Advances in Industrial Engineering, Autumn 2020, 54(4): 355-364
DOI: 10.22059/jieng.2021.325197.1772

RESEARCH PAPER

Tender Participation Selection Problem with Fuzzy Approach

Amin Jamili[*]

School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran.

Received: 06 June 2021, Revised: 22 June 2021, Accepted: 22 June 2021

Abstract

One of the key factors for the successiveness of a company is to share the finance, facilities and human resources to the most profit-making projects, this factor can be much more affecting to those kinds of companies conducting overseas projects. In a competitive environment, projects are putting out to tenders. A successive company is that participate in money-making low-risk tenders considering all resources of its company. In this paper after a brief introduction of this problem, a multi-objective binary model and a mixed-integer linear model will be introduced. The latter one addresses the situation where the decision-makers have different approaches to different tenders considering the rate of return as well as the probability of winning the tenders. As all the parameters of these models are uncertain, two different fuzzy approaches are applied to these problems. Finally, to illustrate the application of the proposed models some examples are presented. The results show that by the fuzzy approach new chances to improve the potential benefits arise.

Keywords:
Pure 0-1 Programming;
Uncertainty;
Rate of Return

Introduction

Further to the sub-contractor selection problem, which is concerned by the clients' bidders are involved in another decision-making problem [1,2,3]. These companies' decision-makers are usually involved to decide to participate in a tender or not. This problem is not always easy to solve without considering artificial intelligence methods. Occasionally, when the firm is involved with different variety of projects and tenders to participate, selecting the best tenders between many choices is rather hard, and a bad decision in this situation may lead to extra costs and even bad quality which results in hazarding the reputation of the company. As a result, the tender participation selection problem can be used as a tool to help the managers to take the most appropriate decisions. Mats et al. [4] provided a simple theoretical framework, for tender evaluation including scoring and weighing and discussed the pros and cons of methods such as highest quality, lowest price and price-and-quality-based evaluations. Ballesteros-Pérez et al. [5] proposed a practical methodology based on simple statistical calculations for modeling the performance of a single or a group of bidders, constituting a useful resource for analyzing one's own success while benchmarking potential bidding competitors. Maqsoom et al. [6] investigated the prevalent rules for the bid evaluation and the criterion used by both clients and consultants in selecting the contractors during the bids evaluation phase of construction projects in Pakistan, using the relative importance index and severity index approach to analyze the data. Indah Kusumarukmi et al. [7] identified and analyzed problems in the public tendering process,

[*] Corresponding author: (A. Jamili)
Email: a_jamili@ut.ac.ir

and proposed potential solutions to resolve these problems, utilizing publicly available studies and interviews as starting points of problems identifications. To measure the questionnaires distributed to tendering, Likert scale assessment and factor analysis were used and analyzed.

By considering the above-mentioned literature review, it is found that there are no considerable researches that address mathematical models to solve the problem. Moreover, based on the author' knowledge the uncertainty of the parameters is not analyzed, and therefore the fuzzy approach is not considered to address the uncertainty. In this paper, a new approach by proposing the mathematical models are introduced. Moreover, to consider the uncertainty of the model, two different fuzzy approaches are applied to the model. By assuming a constant probability of winning each tender, one can find that this problem is a sort of Knapsack problem. In addition to employing fuzzy set theory to the knapsack problem [8], there are other attempts that addresses the Fuzzy Binary Linear Programming (FBLP) [9]. Moreover, in order to define a practical tool for decision makers to reach the best choices between potential tenders considering the quoted prices which will affect the Rate of Return (ROR) as well as the probability of winning the tenders, the necessary changes are applied to the proposed model. With the assumption of the variable probability of winning each tender, an Integer Linear Programming (ILP) model appears. In the case of applying a fuzzy approach to an integer linear model in which all parameters including coefficients of objective and constraints as well as the right-hand side of constraints are uncertain, some different methods have been presented [10].

The current paper is organized as follows: In Section 2, the problem definition is proposed. Section 3 addresses the proposed mathematical model to solve the problem. In Section 4, the fuzzy approach is proposed and applied to the model. Section 5 is to introduce a new mathematical model to the problem in variable tender winning probability mode. Finally, the concluding remarks are given at the end to summarize the contribution of this paper.

Problem definition

Consider a company that has lots of opportunities to participate in different tenders. This company has different chances to win each of these tenders which are dependent on the Minimum Attractive Rate of Return known as MARR. The model can be with the assumption of constant or variable MARR. Meanwhile, this company has limited finance and human resources so participating in all tenders is not a rational decision. Participating in each tender has its relevant costs concerning to prepare an adequate proposal. Furthermore, this company has a chance to neglect to contract after winning the tender by paying the bid-bond amount specified in Request for Proposal (RFP) documents. For some reasons that will be specified later this issue is not considered in the model. It is clear that all parameters of the model including all costs, interest, human and financial resources are uncertain. The objectives are listed as follows:

1. Maximizing the estimated profit earned in the case of winning tender
2. Minimizing the proposal preparing cost
3. minimizing the lost money, bid-bond, in the case of refusing to contract after winning the tenders.

The constraints should cover the human resources, and finance resources limitations.

Mathematical model

Parameters
T: Set of all potential tenders
A: Set of time horizon in year
p_i: Indicates the awarding contract probability of tender i

I_i: Indicates the estimated rate of return of tender i
v_i: Indicates the estimated value of tender i,
c_i: Indicates the proposal preparing costs of tender i
hr_{ij}: Shows the required man-day to perform the winning tender (i) in year j
H_j: The available human resources for year j (man-day)
m_{ij}: The required finance of tender i in year j
M_j: The available budget for year j
b_i: The bid-bond amount that will be lost in the case of refusing to sign the contract after winning the tender i

Variables

$x_i \begin{cases} = 1. & \text{if company takes a go-decision on participating in the tender } i \\ = 0. & \text{otherwise} \end{cases}$

$y_i \begin{cases} = 1. & \text{if company decides to cancel the participation in the tender i after winnig the contract} \\ = 0. & \text{otherwise} \end{cases}$

The objective functions are shown by Eqs. 1, 2, and 3. Eq. 1 maximizes the estimated profit earned in the case of winning tender i. Note that $w_i = p_i \times ROR_i = cte$, in other words, we assumed that the multiplication of awarding contract probability of tender i with the rate of return of tender i is constant. The relation between these two parameters is depicted in Fig. 1.

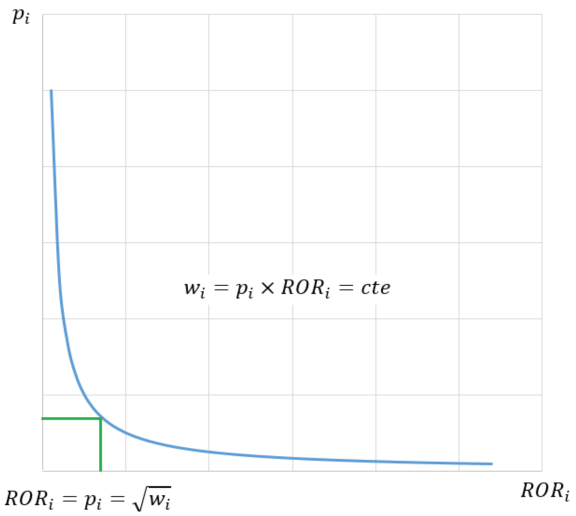

Fig. 1. Relation between rate of return and tender winning probability

Eq. 2 is to minimize the proposal preparing cost and Eq. 3 minimizes the lost money, bid-bond, in the case of refusing to contract after winning the tenders. As all defined objectives have the same unit, they can be simply added, making a single objective function shown by Eq. 4. Eq. 5 ensures that the required human resources of all tenders should be less than the maximum available in year j. Eq. 6 guarantees that the required financial resources allocated to each project is always less than the maximum available in year j.

$$Maximize \sum_i w_i v_i x_i \quad (1)$$

$$Minimize \sum_i c_i x_i \quad (2)$$

$$Minimize \sum_i (b_i p_i + w_i v_i) y_i \quad (3)$$

$$Maximize \sum_i (w_i v_i x_i - c_i x_i - (b_i + w_i v_i) p_i y_i) \quad (4)$$

Subject to

$\sum_i hr_{ij} \times p_i \times x_i - \sum_i hr_{ij} \times p_i \times y_i \leq H_j \qquad \forall j \in A$ (5)

$\sum_i m_{ij} \times p_i \times x_i - \sum_i m_{ij} \times p_i \times y_i \leq M_j \qquad \forall j \in A$ (6)

$y_i \leq x_i \qquad \forall i \in T$ (7)

The above-mentioned model is a two stage stochastic with recourse in nature where variables $x_i \in T$ are first stage where the values of these variables are fixed before the fact realization and variables $y_i \in T$ are second stage ones, which are dependent to the different scenarios which can be defined. Moreover, in order to minimize the expected value of the constraint violation due to the uncertainty of the parameters, some new second stage variables should be defined to count the amount of constraint violation. Besides, the expected value of the constraint violation should be added to the objective function. Therefore, all the decision makers like to reach a solution where all $y_i \in T$ variables are equal to 0. In the rest of this paper, considering the following explanations, the variable $y_i \in T$ is eliminated to simplify the problem considering all the uncertainties that exist in the model.

In reality, if we consider that after winning the tender the company decides to refuse to contract, it means that for some reason the company prefers to lose not only the relevant interest I, but also the bid-bond price. Some main reasons for this decision may be the followings:

1- Loss estimation for this project
2- Political issues
3- Shortage of resources

The first item is due to the wrong estimation of the interest of the project during preparing the proposal.

The second item rarely can be estimated.

The last item may because of facing a situation in which the company is successful to more tender than what is estimated.

Finally, as entering these cases into the mathematical model highly complicates the problem, it seems rational to neglect variable y, so we assume that the company never decide to refuse the contract after winning the tender first.

In addition to the above-mentioned fact, we assume that the parameter p_i, the probability of winning tender i, is constant as well as the considered interest of the project. In section 4, we propose a new model with the assumption of considering p as a variable.

Further to above mentioned assumptions, one should consider that all parameters of the model except the amount of bid-bond, which is neglected according to the above explanation, are subject to uncertainty. As defining stochastic distribution for the mentioned parameters complicates the model, it is concluded that the model should have fuzzy coefficients in the objective function, the fuzzy coefficient in the constraint matrix and fuzzy numbers on the right-hand side of the constraints. In the next section, the applied fuzzy approach to this model is presented.

Fuzzy approach for BLP mode

In this paper, in order to apply the fuzzy approach to the model, we have used the algorithm proposed by Yu and Li [9]. This algorithm solves a Binary Linear Problem (BLP) with fuzzy coefficients in the objective function, the fuzzy coefficient in the constraint matrix and fuzzy numbers on the right-hand side of the constraints. A brief explanation of Chian-Son Yu's algorithm is proposed as follows:

Considering model 8:

$$Maximize \quad z = \sum_{i=1}^{n} \tilde{c}_i x_i \tag{8}$$

$$Subject\ to \qquad \sum_{j=1}^{n} \tilde{a}_{ij}x_j \leq \tilde{b}_i \qquad \forall\, i = 1.\dots.m$$

Where x_j is zero-one variable, and $\tilde{b}_i$denotes the fuzzy number in the right-hand side of the I^{-th} constraint. $\tilde{c}_i$ and $\tilde{a}_i$ are the fuzzy coefficients in objective and constraint functions, respectively. We first explain the fuzzy approach to coefficients of the objective function. This method can be enhanced to the right hand side of the constraints and also the coefficients of the constraints.

The fuzzy number c_i with a triangular membership function, is depicted in Fig. 2, where c_{ik} $(k \in \{1.2.3\})$ are respectively the possible lowest, middle and highest numbers and s_{ik} $(k \in \{1.2\})$ are the slops of line segments between c_{ik} and c_{ik+1}. Then $\mu(c_i)$ can be expressed as below:

$$\mu(c_i) = \mu(c_{i1}) + s_{i1}(c_i - c_{i1}) + \frac{s_{i2} - s_{i1}}{2}(|c_i - c_{i1}| + c_i - c_{i2})$$

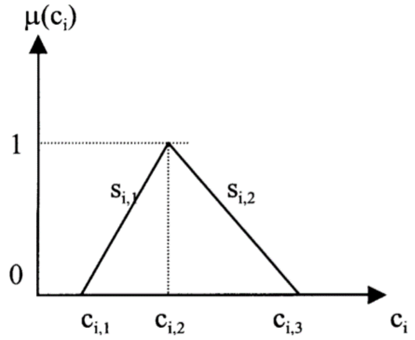

Fig. 2. A triangle membership function

Furthermore, we have:

$$\mu(c_i) = \mu(c_{i1}) + s_{i1}(c_i - c_{i1}) + (s_{i2} - s_{i1}) \times (c_i - c_{i2} + d) where: c_i - c_{i2} + d_i \geq 0. d_i \geq 0$$
$$\mu(a_i) = \mu(a_{i,1}) + s'_{i1}(a_i - a_{i1}) + (s'_{i2} - s'_{i1}) \times (a_i - a_{i2} + d) where: a_i - a_{i2} + d_i \geq 0. d_i \geq 0$$
$$\mu(b_i) = \mu(b_{i1}) + s''_{i1}(b_i - b_{i1}) + (s''_{i2} - s''_{i1}) \times (b_i - b_{i2} + d) where: b_i - b_{i2} + d_i \geq 0. d_i \geq 0$$

Then we have the following model:

$$Maximize \quad z = \sum_{j=1}^{n} c_i x_i$$
$$Maximize \quad z' = \sum_{j=1}^{n} \mu(c_i)$$
$$Maximize \quad z'' = \sum_{j=1}^{n} \mu(b_i)$$
$$Maximize \quad z''' = \sum_{j=1}^{n} \mu(a_i)$$

Subject to:

$$\textstyle\sum_{j=1}^{n} a_{ij}x_i \leq b_i \qquad \forall\, i = 1\dots.m \tag{9}$$
$$c_i - c_{i2} + d_i \geq 0 \quad \forall\, i = 1\dots.m \tag{10}$$
$$d_i \geq 0 \qquad \forall\, i = 1\dots.m \tag{11}$$
$$a_i - a_{i2} + d'_i \geq 0 \quad \forall\, i = 1\dots.m \tag{12}$$
$$d'_i \geq 0 \qquad \forall\, i = 1\dots.m \tag{13}$$

$b_i - b_{i2} + d_i'' \geq 0 \quad \forall\, i = 1 \ldots . m$ (14)
$d_i'' \geq 0 \quad \forall\, i = 1 \ldots . m$ (15)

To integrate the objective functions of the above model, following crisp linear model 16 will be concluded:

$$Maximize\ \ z' = \sum_{j=1}^{n} c_i x_i - \sum_{j=1}^{n} \left(\frac{\delta_j^+}{s_{j1}} - \frac{\delta_j^-}{s_{j2}}\right) - \sum_{j=1}^{n} \left(\frac{\delta_j'^+}{s_{j1}'} - \frac{\delta_j'^-}{s_{j1}'}\right) - \sum_{i=1}^{ni} \left(\frac{\delta_i''^+}{s_{i1}''} - \frac{\delta_i''^-}{s_{i2}''}\right) \quad (16)$$

Subject to:
$\mu(c_{i1}) + s_{i1}(c_i - c_{i1}) + (s_{i2} - s_{i1}) \times (c_i - c_{i2} + d) - \delta_i^+ + \delta_i^- = 1$
$\mu(a_{i1}) + s_{i1}'(a_i - a_{i1}) + (s_{i2}' - s_{i1}') \times (a_i - a_{i2} + d) - \delta_i'^+ + \delta_i'^- = 1$
$\mu(b_{i1}) + s_{i1}''(b_i - b_{i1}) + (s_{i2}'' - s_{i1}'') \times (b_i - b_{i2} + d) - \delta_i''^+ + \delta_i''^- = 1$

Equations 9-15
For more details refer to Yu and Li [9].

Applying this method to the presented tender participating selection yields fuzzy tender participating selection model. To that end, it is only required to conisder the coeficients of the variables x_i and y_i in Eq. 4 as the parameter c_i of the above model, and the right hand side of the constraints (5) and (6), i.e. H_j and M_j as parameter b_i, and the parameters "$hr_{ij} \times p_i$" and "$m_{ij} \times p_i$" as the parameters a_{ij} of the above model.

$$Maximize\ \sum_i (w_i v_i x_i - c_i x_i - (b_i + w_i v_i) p_i y_i) \quad (4)$$

Subject to

$$\sum_i hr_{ij} \times p_i \times x_i - \sum_i hr_{ij} \times p_i \times y_i \leq H_j \qquad \forall j \in A \quad (5)$$

$$\sum_i m_{ij} \times p_i \times x_i - \sum_i m_{ij} \times p_i \times y_i \leq M_j \qquad \forall j \in A \quad (6)$$

$$y_i \leq x_i \qquad \forall i \in T \quad (7)$$

To illustrate this problem, following example is exhibited.
Example:

Consider a firm which has 6 potential tenders to participate, the available human and financial resources for 5 future years are shown in Table 1.

Table 1. Available firm's resources

Years	2022	2023	2024	2025	2026
Human Resources	450	550	550	650	700
Finance Resources	70	70	80	80	80

The required human and financial resources for each tender during future years are specified in Table 2.

Table 2. Required resources of tenders

	2022						2023						2024						2025						2026					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Human R.	80	240	40	150	60	50	100	300	40	120	60	50	120	200	40	120	60	50	100	180	----	150	60	50	100	160	----	150	----	----
Finance R.	20	25	10	35	15	35	20	35	10	50	15	35	20	35	10	50	15	35	20	35	----	50	15	20	20	35	----	50	----	----

The summary of Tables 1 and 2 are shown in Fig. 3.

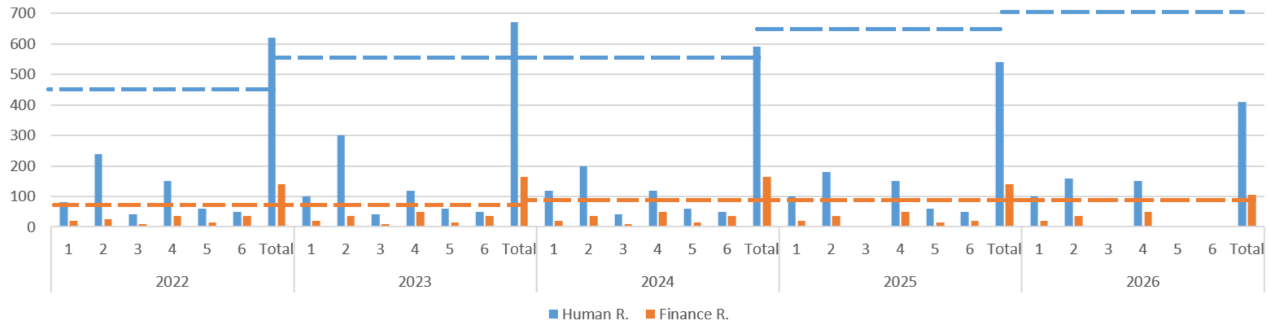

Fig. 3. The summary of problem definition

In Fig. 3, the available resources are shown by horizental dashed lines.
The other information of tenders is specified in Table 3.

Table 3. Tender's data

Tender No.	1	2	3	4	5	6
Winning Probability	0.5	0.85	0.4	0.75	0.4	0.4
Profit ($w_i v_i$)	400	600	150	900	350	300
Proposal Preparing Cost	5	10	5	25	5	5

With the assumption of 50% tolerance in all parameters specified in Tables 1, 2 and 3, the sample symmetric triangular fuzzy number is depicted in Fig. 4.

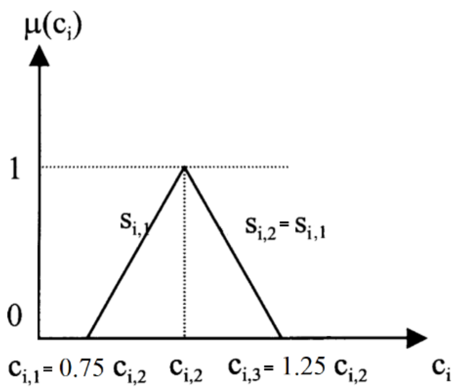

Fig. 4. A triangle membership function with the assumption of 50% tolerance

Applying Yu and Li approach and using Lingo 15.0 software package, in the optimum solution the decision-makers should select tenders no. 1, 2 and 4, where in the crisp mode, only tenders no. 2 and 4 were selected.

In order to analyze the effects of fuzzy numbers on the final solution, the expected value of profits are determined considering different tolerances of the fuzzy numbers and the results are specified in Fig. 5.

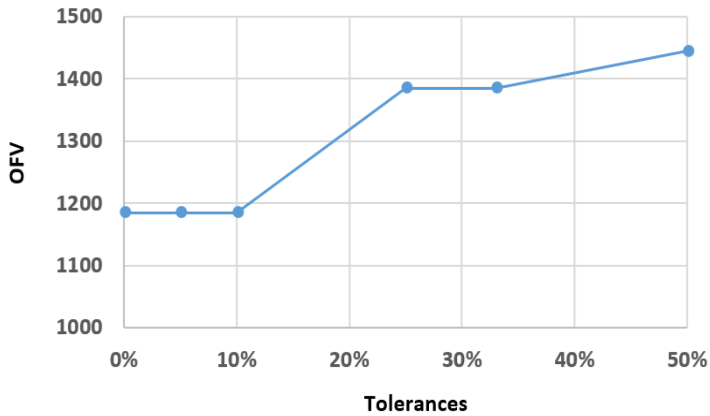

Fig. 5. Sensevity analysis on fuzzy numbers

According to Fig. 5, the OFV increases as the tolerances of the fuzzy numbers increase. Moreover, it is found that when the tolerances increase from 0% up to 10%, no changes in the optimum solution arises which means that this solution is robust against any uncertainty in 10% interval.

Variable tender winning probability mode

In previous sections of the paper, we have discussed the problem of the constant condition of tender winning probability, in this situation the desired interest of each project is determined by the model. In this section, we consider a situation in which the desired interest and therefore the probability of winning the tender is variable and should be determined by solving the model. Here is the explanation of the mathematical model.

As it is explained before by eliminating the variable y, the mathematical model of this problem is achieved as follows:

$$Maximize\ \sum_i (w_i x_i - c_i x_i) \tag{17}$$

Subject to:

$$\sum_i hr_{ij} \times p_i \times x_i \leq H_j \qquad \forall j \in A \tag{18}$$

$$\sum_i m_{ij} \times p_i \times x_i \leq M_j \qquad \forall j \in A \tag{19}$$

Considering p as a variable, the Eqs. 18 and 19 are non-linear, These equations can be replaced with integer linear Eqs. 20-23.

$$\sum_i hr_{ij} \times z_i \leq H_j \qquad \forall j \in A \tag{20}$$

$$\sum_i m_{ij} \times z_i \leq M_j \qquad \forall j \in A \tag{21}$$

$$z_i \leq B \times x_i \qquad \forall j \in A \tag{22}$$

$$z_i \geq P_i - B \times (1 - x_i) \qquad \forall j \in A \tag{23}$$

Where, z_i is a variable, and B is a big constant equals 1, as we have always $P_i \leq 1$.

Computational fuzzy approach for ILP mode

As it is specified before several different approaches have been presented in the case of solving linear programming with imprecise coefficients. One of the simplest ones is Fuller's approach presented by Lai and Hwang [10]. In this method simply the fuzzy numbers replaced with crisp numbers. In order to convert the triangular fuzzy number (c_1 c_2 c_3) to crisp one, Eq. 24 is used.

$$c = \frac{c_1+c_2+c_3}{3} \quad (24)$$

Using this approach, the final optimum answer for the above-introduced example will be as shown in Table 4.

Table 4. The final decision based on consiering p as a variable

Tender No.	1	2	4	5
Winning Probability	0.52	0.58	0.89	0.66
Profit ($w_i v_i$)	406	711	970	422

As shown in Table 4 by this mathematical model, the decision-maker can consider different ROR and probability of winning the tenders to reach the best possible solution. In other words, this solution specifies the price which should be quoted in the tender, by the company. Obviously, this solution cannot be achieved by any other tools except solving the mathematical model. By the proposed model, the future income of the company, as well as the profits, can be estimated which make proper substructure for strategy planning.

Conclusions

This paper addressed a company willing to select the best possible tenders considering limited finance and human resources, in order to maximize the profits by participating in money-making and low risk tenders considering all available resources. In this paper, two mathematical models including a multi-objective binary model and a mixed-integer model were introduced. Considering the uncertainty of parameters, two different fuzzy approaches were applied. Finally, to illustrate the application of the proposed models an illustrative example was presented. The results showed that by considering the fuzzy approach we increase the chance of reaching higher benefits for the company. Moreover, by the assumption of considering p, probability of winning the tender, as a variable, the decision-makers had different choices by tuning the quoted price which affects the ROR as well as the probability of winning the tenders. For future researches, the two stage stochastic programming is suggested to apply to the model, and the L-shape method is utilized to solve the problem where the Sub-Problems are the same as the problems addressed in this paper.

References

[1] Arslan G., Kivrak S., Talat Birgonul M. and Irem Dikmen, Improving sub-contractor selection process in construction projects: Web-based sub-contractor evaluation system (WEBSES), Automation in Construction Volume 17, Issue 4, May 2008, pp. 480-488.

[2] Polat G., Subcontractor Selection Using The Integration Of The Ahp And Promethee Methods, Journal Of Civil Engineering And Managementissn, Volume 22(8), 2016, pp.1042–1054.

[3] Cheng M-Y., Yeh S-H, Chang W-C, Multi-Criteria Decision Making of Contractor Selection in Mass Rapid Transit Station Development Using Bayesian Fuzzy Prospect Model, Sustainability, Volume 12 (4606), 2020, pp. 1-32.

[4] Mats A. Bergman, Sofia Lundberg, Tender evaluation and supplier selection methods in public procurement, Journal of Purchasing and Supply Management, Volume 19, Issue 2, 2013, pp. 73-83.

[5] Ballesteros-Pérez P., Luisa del Campo-Hitschfeld M., Mora-Melià D., Domínguez D., Modeling bidding competitiveness and position performance in multi-attribute construction auctions, Operations Research Perspectives, Volume 2, 2015, pp. 24-35.

[6] Maqsoom A., Bajwa S., Zahoor Ahmad Khan H., Dawood M., Optimizing contractor's selection and bid evaluation process in construction industry: Client's perspective, Revista de la Construcción, Volume 18, Issue 3, 2019, pp. 445-458.

[7] Indah Kusumarukmi E., Joko Wahyu Adi T., Public tendering process for construction projects: problem identifications, analysis, and proposed solutions, International Conference on Sustainable Civil Engineering Structures and Construction Materials, Yogyakarta, Indonesia, September 5-7, 2018, pp. 1-8.

[8] Abboud N. J., Sakawa M. and Inuiguchi M., A fuzzy programming approach to multiobjective multidimensional 0-1 knapsack problems, Fuzzy Sets and Systems Volume 86, Issue 1, 16 February 1997, pp. 1-14.

[9] Yu C., Li H., An algorithm for generalized fuzzy binary linear programming problems, European Journal of Operational Research, Volume 133, 2001, pp. 496-511.

[10] Lai Y. J. and Hwang C. L., Fuzzy Mathematical Programming: Methods and Applications, Springer; 1 edition (March 17, 1995)