Journal of Construction Engineering, Management & Innovation
2018 Volume 1 Issue 1 Pages 18-32
https://doi.org/10.31462/jcemi.2018.01018032
www.goldenlightpublish.com

RESEARCH ARTICLE

Subcontractor selection with additive ratio assessment method

S. Koçak[1], A. Kazaz[1*], and S. Ulubeyli[2]

[1] *Akdeniz University, Department of Civil Engineering, Antalya, Turkey*

[2] *Bulent Ecevit University, Department of Civil Engineering, Zonguldak, Turkey*

Abstract

During the last decades, especially in large-scale construction projects, it is one of the widely applied strategies that the main contractors work with many subcontractors and overtake a large part of the works. This trend brings out the problem of selection of subcontractors. The classical approaches in the construction industry to select the subcontractor are the general practice reference, the lowest bid, and the familiarity. This creates major risks for contractors since the construction sector involves time-limited projects with a large variety of complex works. Putting the subcontractor selection on a scientific basis and minimizing the risks by choosing the most appropriate subcontractor among the bidders for a particular type of work, require for the construction industry to determine not only consistent and efficient but also uncomplicated and plain model. Instead of the widespread conventional application, this study represents a new alternative approach to the subcontractor selection with Additive Ratio Assessment Method, which is one of the multi-criteria decision-making techniques. Additive Ratio Assessment Method is quite practical and convenient to use among the other multi-criteria decision-making methods. This study aimed to demonstrate the use of Additive Ratio Assessment Method on sub-contractor selection problems by exemplifying a real case application.

Keywords

Subcontractor selection; Additive ratio assessment method; Multi-criteria decision making; Construction management; construction

Received: 19 March 2018; Accepted: 23 March 2018
ISSN: 2630-5771 (online)

1. Introduction

Construction projects which incorporate many technical disciplines, are generally undertaken by the main contractor and are subdivided into sub-contractors specialized in their fields [1]. Globally, the last decades in construction business has been seen as a period that using the services of subcontractors are becoming more widespread every day. According to El Mashaleh [2], subcontractor use in the construction business is about 80-90% of all construction works. Also, it has been stated in many studies that contractor or subcontractor selection methods in the construction sector have not changed much since the 1940's [3]. Behind this widespread adoption of the subcontracting practice, there are parameters such as the specialization opportunities on the large construction industry, administrative efforts, resources and main capital provided by the system [4].

In Turkey, although formal entry of the contractor-subcontractor relation regulations into

* Corresponding author
Email: akazaz@akdeniz.edu.tr

labor law legislation dates back to the year 1936 when Turkey's Labour Law with No. 3008 was entered in the force, the widespread adoption of subcontracting in the industry has occurred since the 1980s. One of the main reasons for the widespread adoption of subcontracting is to reduce labor costs-low labor costs - and thus to create a chance of competition [5]. The provisions of the new Labour Law with No. 4857 which was entered in the force in 2003 and the Sub-Employment Regulations which was prepared in 2008 for detailing and concreting the provisions of the law, handled the relationship between subcontractors and contractors from many perspectives, and also they became important steps to prevent many problems [6]. The great change that has taken place in the Turkish Economic Structure since the 1980s has made subcontracting an essential part of the new business relationship that is sought after insistently [7].

The benefits of using the services of subcontractors to the construction sector are generally complementary. It brings flexibility to the contractor's decisions, especially regarding cost, quality, and duration. The subcontractor that undertakes and shares a part of uncertainty and high risks of confronting the main contractor functions as a buffer. Besides, the unnecessary expert/worker being kept out of cadence and providing a certain balance of cost, it is also the case that there grows a relationship that can be called semi-integration between them over time. Using the services of subcontractors in the construction business is the most effective solution for the production of complex projects. Along with that, the number of subcontractors of which services are used varies for each organization. The subcontractor utilization rate seems to be changing depending on the growth of firms and the number of types of work. And the criteria that are most influential in a construction project in the industry are usually financial factors [1,8,27,32].

Although it has many advantages, subcontracting is not without risks. The risks of subcontracting could be investigated under two topics [17]:

1. Company derived risks: Lack of commitment, inadequate communication, as well as incompatible personalities are typical problems of subcontracting ventures.
2. Subcontractor performance risks: Poor quality, subcontractor failure to deliver on-time, data security problem, transferring knowledge and cultural issues.

Since the construction projects are time-limited and unique, contractors are struggling with financial risks from the beginning to the end of the work. The use of subcontractors reduces the financial risks of construction companies. In this context, the contractors undoubtedly have to receive the bid amount as an essential criterion in the subcontractor selection, but it should not be overlooked that many other criteria must be taken into consideration in the subcontractor selection process [9]. Although the reasons for subcontractor use differ geographically and culturally, the main causes are quite similar in all countries [10].

Understanding the purpose of the subcontractor's use may create ancillary data with the criteria that must be used for selecting the subcontractor. Today, the traditional method, which is generally applied for selection of subcontractors, is the result of superficial decisions based on various justifications of the administrative stuff of companies [11]. According to Khalfan et al. [11], it can be said that in the construction business, administrators of the main contractors widely follow five different non-objective decision-making approaches:

1. Single source subcontractor: when the main contractor has only one subcontractor for a specific trade, which is fully integrated within main contractor's business.
2. Preferred subcontractors/suppliers: when main contractors have selected either 3-4 subcontractors for a specific trade.
3. Specialist subcontractor: when the main contractor knows the subcontractors who could deliver specialist tasks and services and use them whenever required.
4. A long list of suppliers and subcontractors: when the main contractor has selected a number

of subcontractors for each trade work, and get them compete with each other for getting the lowest price

5. Open tender: when the main contractor does not have preferred or a long list of subcontractors and looks for new supply chain partners traditionally. In some cases, main contractors with preferred subcontractors may use this type of tendering to test the market and also put pressure on subcontractors to reduce their costs and take on more risk.

Among these approaches, subcontractor selection by open tender is not considered as a widely applied method [12, 34]. Applying the open tender approach by taking only one criterion of the lowest bidder into account brings new risks and uncertainties. In the process of selecting a subcontractor, different researchers have got different approaches to the most important criteria. For instance, the survey research of Lavelle et al. [13] with feedback from 140 professionals in England shows that the lowest bid criterion is in third place and comes after health and safety records and past performance indicators by order of importance. And the other approaches include non-objective views of the managers of the main contracting company.

There is no scientific basis for the subcontractor selection to be decided by the main contractor managers according to the non-objective criteria. For this reason, the models created by multi-criteria decision-making methods aiming to place the selection process on a scientific basis have recently become widespread in the academic environment. And a study of "whether there are applications of these models in the construction business" has not been found in the construction management literature.

According to Sciancalepore et al. [14], in the construction business, bid evaluation methods might be classified into five categories:

1. Linear weighting-based methods: These use specific algorithms to find weights to be used for scoring each bid.
2. Comparison-based methods: Each bid is compared to all others quantitatively or qualitatively. With this procedure, a final score is assigned to each offer through techniques such the Analytic Hierarchy Process (AHP)
3. Cost-benefit analysis: The cost and benefits of each offer are estimated. The weighted sum of these indicators determines the final score.
4. Utility-based methods: Specific utility curves, as a function of different criteria, are defined to estimate the overall utility of each bid.
5. Costing-based methods: The cost consequences of nonprice related performance are determined and summed to the bid cost. The resulting overall cost is the indicator used for the award.

Yet, according to literature review of this study, the construction companies do not seem to apply any of these methods in real cases [12]. Modeling a subcontractor selection technique is crucial for a construction corporation because the sustainable supply chain management is key to achieving the sustainable development of enterprise and industry [15]. Proper selection of supplier or subcontractors can certainly contribute significantly to a firm's competitive advantage and its organizational success [16]. Another crucial factor is the utility and practicality of the method. This study represents a simple subcontractor selection method for the companies from all sizes.

2. Research methodology

Since the set of criteria for subcontractor selection problem has the most vital importance for such research, firstly it has been determined what criteria should be applied to the model. For this purpose, construction management and multi-criteria decision-making literature have been reviewed. The literature review section of this study firstly aimed to browse the international scientific journals with specific keywords such as "subcontractor selection", "contractor selection", "tender evaluation" and "multi-criteria decision making". The research revealed that the oldest adoptions of multi-criteria decision-making to subcontractor/contractor selection problem dates back to 1980's. That is the reason, this study involved the publications of the last 30-35 years. The next step involved narrowing the list by determining the studies which included a "criteria study" for a tender practice in a construction application. These studies could be conduction of surveys, questionnaires, reviews, collections or interviews. After the criteria are determined from the literature and weighted by statistical techniques, application of the method has been exemplified with a real case data set, which was collected from an international construction project in Russian Federation.

3. Subcontractor selection criteria

There are quite a number of studies conducted to determine subcontractor selection criteria for contractors. Majority of these are expert opinion-based and survey-based studies. The entry of subcontractor or supplier selection process into scientific literature took place in the 1960s [17]. Dickson's empirical study [64] which was conducted with 273 purchasing managers in North America is one of the first examples in this area [18]. According to this study, 23 criteria in subcontractor or supplier selection are ranked in four different groups according to their importance value as extreme importance, considerable importance, average importance and slight importance [64].

Considering the recent years, on the use of multi-criteria decision-making and similar methods for subcontractor selection, Acar [37] have proposed a model for the selection of subcontractors with the analytic network process. Diabagate et al. [21] presented a method of determining the best bid for a tender by analytic hierarchy method. Oladapo and Odeyinka [22] compared multi-criteria decision-making methods with multi-attribute analysis and analytic hierarchy process methods in subcontractor or contractor selection and found that these two methods show little difference. Sabuncuoglu and Gorener [23] presented fuzzy TOPSIS multi-criteria decision-making as an alternative to subcontractor selection process.

Lorentziadis [38] presented a linear weighting-based method for selecting subcontractors. Krzeminski [39] proposed a method with fuzzy sets. Sipahi and Esen [40] introduced a model with analytic hierarchy operation. And Topcu [41] published on the analytical hierarchy process based prequalification and weighted normalized sum of pre-qualification score and price.

Browsing the databases for the publications which tended to stress on subcontractor selection using multi-criteria decision-making methods, Sabuncuoglu and Gorener [23] presented the compilation of criteria used in 9 different publications in their study. Koseokur [24] has listed the criteria that are important in the selection of subcontractors from 11 different publications. Rencber and Kazan [25] tabulated the criteria in 7 different publications and Imeri [18] compiled the criteria listed in 3 different publications. According to the literature review on publications about subcontractor selection, these lists are the results of expert opinions, surveys, and questionnaires conducted to sector professionals. For example, Ulubeyli [33] listed the criteria by interviewing 96 professionals from 96 different sector companies or Zavadskas et al. [42] carried out a survey and questioned 20 experts. All of these studies allow us to tabulate a more comprehensive list of subcontractor selection criteria that goes through 38 different articles.

Summarizing Table 1 and picking out the articles which included criteria lists for subcontractor selection would allow us to draw Table 2 with the help of the frequencies.

Table 2 has not only found an answer to the question “What criteria should be used in multi-criteria decision-making for subcontractor selection models” but also offers a new resolution for the weights of these criteria. Each publication covered in this table contains the expert opinion of many professionals about the criteria that can be used in the selection of subcontractors. For this reason, the table might be considered as a broad survey of the various geographies of the world with the participation of many experts.

Table 1. Subcontractor selection criteria in publications

No	Criteria	Year	Study
1	Price, stuff quality, effective organization, duration, financial structure, experiences	1993	[43]
2	Management skills, experience, advanced performance qualification	1994	[44]
3	Price	1995	[45]
4	Duration, performance, price	1995	[46]
5	Honesty, creativity, duration, quality, interest in the project, cooperation, harmony, budget, technical capability, full understanding of the contract's terms and conditions fulfilling the needs in a modern way, health and safety record	1997	[47]
6	Price, technical capability, health and safety records, financial status, previous performance and quality, reputation	1998	[3]
7	Price cut, duration, technology and quality, reliability of commitment to contract, management skills	1998	[49]
8	Specific experience, current workload, financial capacity, equipment, workforce	1998	[50]
9	Reliability, performance, financial status, management skills, duration, quality, location, experience, references	1999	[51]
10	Previous performance, financial status, insurance, credibility, conditions of resources	1999	[52]
11	Price, financial capacity, previous performance, experience, resources, work force, previous cooperation, health, and safety record	2000	[53]
12	Technical capacity, financial capacity, quality warranty, duration performance, health and safety, human resources management, skill/ability	2000	[24]
13	Quality, speed, reliability, flexibility, price	2000	[54]
14	Design capability, cooperation experience & response, level of understanding the content of the project, value engineering, response to construction thoughts, response to realistic costs, quality	2000	[55]
15	Price, quality, health and safety, previous performance	2000	[56]
16	Duration, management skills, project size, price, quality, technological capability, responsibility, reliability, performance	2000	[57]
17	Price, logistics, quality, development, management	2001	[58]
18	Experience, understanding of the project objectives, ability to identify key points, understanding of constraints and special needs, representing creative ideas, Interest and ability to reduce costs by discussing examples in past projects, attitude towards cost-effective handling in this project, technical approach, work schedule, contract management and work site inspection arrangements, organizational structure of project team, the responsibilities of the important workforce and the desire to participate in the project, professional and technical competence of the labor input	2001	[59]
19	Logistics, technology, commercial features, reciprocal relations	2003	[60]
20	Experience, cost, time quality, low offer, risk	2004	[41]
21	Health and safety, current capacity, last 5 years work experience, special work experience, experience of staff	2005	[61]
22	The ability to complete the project on time, the attitude and performance of health and safety, the quality of work and materials, the availability of adequate resources, the price level, the attitude to common teamwork, the attitude to solve problems jointly, the workings in similar projects, the workplace relations, technical specifications, financial strength	2005	[62]
23	Complete documentation, building references, technical staff competence, tunnel formwork reference, delivery time, cost, financial status	2006	[29]
24	Trust, quality, harmony, cooperation, special/specific labor, price, credit reputation, consistency, reciprocity, reputation, experience	2007	[19]
25	Total Cost, maintenance and continuity solutions, delivery parameters, duration, warranty, other technological and economic objectives.	2008	[30]
26	Price, delivery time, management experience, experience as contractor, communication, condition of previous works, quality	2008	[42]

Table 1. Cont'd

27	General and similar work experience, level of performance in previous projects, previous collaboration, financial capacity, current and probable workload, previous health and safety performance, reputation, legal cases in previous projects, the existence of personal relationship, distance from headquarters, complete understanding of the project, reliability, dedication to work, level of communication, price of the proposal, technical staff, workforce, equipment, payment schedule, percentage of the subcontracting, the amount of the delay indemnity	2008	[20]
28	Amount of bid proposal, performance of relevant previous projects, financial capacity, completion of job within time, prompt payment to labor, quality of production, standard of workmanship, quality of materials used, compliance with contract, compliance with site safety requirements, collaboration with other subcontractors	2009	[2]
29	Experience, technology, equipment, management, financial stability, quality, previous experience of team, compliance with the country where project is applied, prestige, innovation, creativity	2009	[48]
30	Financial status, equipment, staff, management capacity, quality management system, safety, condition of ongoing projects, experience	2011	[66]
31	Price, duration, post-delivery maintenance, development plans	2011	[14]
32	Technical capacity, experience, management capabilities, previous performances, financial status, health, and safety record	2012	[31]
33	Price, quality, duration, qualification	2013	[67]
34	Price, quality, duration, professional competence, financial status, health and safety records, communication	2013	[63]
35	Price, completeness of bid document, past performance, staff skills and experience, reputation, quality, management capacity, bid understanding, plant and equipment resources, health and safety performance	2013	[4]
36	Speed, quality, price, reliability, flexibility, leadership, teamwork, adequacy of stuff, management type, quality certificate, financial status, technological competence, experience	2014	[25]
37	Knowledge level, experience, time, transportation, price, warranty	2014	[35]
38	Price, financial status, quality, health and safety, technical capability, experience	2015	[63]

Table 2. Frequency of criteria listed in 38 different publications on subcontractor selection

Criterion No	Criteria	Number Of Articles	Frequency %
K1	Price	31	82%
K2	Performance history	28	74%
K3	Quality	25	66%
K4	Technical capability	24	63%
K5	Financial status	20	53%
K6	Delivery/Duration	19	50%
K7	Health and safety record	14	37%
K8	Management	14	37%
K9	Production and capacity	11	29%
K10	Reputation	10	26%
K11	Location	3	8%

Therefore, if "% column" in the table is subjected to a ratio which gives a sum of 100%, the weights of the criteria should be obtained as seen in Table 3.

4. Additive Ratio Assessment (ARAS) method

Multi-criteria decision-making methods (MCDM) began to be developed in the 1960s, when a number of tools were needed to help decision-making. MCDM is defined as the process of assigning values to alternatives by evaluating many criteria together. In construction industry for any kind of decision problems, the managers and decision makers might use the benefits of numerous types of MCDM [36]. One of these methods, namely ARAS Method, was introduced by Lithuania's Vilnius Gediminas Technical University academicians Edmundas Kazimieras Zavadskas and Zenonas Turskis in 2010 as a method of solving multi-criteria decision problems. The abbreviation ARAS

Table 3. Weights of the criteria

Criterion No	Criteria	Weight
K1	Price	16%
K2	Performance history	14%
K3	Quality	13%
K4	Technical capability	12%
K5	Financial status	10%
K6	Delivery/Duration	10%
K7	Health and safety record	7%
K8	Management	7%
K9	Production and capacity	6%
K10	Reputation	5%
K11	Location	2%

comes from the first letters of the statement “Additive Ratio Assessment". In the classical approach, multi-criteria decision-making methods focus on ranking. Many of the MCDM methods compare the utility function values of existing solutions with the ideal positive alternative solution value or take the distance to ideal positive and ideal negative solution into consideration. But ARAS method compares the utility functions of the alternatives with the optimal utility function value added by the researcher to the decision problem. ARAS method can also be applied together with fuzzy logic and gray relational analysis.

Application steps of the ARAS method proposed by Zavadskas and Turskis [26]:

The ARAS method starts with the stage of preparation of the decision-matrix just as it is in all other multi-criteria decision-making methods. The difference from typical methods is that the optimum values for each criterion are shown in a row in the decision matrix.

$$X = \begin{bmatrix} X_{01} & \cdots & X_{0j} & \cdots & X_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ X_{i1} & \cdots & X_{ij} & \cdots & X_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mj} & \cdots & X_{mn} \end{bmatrix}; \; i = \overline{0,m}; \; j = \overline{1,n}. \quad (1)$$

The decision matrix can be expressed as Eq. (1), where m is the number of alternatives and n is the number of the criterion. The optimal value for each column in this matrix should be chosen and be added as a row on the top. If the optimal value of the j-criterion is not known, the following algorithm is applied:

$$\begin{aligned} x_{0j} &= \max_i x_{ij} \; if \; \max_i x_{ij} \; \textit{is preferable} \\ x_{0j} &= \min_i x_{ij} \; if \; \min_i x_{ij} \; \textit{is preferable} \end{aligned} \quad (2)$$

Since the criterion performance values are at different scales and units, the second stage is to normalize the decision matrix. The mathematical representation of the normalized matrix is as follows:

$$X = \begin{bmatrix} \bar{X}_{01} & \cdots & \bar{X}_{0j} & \cdots & \bar{X}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{X}_{i1} & \cdots & \bar{X}_{ij} & \cdots & \bar{X}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{X}_{m1} & \cdots & \bar{X}_{mj} & \cdots & \bar{X}_{mn} \end{bmatrix}; \; i = \overline{0,m}; \; j = \overline{1,n}. \quad (3)$$

The criteria, whose preferable values are maxima, are normalized by Eq. (4).

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \quad (4)$$

The criteria, whose preferable values are minima, are normalized by applying two-stage procedure:

$$x_{ij} = \frac{1}{x_{ij}^{*}}; \bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \quad (5)$$

If the significance values of the criterion cannot be obtained by statistical or mathematical models, ideas of the experts or the decision-makers subjective viewpoint could be used. The importance of criteria mean the weights of the criteria and the sum of the weights has to be equal to 1. Accordingly, each matrix value in the normalized matrix is multiplied by the corresponding weight ratio, and the weighted normalized decision matrix is obtained.

The mathematical representation of the normalize decision matrix is as follows:

$$\sum_{j=1}^{n} w_j = 1 \quad (6)$$

$$\hat{X} = \begin{bmatrix} \hat{X}_{01} & \cdots & \hat{X}_{0j} & \cdots & \hat{X}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{X}_{i1} & \cdots & \hat{X}_{ij} & \cdots & \hat{X}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{X}_{m1} & \cdots & \hat{X}_{mj} & \cdots & \hat{X}_{mn} \end{bmatrix} \quad i = \overline{0,m};\ j = \overline{1,n}. \tag{7}$$

$$\hat{x}_{ij} = \bar{x}_{ij} w_j ; i = \overline{0,m}, \tag{8}$$

In the following equation, the scores of the alternatives are calculated to indicate the value of S_i which is optimality function of i alternative:

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}, \qquad i = 0,1,...m \;\; j = \overline{1,n}, \tag{9}$$

Using the values in the range [0, 1], the relative efficiency of the utility function values of the alternatives is calculated. Utility degree K_i is calculated by dividing the S_i value by ideally best one S_0:

$$K_i = \frac{S_i}{S_0} \qquad i = \overline{0,m}, \tag{10}$$

5. Case study and results

The project manager of a multipurpose living project in Russian Federation wanted to select a subcontractor for the parking garage works. Company engineers have prepared the technical specifications of the work, quantity surveying, and the subcontractor qualification forms and tender documents have been delivered to the subcontractor candidates. The subcontractor qualification forms are arranged according to the findings of the literature review of this study and the criteria represented the functions as follows.

5.1. Price

Price is the final bid offer determined by the subcontractor candidate for the complete scope of works. This amount might be entered as a monetary value in the decision matrix.

Price= f (final offer) (11)

5.2. Performance history

Contract values of similar works which the candidates have successfully completed before might be used after being converted to a single monetary value by updating with present value analysis. Also in the performance history, parameters such as the speed of finishing the project, total construction area, the number of projects completed with success and the total man-hours completed since the beginning can also function.

Performance history= f (job completion, speed, constructed area, number of completed projects, total man hour) (12)

For the case study, this value is evaluated over the total manhour value (ΣMxH) of the candidate firm during its total business life.

5.3. Quality

In order to measure the quality concern of a construction company, it may be sufficient to examine the company's corporate structure and its quality certificates. Also, checking whether the firm has implemented total quality management will contribute to measuring its quality standard.

Quality= f (Corporate structure, total quality management, certificates of quality standard) (13)

For the case study, a scoring system between 1 and 4 is used. The score of the company whose quality certificates are complete gets 4 and the company which does not have any certificate gets 1 over 4.

5.4. Delivery / Duration

The duration parameter may be determined by the work schedule to be requested from the subcontractor candidates for the part of the work to be transferred to the subcontractor. It gives an advantage to the company which promises to perform the work faster without sacrificing the terms of the technical specifications and without sacrificing the quality. For this reason, the substantial parameter of the delivery function will be the duration offered by the candidate.

Delivery = f (offered duration by candidate) (14)

For the case study, this value is assumed as the duration needed to complete the total works. The unit of duration is assumed to be “day”.

5.5. Health and safety record

For the objective measurement of work safety performance, firstly the total manhour value of the candidate company should be determined. Then, by using the statistics of work accidents, the intensity of occupational accidents at the unit man-hour might be obtained. This value might constitute an adequate index for the health and safety performance of the relevant subcontractor candidate.

Health and safety record = f (work accident/total man hour) (15)

For the case study, this value is defined as the number of work accidents per 1,000,000 man hours from the records of total man hour and health and safety records and demonstrated by the unit of "number of workplace accident / 1 million man-hours" (NWA/1M. ∑MxH).

5.6. Technical capability

It can be evaluated by the number of technical personnel that the candidate firm currently has.

Technical capability=f (number of technical stuff) *(16)*

For the case study, this value was evaluated as the number of technical staffs with a technical education regardless of their level of education.

5.7. Production and capacity

The production capacity of the subcontractor is determined according to the planned work to be carried out. For example, if the work to be performed is concrete floor hardener, a value can be obtained through the concrete hardener flooring speed of the company.

Production and capacity=f (unit production capacity) (17)

For the case study, this value considered as the daily production capacity of concrete floor hardener and its unit is m^2/day.

5.8. Financial Status

The financial capacity value can be used as a single monetary value which is the result of a specific linear programming in the model or as a monetary value which can be obtained from the cash flow graph of the willing subcontractor candidates by the present value analysis.

Financial status= f (cash flow diagram) (18)

For the case study, this value is obtained by considering the cash flow statements of the companies at the net present value. Its unit is US Dollars.

5.9. Management

It may be worthwhile to evaluate how many years of experience the managers of the subcontractor companies have in their fields.

Management = f (experience year of the management team) (19)

For the case study, this value is taken as the average of the years of experience of managers of the company. Its unit is year.

5.10. Location

An assessment can be made on the distance of the subcontractor firms' offices to the site where the project is being implemented.

Location= f (distance to site) (20)

For the case study, this value is considered as the distance from the office of the candidate to the site in kilometers.

5.11. Reputation

It can be determined by a questionnaire prepared by the company managers, which demonstrates all of the technical personnel participants’ views about the reputation of the subcontractor firm.

Management = f (experience year of management team) (21)

For the case study, this value is the average score of the questionnaire result which examined the reputation of the candidate firms by views of the technical stuff of the contractor company with scores ranked from 1 to 4 (1 indicates the lowest and 4 indicates the highest reputation).

For the case study, the criteria set, that is revealed in the literature review, was reported to the managerial office of the multi-purpose living complex project. Also, it is requested to open a tender which complies with these criteria. Dataset of the sample decision problem, which is given in Table 4, has been prepared according to the results of this tender process. After creating the dataset, the steps of the subcontractor selection with Additive Ratio Assessment Method would be as follows:

Step 1: Representation of data set as decision matrix and creation of decision matrix (Table 5).

Optimum values are listed in the first row. It should be noted here that the optimum for K1, K6, K7, and K11 are the smallest values and for the other criteria the optimums are the biggest values. It should also be remembered that the weight ratios are calculated in Table 3.

Step 2: Normalization of the decision matrix (Table 6).

Eq. (4) and Eq. (5) are used in the normalization process. If it is assumed that higher value is better, then each element is divided by the sum of its column and the resulting value is written to the cell of that element. If it is considered that smaller value is better, then the procedure given in Eq. (5) is applied.

Step 3: Forming weighted normalized decision matrix (Table 7).

Forming the weighted normalization decision matrix, the weight values of the criteria are multiplied by each matrix element in its own column and replaced by the old one.

Step 4: Calculation of optimality function values

S_i values are calculated by Eq. (9) and Ki values are then calculated by Eq. (10). The values found are shown in Table 8. According to Table 8, company "C" is the most appropriate subcontractor candidate with 74.3% similarity to the optimal.

Table 4. Data set of sample decision problem

CANDIDATE	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11
	Price (USD)	Performance history (∑mxh)	Quality (out of 4)	Technical Capability (out of 4)	Financial Status (USD)	Duration (Day)	Health and Safety Record (nwa/1m. ∑mxh)	Management (Year)	Production and Capacity (m2/day)	Reputation (out of 4)	Location (km)
A	1,955,000	1,900,000	3	2	1,260,000	77	2	20	40	3	160
B	1,756,000	1,600,000	3	3	600,000	71	3	23	44	2	110
C	1,820,000	1,100,000	2	4	850,000	67	2	21	47	2	10
D	1,925,000	1,300,000	4	1	780,000	63	4	19	50	3	10
E	1,892,000	400,000	2	2	1,120,000	57	5	11	56	1	10
F	1,673,000	1,800,000	3	3	250,000	81	3	25	38	1	60
G	1,770,000	2,000,000	1	2	520,000	87	4	27	35	2	140
H	1,690,000	600,000	2	2	120,000	89	5	32	34	2	80

Table 5. Decision matrix

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11
OPT.	1,673,000	2,000,000	4	4	1,260,000	57	2	32	56	3	10
A	1,955,000	1,900,000	3	2	1,260,000	77	2	20	40	3	160
B	1,756,000	1,600,000	3	3	600,000	71	3	23	44	2	110
C	1,820,000	1,100,000	2	4	850,000	67	2	21	47	2	10
D	1,925,000	1,300,000	4	1	780,000	63	4	19	50	3	10
E	1,892,000	400,000	2	2	1,120,000	57	5	11	56	1	10
F	1,673,000	1,800,000	3	3	250,000	81	3	25	38	1	60
G	1,770,000	2,000,000	1	2	520,000	87	4	27	35	2	140
H	1,690,000	600,000	2	2	120,000	89	5	32	34	2	80
Weights	16%	14%	13%	12%	10%	10%	7%	7%	6%	5%	2%

Table 6. Normalized decision matrix

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11
OPT.	0.12	0.16	0.17	0.17	0.19	0.14	0.16	0.15	0.14	0.07	0.22
A	0.10	0.15	0.13	0.09	0.19	0.10	0.07	0.10	0.10	0.06	0.01
B	0.11	0.13	0.13	0.13	0.09	0.11	0.05	0.11	0.11	0.11	0.02
C	0.11	0.09	0.08	0.17	0.13	0.12	0.07	0.10	0.12	0.11	0.22
D	0.10	0.10	0.17	0.04	0.12	0.12	0.04	0.09	0.13	0.07	0.22
E	0.11	0.03	0.08	0.09	0.17	0.14	0.03	0.05	0.14	0.21	0.22
F	0.12	0.14	0.13	0.13	0.04	0.10	0.05	0.12	0.10	0.24	0.04
G	0.11	0.16	0.04	0.09	0.08	0.09	0.04	0.13	0.09	0.12	0.02
H	0.12	0.05	0.08	0.09	0.02	0.09	0.03	0.15	0.09	0.12	0.03
Weights	16%	14%	13%	12%	10%	10%	7%	7%	6%	5%	2%

Table 7. Weighted normalized decision matrix

	K1	K2	K3	K4	K5	K6	K7	K8	K9	K10	K11
OPT.	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00
A	0.02	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00
B	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.01	0.01	0.01	0.00
C	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00
D	0.02	0.01	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.00
E	0.02	0.00	0.01	0.01	0.02	0.01	0.00	0.00	0.01	0.01	0.00
F	0.02	0.02	0.02	0.02	0.00	0.01	0.00	0.01	0.01	0.01	0.00
G	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00
H	0.02	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	0.00

Table 8. Calculation of optimality function values and the results

	Si	Ki	%Ki	Rank
OPT.	0.15			
A	0.11	0.74	73.9%	3
B	0.11	0.72	72.1%	4
C	**0.11**	**0.74**	**74.3%**	**1**
D	0.11	0.69	68.7%	5
E	0.10	0.66	65.9%	6
F	0.11	0.74	74.1%	2
G	0.10	0.62	62.0%	7
H	0.08	0.53	52.9%	8

6. Conclusions

Construction firms, which are business types that are operated with commercial profit motivation, need an objective approach to place the major decision problem of selection of subcontractors on a scientific basis. As mentioned in the literature review, there are many examples of multi-criteria decision-making methods that the subcontractor selection can be made with. However, there is no publication related to the ARAS method on this topic specifically. This is probably due to the fact that the ARAS method is one of the very new techniques. The ARAS method is one of the multi-criteria decision-making techniques based on quantitative measures and its implementation is quite convenient [28].

In the study, the subject of subcontractor selection from multiple alternatives for construction firms, which is a decision-making problem with multiple criteria, is exemplified with a real case application and it has been demonstrated that the ARAS method might be a practical and convenient way to solve these kinds of problems for construction professionals. In the real case study, the properties of 8 different candidates are compared with each other according to 11 different criteria and found that company “C” is the best decision. It is also found that the ranking of the companies is: C>F>A>B>F>E>G>H. If this method is compared with the conventional method in which the lowest bidder wins the tender offer, the difference between two methods is better understood by the fact that one of the lowest bidder H seems like the worst decision in this example. This could be explained by the fact that selection of alternative H might create some risks and the main contractor may deviate from the successful completion of the project due to these risks. If the sub-contractor selection process is carried out with the traditional methods, which might include the lowest bid offer, familiarity of candidate or the subjective approach of company's managerial office, most of the criteria found in the literature review would be left out of evaluation. For instance, literature review of this study revealed that the criteria of performance history is distinctly essential in subcontractor selection process. In other words, risk containment and contingency of the project should include the provision of poor performance of subcontractor. According to the case study, performance history of the alternative H is one of the lowest value in the list of candidates. The risk of poor performance of the alternative H may be the cause of the failure of the project success. Subcontractor selection with ARAS method increases the possibility of the success of the project by evaluating the subcontractor candidates according to the 11 criteria.

As mentioned before, there are other multi-criteria techniques which were adopted to the subcontractor selection problem, such as Analytical Hierarchy Process (AHP) and Fuzzy Sets [25,34]. The basic difference of the subcontractor selection with ARAS method is practicality. Application of the method is quite simplistic through Excel. Some of the professionals may not have enough time to acquire the theoretical background of the complex methods such as AHP or they might not obtain the user-friendly fuzzy sets analysis software for subcontractor selection. So, the sector professionals who need a simplistic solution for the problem of subcontractor selection, could learn and apply this method quickly. Another novelty of this study could be accepted as the proposal of the standard criteria set for subcontractor selection problem. Since the consistency of the criteria is one of the most important factors for this type of a decision problem, the future researchers might focus to create precise criteria set.

Acknowledgments

The authors gratefully acknowledge the financial support provided by Committees on Research Grants of Akdeniz University and Bulent Ecevit University.

References

[1] Yoke-Lian L., Hassim S., Muniandy R., Teik-Hua L. Review of Subcontracting Practice in Construction Industry. IACSIT International Journal of Engineering and Technology 4(4) (2012) 442-445.

[2] El Mashaleh M. A Construction Subcontractor Selection Model. Jordan Journal of Civil Engineering 3(4) (2009) 375-383.

[3] Hatush Z., Skitmore M. Contractor Selection Using Multi-criteria Utility Theory: An Additive Model. Building and Environment 33(2-3) (1998) 105-115.

[4] Enshassi A., Medoukh C. The Contractor-Subcontractor Relationship: The General Contractor's View. Journal of Financial Management of Property and Construction 17(1) (2012) 92-112.

[5] Safak C. Subcontractor (Sub-Employer) in the frame of Labour Act No. 4857. Journal of the Union of Turkish Bar Associations 51 (2004) 111-132.

[6] Tozlu A., Eraslan M T. The Subcontracting Practice in Turkey. Journal of Turkish Court of Accounts/Sayistay Dergisi 84 (January-March 2012) 45-62.

[7] Guller A. A Review on the Subcontracting Institution Which is the Chronic Problem of Infrastructure. Hacettepe University Faculty of Law Review 5(1) (2015) 91-104.

[8] Ghoddousi P., Hosseini M. R. A survey of the factors affecting the productivity of construction projects in Iran. Technological and Economic Development of Economy 18(1) (2012) 99-116.

[9] Turskis Z. Multi-attribute contractors ranking method by applying ordering of feasible alternatives of solutions in terms of preferability technique. Technological and Economic Development of Economy 14(2) (2008) 224-239.

[10] Kakabadse A., Kakabadse N. K. Outsourcing: Current and Future Trends. Article in Thunderbird International Business Review 47(2) (2005) 183-204.

[11] Khalfan M. M. A., Eriksson P. E., Dickinson M., McDermott P. Listening to the Voices of Suppliers and Subcontractors! (2006)

[12] Ajayi O. M., Ayanleye A., Achi F., Johnson O. Criteria for Selection of Subcontractors and Suppliers in a Building Project in Lagos State. Proceedings 5th Built Environment Conference 18-20 July 2010, Durban, South Africa.

[13] Lavelle D., Hendry J., Steel G. The Selection of Subcontractors: Is Price the Major Factor? Proceedings 23rd Annual ARCOM Conference, 3-5 September 2007, Belfast, UK.

[14] Sciancalepore F., Falagario M., Constantino N., Pietroforte R. Multi-Criteria Bid Evaluation of Public Projects. Management and Innovation for a Sustainable Built Environment, 20-23 June 2011, Amsterdam, The Netherlands.

[15] Rao C., Goh M., Zheng J. Decision Mechanism for Supplier Selection Under Sustainability. International Journal of Information Technology & Decision Making 16(1) (2017) 87-105.

[16] Khorramshahgol R. An Integrated Strategic Approach to Supplier Evaluation and Selection, International Journal of Information Technology & Decision Making 11(01) (2012) 55-76.

[17] Paasio P. The Process of Selecting Subcontractors, Case: Laitex Oy, MSc. Thesis. Saimaa University of Applied Sciences, 2011.

[18] Imeri S. Key Performance Criteria for Vendor Selection- A Literature Review. Management Research and Practice 5(2) (2013) 63-75.

[19] Favie R., Abdalla G., Maas G. J. The Best Criteria for the Selection of Contractors in the Dutch Construction Industry! In W. Hughes (Ed.), Proceedings of the CME25: Construction Management and Economics: Past, Present and

Future, Reading (UK), July 2007. (pp. 1-7). Reading: University of Reading.

[20] Ulubeyli S. Fuzzy multiple criteria decision-making model for subcontractor selection in international construction projects. Ph.D. Thesis. Istanbul University, 2008.

[21] Diabagate A., Azmani A., El Harzli A. The Choice of the Best Proposal in Tendering with AHP Method: Case of Procurement of IT Master Plan’s Realization, I.J. Information Technology and Computer Science, 12 (2015) 1-11 Published Online November 2015 in MECS (http://www.mecs-press.org/) doi: 10.5815/ijitcs.2015.12.01.

[22] Oladapo A. A., Odeyinka H. Tender Evaluation Methods in Construction Projects: a Comparative Case Study. Acta Structilia 13(1) (2006) 106-131.

[23] Sabuncuoglu A. O., Gorener A. Decision Making Through the Fuzzy TOPSIS Method: Contractor Selection in Construction Projects. Journal of Research in Business & Social Science 5(2 Special Issue) (2016) 71-82.

[24] Koseokur H. Selection of Subcontractor with Artificial Neural Networks in the Construction Sector. MSc. Thesis. Istanbul Technical University, 2007.

[25] Rencber O. F., Kazan H. Choosing A Subcontractor For Large Scale Projects Proposal Evaluation: Decision Making With Analytic Hierarchy Process Method, International Journal of Social Science Research 3(4) (2014) 11-24.

[26] Zavadskas E. K., Turskis Z. A New Additive Ratio Assessment (ARAS) Method in Multi criteria Decision-Making, Technological and Economic Development of Economy 16(2) (2010) 159-172.

[27] Tas E., Kutlu D. Investigation of the Procurement Procedures for World Bank Financed Construction Projects. Construction Management Congress 30-31 October 2007 TMMOB Chamber of Civil Engineers, Istanbul Branch, Istanbul, Turkey.

[28] Ecer F. Selection of Enterprise Resource Planning Software by using ARAS Method. International Journal of Alanya Faculty of Business 8(1) (2016) 89-98.

[29] Kactioglu S., Kusakci A. O., Ayvaz B., Okul B., Aydin H. Subcontractor Selection with Multi Criteria Decision Making Methods: An Application in Construction Sector. Bartin University Journal of Faculty of Economics and Administrative Sciences 14 (2016) 29-40.

[30] Kovacs G., Bona K. Applying a multi-criteria decision methodology in the implementation of tenders for the acquisition of the infrastructure of logistics systems, Periodica Polytechnica Transportation Engineering 37(1-2) (2008) 39–44.

[31] Nieto-Morote A., Ruz-Vila F. A fuzzy multi-criteria decision making model for construction contractor prequalification. Automation in Construction 25 (2012) 8–19.

[32] Ugur L. O., Baykan U. N. An Area Study for Determining Construction Contractors' Risks and Risk Attitudes in Construction Projects Selcuk University Journal of Technical-Online 7(1) (2008) 73-85.

[33] Ulubeyli S., Manisali E., Kazaz A. Subcontractor Selection Practices in International Construction Projects, Journal of Civil Engineering and Management 16(1) 2010 47-56.

[34] Ulubeyli S., Manisali E., Kazaz A. Fuzzy multi-criteria decision-making model for subcontractor selection in international construction projects, Technological and Economic Development of Economy 22(2) (2010) 210-234.

[35] Can S., Arikan F. Multi Criteria Subcontractor Selection Problem and Its Solution for a Defence Industry Firm, Journal of the Faculty of Engineering and Architecture of Gazi University 29(4) (2014) 199-206.

[36] Zavadskas E. K., Viniunas P., Turskis Z., Tamosaitiene J. Multiple Criteria Decision Support System for Assessment of Projects Managers in Construction, International Journal of Information Technology & Decision Making 11(2) (2012) 501-520.

[37] Acar Y. Subcontractor Selection by ANP (Analytic Network Process) Method in Construction Business. MSc Thesis. Eskisehir Osmangazi University, 2014.

[38] Lorentziadis P. Post-objective determination of weights of the evaluation factors in public procurement tenders. European Journal of Operational Research. 200(1) (2010) 261-267.

[39] Krzemiński M. The selection of construction sub-contractors using the fuzzy sets theory.AIP Conference Proceedings 1648, 600005 (2015).

[40] Sipahi S., Esen O. A multi-criteria model for bidding evaluation: An alternative selection of the best firms for the presentation of Istanbul 2010, Management Decision, 48(2) (2010) 296-313.

[41] Topcu Y. I. A Decision Model Proposal for Construction Contractor Selection in Turkey. Building and Environment 39(0) (2004) 469 – 481.

[42] Zavadskas E. K., Turskis Z., Tamošaitiene J. Contractor selection of construction in a competitive environment. Journal of Business Economics and Management. 9(3) (2008) 181-187.

[43] Brook M. Estimating and Tendering for Construction Work. Butterworth Heinemann, London, 1993.

[44] Latham M. Constructing the Team, HMSO, London, 1994.

[45] Smith A. J. Estimating, Tendering and Bidding for Construction, Macmillan, London, 1995.

[46] Holt G. D, Olomolaiye P. O., Harris F. C. A review of contractor selection in the UK construction industry, Building and Environment, 30(4) (1995) 553-561.

[47] Love S. 1997. Subcontractor Partnering: I'll Believe It When I See It. Journal of Management in Engineering, 13(5) (1997) 29-31.

[48] Darvish M., Yasaei M., Saeedi A. 2009. Application of the graph theory and matrix methods to contractor ranking. International Journal of Project Management, 27(6) (2009) 610-619.

[49] Albino V., Garavelli A. C. A. Neural network application in sub-contractor rating in construction firms. International Journal of Project Management, 16(1) (1998) 9-14.

[50] Shash A. A. Bidding Practices of Subcontractors in Colorado. Journal of Construction Engineering and Management. 124(3) (1998) 219-225.

[51] Ng S. T., Rm S. Client and consultant perspectives of prequalification criteria, Building and Environment, 34(5) (1999) 607-621.

[52] Palaneeswaran E., Kumaraswamy M. M., Tam P. W. M. Identifying best practices in contractor selection for enhanced harmony and profit, in Proceedings of CIB W92 Construction Procurement Symposium, 1999, 637–647, Eds. Ogunlana, S., Asian Inst. Of Technology, Chiang Mai, Thailand.

[53] Fong P. S. W., Choi S. K. Y. Final contractor selection using the analytical hierarchy process. Construction Management and Economics 18(5) (2000) 547–557.

[54] Krause D., Pagell M., Curkovic S. Towards a measure of competitive priorities for purchasing. Journal of Operations Management 19(4) (2000) 497-512.

[55] Kumaraswamy M. M., Matthews J. D. Improved subcontractor selection employing partnering principles. Journal of Management in Engineering 16(3) (2000) 47-57.

[56] Matthews J., Pellew L., Phua F., Rowlinson S. Quality relationships: partnering in the construction supply chain. International Journal of Quality & Reliability Management 17(4) (2000) 493-510.

[57] Palaneeswaran E., Kumaranswamy M. Contractor selection for design/build projects, Journal of Construction Engineering and Management 126(5) (2000) 331-339.

[58] Birch D. Made for each other? Supply Management (2001) 42-43.

[59] Lam K. C., Hu T. S., Ng S. T., Skitmore M., Cheung S. O. A fuzzy neural network approach for contractor prequalification. Construction Management and Economics 19(2) (2001) 175–188.

[60] Cebi F., Bayraktar D. An integrated approach for suppliers selection. Logistics Information Systems 16(6) (2003) 3-13.

[61] McCabe B., Tran V., Ramani J. Construction prequalification using data envelopment analysis. Canadian Journal of Civil Engineering 32(1) (2005) 183–193.

[62] Rahman M. M., Kumaraswamy M. M. Relational selection for collaborative working arrangements. Journal of Construction Engineering and Management 131(10) (2005) 1087-1098.

[63] Polat G. Subcontractor selection using the integration of the AHP and PROMETHEE methods. Journal of Civil Engineering and Management 22(8) (2015) 1042-1054.

[64] Dickson G. W. An analysis of vendor selection systems and decisions. Journal of Purchasing 2(1) (1966) 5-17.

[65] Ciftcioglu B. Sub-contractor selection by the AHP method in construction sector: application in a housing project. MSc Thesis. Istanbul Technical University. 2013.

[66] Huang X. An analysis of the selection of project contractor in the construction management process. International Journal of Business and Management 6(3) (2011) 184-189.

[67] Abbasianjahromi H., Rajaie H., Shakeri E. A framework for subcontractor selection in the construction industry. Journal of Civil Engineering and Management 19(2) (2013) 158-168.