost” (SC4-3), “capability of the R&D department” (SC5-1), “production technology” (SC5-2), “capability of pursuing new technologies” (SC5-3), “qualifications of the technical personnel” (SC5-4), “wireless” (SC8-1), “wired” (SC8-2), “mixed” (SC8-3). After determining the criteria for selection of smart home subcontractor, the decision-making team formed the decision hierarchy (Figure 1) as a first step of the AHP method, which is used to compute the relative priorities of the criteria.

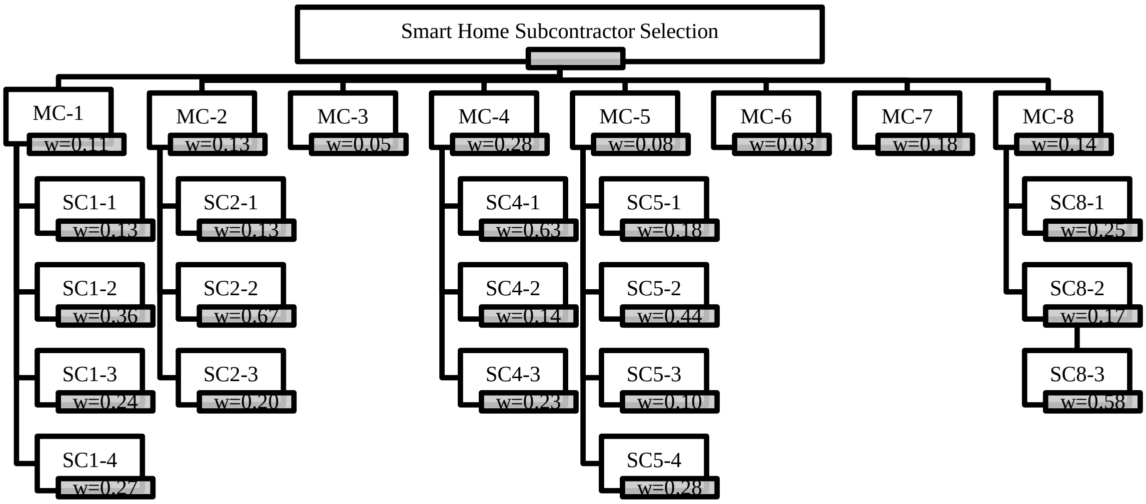

Figure 1. Decision hierarchy of smart home subcontractor selection problem

The decision makers compared the subcontractor selection criteria in pairs using the Saaty’s (1980) [17] rating scale. Subsequently, they evaluated the alternative subcontractors according to each criteria using the nine-point scale (Table 2).

Table 1. 9 Point scale used for smart home subcontractor evaluation

Linguistic Variable	Numerical value
Very Bad (VB)	1
Very Bad-Bad (VB-B)	2
Bad (B)	3
Bad-Average (B-A)	4
Average (A)	5
Average-Good (A-G)	6
Good (G)	7
Good-Very Good (G-VG)	8
Very Good (VG)	9

Since there were four engineers in the decision-making team, group decision making techniques were used in the AHP calculations. The decision making team individually formed the pairwise comparison matrices and calculated the geometric values of these values to get the final pairwise comparison matrix. Only the aggregated pairwise comparison matrix is presented in Table 2 rather than presenting the aggregated pairwise comparison matrices established for the sub-criteria due to the space limitations.

Table 2. Pairwise Comparison Matrix for 8 Main Criteria and Results Obtained from AHP Computations

Criteria	MC-1	MC-2	MC-3	MC-4	MC-5	MC-6	MC-7	MC-8	Weights	
MC-1	1.00	0.67	2.22	0.37	1.73	5.32	0.55	0.95	0.11	
MC-2	1.50	1.00	2.06	0.32	1.93	5.54	0.74	0.76	0.13	
MC-3	0.45	0.49	1.00	0.28	0.53	2.00	0.24	0.25	0.05	
MC-4	2.69	3.08	3.57	1.00	4.12	7.42	1.78	2.00	0.28	
MC-5	0.58	0.52	1.88	0.24	1.00	3.46	0.45	0.71	0.08	
MC-6	0.19	0.18	0.50	0.13	0.29	1.00	0.17	0.21	0.03	
MC-7	1.81	1.35	4.24	0.56	2.24	6.05	1.00	1.57	0.18	
MC-8	1.06	1.32	3.94	0.50	1.41	4.70	0.64	1.00	0.14	CR: 0.01

According to the results presented in Table 2, "cost" (MC-4), "quality of the product" (MC-7), and "experience in implementation technique" (MC-8) have the highest weights, respectively. On the other hand, "past experience with the company" (MC-6), "financial capacity" (MC-3), and "technical capability" (MC-5) have low impact on the selection of smart home subcontractor. Consistency ratio (CR) of the pairwise comparison matrix is calculated as $0.01 < 0.10$, which indicates that the judgment matrix is consistent and the weights can be used in the selection process.

Even though four engineers were involved in formation of the aggregated pairwise comparison matrix, only the team supervisor evaluated the alternative subcontractors according to the assessment criteria using the nine-point evaluation scale shown in Table 1. Evaluation results of the decision maker are shown in Table 3.

Table 3. Evaluation matrix of subcontractors

Criteria	Unit	Best Value	Weight	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8
MC-1			0.11								
SC1-1	-	Max	0.13	G	B-A	A	B	A	VB-B	A-G	B
SC1-2	-	Max	0.36	G-VG	A-G	A	B	G	B	A	B-A
SC1-3	Day	Min	0.24	7	1	3	3	7	1	7	3
SC1-4	Day	Min	0.27	30	3	7	30	30	7	30	7
MC-2			0.13								
SC2-1	-	Max	0.13	B	G-VG	A	B-A	B	B	B	B
SC2-2	-	Max	0.67	G	A	A-G	VB-B	A	VB-B	B-A	B
SC2-3	-	Max	0.20	G-VG	A	A	VB	A-G	VB	A	B-A
MC-3	-	Max	0.05	G-VG	A	A-G	B-A	G	B	G	A
MC-4			0.28								
SC4-1	Euro	Min	0.63	800	700	760	1100	1300	650	1400	690
SC4-2	Euro	Min	0.14	1050	540	900	460	1500	600	1200	1100
SC4-3	Euro	Min	0.23	250	50	300	250	250	50	200	250
MC-5			0.08								
SC5-1	-	Max	0.18	G-VG	A-G	A	B-A	B-A	VB-B	A-G	B
SC5-2	-	Max	0.44	G	A-G	A	A-G	A-G	B-A	G	A
SC5-3	-	Max	0.10	A	G	B-A	A-G	A	B-A	A-G	B-A
SC5-4	-	Max	0.28	G-VG	A-G	A	VB-B	A	VB-B	A-G	A
MC-6	-	Max	0.03	A	VG	G-VG	A-G	B	A-G	B	G
MC-7	-	Max	0.18	G-VG	A-G	A	A	G-VG	B-A	G	A
MC-8			0.14								
SC8-1	-	Max	0.25	B	G-VG	B	A-G	VB-B	VB	B	VB-B
SC8-2	-	Max	0.17	G	A-G	A-G	VB	A	B-A	A-G	A
SC8-3	-	Max	0.58	B-A	G	B	VB	B	VB-B	A	B

When the AHP computations are over, ranking of the alternative subcontractors was done via IDS-Intelligent Decision System for Multiple Criteria Assessment software program, which is specifically developed for ER computations. When the required data regarding the weights of the criteria, evaluations of alternatives according to assessment criteria are inputted, IDS performed all the required computations to obtain the ranking of alternative subcontractors. Ranking results of the alternatives are shown in Table 4. According to the ranking results, the subcontractor referred as A2 is suggested as the best alternative, which was followed by subcontractor A1, A3, and A8, respectively.

Table 4. Alternative rankings

Alternative	Assessment Score	Ranking
A1	0.6800	2
A2	0.7523	1
A3	0.5762	3
A4	0.3430	8
A5	0.4032	6
A6	0.5071	5
A7	0.3914	7
A8	0.5290	4

The results of the case study validated the usefulness of the proposed approach by providing the same decision that was made by the contractor's team that is in charge of selecting subcontractors. Indeed, the supervisor of the decision-making team stated that subcontractor A2 was selected to install the smart home systems on the residential project, which the construction company has agreed to perform. The opinions of four decision makers, who had the opportunity to use the proposed model, were sought through face-to-face interviews in order to check the validity of the developed model and its usability in their company. The decision makers stated that the developed DEA model was a useful and efficient tool, and could be easily used in their company for subcontractor selection in future projects.

4. Conclusion

Selecting the appropriate subcontractor is one of the most important factors that affect the success of a contracting company. In this study, an approach that integrates the AHP and ER methods was proposed to provide construction companies with a tool that can be used in selection of the most appropriate subcontractor. The proposed approach was applied to a smart home subcontractor selection problem of a construction company, which is the main contractor of a residential project in Istanbul, Turkey. According to the results of this study, the subcontractor referred as A2 is suggested as the best alternative, while the subcontractor A4 was found to be the worst among eight alternatives. The results also validated the usefulness of the proposed approach as it provided the same alternative that was selected by the contractor's team that is in charge of selecting subcontractors.

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