Vol. 33, No. 4 (2023) | DOI: 10.37190/ord230411

OPEN ACCESS

Operations Research and Decisions

www.ord.pwr.edu.pl

OPERATIONS RESEARCH AND DECISIONS QUARTERLY

Assessing telecommunication contractor firms using a hybrid DEA-BWM method

Omid Valizadeh[1] Mojtaba Ghiyasi[*1]

[1] *Faculty of Industrial Engineering and Management Science, Shahrood University of Technology, Shahrood, Iran*

[*] *Corresponding author, email address: mog@shahroodut.ac.ir*

Abstract

Telecommunication companies have an important role in technology development, so evaluating the performance of these companies has been an interest of managers. This article uses a hybrid method using data envelopment analysis (DEA) and the best-worst method (BWM) to measure the performance of communication companies. The hybrid DEA-BWM method is used for the weight determination and performance assessment of 17 telecommunication contractor firms in the Khorsan Razavi province of Iran. We considered four inputs: gross losses, sales cost, legal reserve, and fixed assets. On the other side, three outputs including operation income, operation profit, and retained earnings are considered as outputs. Considering the input-output parameters and using the hybrid method by seven selected criteria, we rank all contractor firms. We found that the BPM firm has the best performance while and GKS firm is found as the firm with the weakest performance. Compared with the classical DEA methods, we found more reliable results with higher discrimination power, using the hybrid DEA-BWM.

Keywords: *performance assessment, data envelopment analysis, best-worst method, telecommunication contractor firms*

1. Introduction

One of the key pillars of each nation for intercity, interactive, and internet broadband suppliers is telecommunications companies. All communication organizations are seeing daily quality and quantity increases due to people's increased desire for modern communication. The government should outsource some of the services it provides, notably telecommunications companies, and contractors following the plans for national growth. It is crucial to have a performance evaluation for the contractors given the dynamic and quick movement of technology in telecommunications companies. Analyzing these companies' performance results in better and higher-quality services for society. Data envelopment analysis (DEA) is a comprehensive non-parametric technique for evaluating the performance of decision-making units (DMUs), initially suggested by Charnes et al. [2]. This method which is a linear programming-based technique can determine the efficacy and efficiency frontier of DMUs and whether the desired DMU is

Received 9 August 2022, accepted 21 September 2023, published online 22 December 2023
ISSN 2391-6060 (Online)/© 2023 Authors

The costs of publishing this issue have been co-financed by the program *Development of Academic Journals* of the Polish Ministry of Education and Science under agreement RCN/SP/0241/2021/1

on the efficiency boundary or not. Flexibility in selecting weights in the DEA models is one of the advantages of this method. DEA is free of biased and exogenous information. However, this possibility may be a weakness too, since it is not possible to consider managerial information and desire in the process of the performance assessment. Different developments like weight restriction [9], common weight [10], cone ratio [13], and assurance region [11] are proposed to overcome the aforementioned drawbacks. All these techniques also have pros and cons. A typical DEA model can indicate that each unit chooses its ideal weight decision [22]. Thus, it becomes a bit difficult to compare and rank based on inputs and outputs. In the weight restriction method, we can first calculate the efficiency of each unit and then rank them based on the points each unit has earned. The advantage of this method is that it can prevent the lack of weighted similarity and that the impact of inputs and outputs is not neglected in any way [9]. We know that flexibility in choosing weights in conventional DEA can stop the comparison of DMUs based on a common base and feature. The use of the cone ratio model in DEA can improve the multi-faceted ratios that are both in the output axis and the input axis. The use of the assurance region model ensures that data envelopment analysis can be the weight of the non-reasonable, the sensitivity of the size, and the loss of important information to prevent and according to the priority, the more important the decision should be adopted. Assurance region models provide the possibility of limiting weights that make the DEA model take control of the relative input and its impact on the total output [13]. Babaee ey al. [1] proposed a common set of weights DEA approach for measuring all units simultaneously while reflecting the hierarchical structure of the indicators in the model. Dellnitz et al. [6] addressed some unusual cases for the returns to scale value, specifically for pollution-generating technology, and then proposed median-based optimization problems to correct this flaw.

Multiple criteria decision-making (MCDM), a sub-branch of operations research can handle several criteria that may be quite different in decision evaluation. In previous years, different methods of MCDM were proposed by different researchers. Analytic hierarchy process (AHP) was introduced by Saaty [19] as well as Vaidya and Kumar [21]. One of the most up-to-date and new methods was raised in 2015 by Rezaei [18], called the best-worst method (BWM). This method, first, determines the best and worst indicators by the decision-makers and then performs a pairwise comparison to find the optimal value of the relative weights. BWM has been used in solving many problems of MCDM in the real world such as trade, economics, information technology, education, etc. In general, this method can be used wherever the goal is to rank and select an option from between options sets. The BWM method has various advantages over other methods including. For instance, by identifying the best and worst criteria before making pairwise comparisons, the decision-maker has a clearer understanding of the scope of the assessment, it requires less data and has more flexibility than other MCDM methods. Denshiri et al. [5] developed a novel group decision-making method based on the BWM to evaluate the criteria for implementing block-chain technology in supply chains. Omrani et al. [16] considered the internal structure of production units when determining the weights incorporating the BWM method then they applied the proposed model for the evaluation of 45 agricultural banks. The world experienced a revolution as a result of technological advancements in the 21st century, known as the Fourth Industrial Revolution [23]. However, transferring technologies to contractor businesses can also be crucial for the growth of the telecommunications infrastructure [4]. Communication networks play an important role in the dynamics of a society's economy and culture Iran has one of the largest infrastructures of communication networks in the Middle

East and due to the rapid advancement of technology in the field of communication, customers expect to receive better and faster services. On the other hand, due to the growth of the telecommunication industry and the increase in projects, contractor companies play an important role in the implementation of projects [20]. Because we have limited resources, making decisions to choose the right contractor to carry out a project can be challenging for companies [14]. The specialized activities of different sectors of the industry are one of the most prominent features of today's businesses, so outsourcing the activities of an organization such as the Telecommunication Company of Iran is one of the most important problems for the managers of the organization [7]. Moreover, choosing the wrong contractor can increase the cost, project delays, and additional costs for project management [15]. We also know that competitive positioning and choosing the right market have a significant impact on the development of contractors in different periods and sectors [24]. The selection of the contractor should be evaluated based on the capabilities of the contractor company using a set of criteria such as reputation, capital, profit, and loss [12]. Cheatitou et al. [3] proposed a hybrid decision-making framework using fuzzy logic and the DEA method for the evaluation and selection of construction contractors in a public organization in the United Arab Emirates. Heydarpour et al. [8] utilized a hybrid AHP and DEA method for the evaluation of contractors of a steel company. In this paper, we consider a hybrid DEA-BWM method for the performance assessment of contractor firms in a telecommunication company. We consider the decision-maker's opinion, endogenously and then determine the optimal weights using the hybrid model exogenously. It can be considered as an ad hoc method when we consider the decision-maker's opinion and it can be different from one case to another. On the other hand, it is the general method for incorporating the decision-maker's opinion and determining the optimal weights. The rest of the paper is organized as follows. Section 2 reviews and provide the required theoretical models. Section 3 analyzes the performance of 17 contractor firms using the hybrid DEA-BWM method. Section 4 provides a conclusion and further potential research lines.

2. Methodology

We utilized a hybrid DEA-BWM model for the performance assessment of the contractor firms, considering the expert's opinions in the evaluation process. We consider a framework for incorporating the decision-makers preferences that helped us to improve the discrimination power of the evaluation. It is important to point out that we need no prior information in such a setting.

2.1. Data envelopment analysis (DEA)

DEA is a non-parametric approach first presented to assess the effectiveness of decision-making units (DMUs) with numerous inputs and outputs [2]. In almost every production or service process, fewer inputs and more outputs are preferred. As a result, we want to maximize output in input-oriented models and decrease input in input-oriented models as much as we can. Each DMU's efficiency is determined by dividing the weighted output produced by the weighted input used, namely, $\left(\sum_{i=m+1}^{m+s} v_i y_{io}\right) / \sum_{i=1}^{m} u_i x_{io}$, where x_{io} is the ith input $(1 \leq i \leq m)$ of jth DMU and y_{io} is the ith output $m+1 \leq r \leq m+s$ of jth DMU $1 \leq j \leq n$, u_i is the weight of the standing for ith output and v_i is the weight of the ith inputs, the subscript o refers to the decision-maker unit index under investigation.

The following linear programming model finds the relative efficiency of the DMU_o, that is the DMU under evaluation.

$$\begin{aligned} \theta_o = \max & \sum_{i=m+1}^{m+s} y_{io} u_i \\ \text{s.t.} & \sum_{i=m+1}^{m+s} y_{ij} u_i - \sum_{i=1}^{m} x_{ij} u_i \leq 0 \\ & \sum_{i=1}^{m} x_{ij} u_i = 1, \quad u_i \geq 0, \quad i = 1, \ldots, m+s \end{aligned} \tag{1}$$

2.2. Best-worst method (BWM)

The BWM method is based on paired comparisons by decision-makers for ranking different criteria. If we consider a set of criteria affecting the decision process then we can perform the following steps for the BWM method.

Step 1. Having the set of assessment criteria $\{C_1, C_2, \ldots, C_n\}$ determined by the expert team. For example, in the case of buying a house, the decision criteria can be $\{C_1-$ price, C_2- year of construction, $C_3 =$ house facilities, $C_4 =$ style, etc.$\}$.

Step 2. Find the best (for example, most important) and worst (for example, least important) criteria chosen by the expert team.

Step 3. Using the range from 1 to 9, identify the preference vector of the **best** criterion over all the criteria as:

$$A_B = (a_{B1}, a_{B2}, \ldots, a_{Bn})^T$$

where a_{Bj} stands for the preference of the best criterion B over criterion j and obviously that $a_{BB} = 1$. Thus, at least one component of A_B is unity, that is, a_{BB}. The vector A_B shows the preference vector of all criteria over the worst criteria.

Step 4. Using the range from 1 to 9, identify the preference vector of all criteria over the **worst** criterion as:

$$A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})T$$

where a_{jW} stands for the preference of criterion j over the worst criteria and obviously that $a_{WW} = 1$. Thus, the vector A_W shows the preference vector of all criteria over the worst criteria.

Step 5. Find the optimal weight which is the weight that is used to establish the following link for each couple $\frac{w_B}{w_i}, \frac{w_i}{w_W}$:

$$\frac{w_B}{w_i} = a_{Bj}, \quad \frac{w_i}{w_W} = a_{jW}$$

The goal is to find the optimal weights in a way that maximum difference $\left|\frac{w_B}{w_i} - a_{Bi}\right|$ and $\left|\frac{w_i}{w_W} - a_{iW}\right|$ is minimized. The associated constraint (the intensity constraint) is the sum of weights equal to unity and of course non-negativity constraints. This yields the following mathematical programming:

$$\begin{aligned} &\min\max \left|\frac{w_B}{w_i} - a_{Bi}\right| \text{ and } \left|\frac{w_i}{w_W} - a_{iW}\right| \\ &\text{s.t.} \sum_{i=1}^{n} w_j = 1, \quad w_i \geq 0 \end{aligned} \tag{2}$$

Model 2 can be transferred to the following problem:

$$\begin{aligned} &\min \xi \\ \text{s.t.} \ &\left|\frac{w_b}{w_j} - a_{Bj}\right| \leq \xi, \quad j = 1, 2, \ldots, n \\ &\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi, \quad j = 1, 2, \ldots, n \\ &\sum_{i=1}^{n} w_j = 1, \quad w_i \geq 0 \end{aligned} \tag{3}$$

In short, five BWM steps are described in Figure 1.

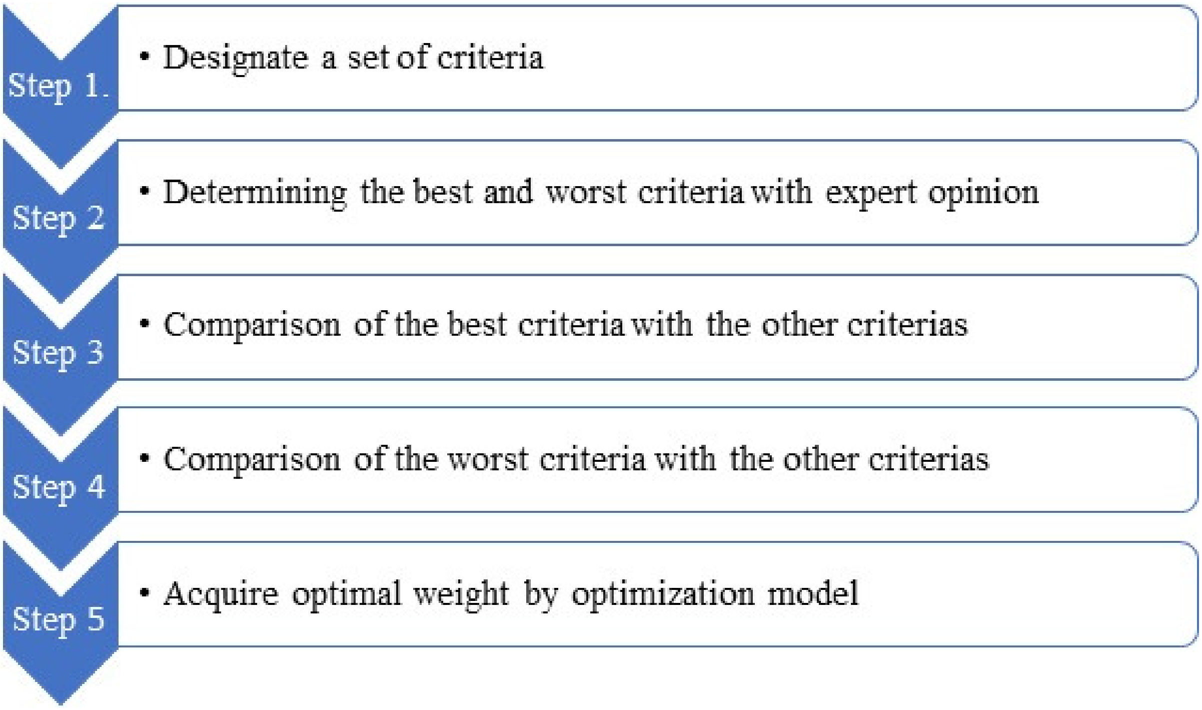

Figure 1. Five steps in BWM

2.3. Hybrid DEA-BWM approach

The DEA models solely provide an evaluation framework based on the observed input and output data. In other words, they do not consider the decision-makers' preferences, specifically the pairwise preferences of criteria in the evaluation process. BWM as an MCDM technique only provides a ranking index for DMUs based on the criteria and actual input-output data. Therefore, a hybrid DEA-BWM model is used in the current paper for analyzing and assessing the performance of communication companies.

In this section, we consider the proposed hybrid DEA-BWM model. The equality constraint of the DEA model is $\sum_{i=1}^{m} u_i x_{ij} = 1$ and it is now considered by the normalized equality constraint $\sum_{j=1}^{n} w_j = 1$ in the BWM model. For more details about this replacement see [25].

$$\begin{aligned}
\max \ & \sum_{i=m+1}^{m+s} y_{i_o} u_i - \theta_o \sum_{i=1}^{m} x_{io} u_i \\
\text{s.t.} \ & \sum_{i=m+1}^{m+s} y_{ij} u_i - \theta_j \sum_{i=1}^{m} x_{ij} u_i \leq 0, \quad j = 1, 2, \ldots, n \\
& \sum_{i=1}^{m+s} u_r = 1 \\
& u_i \geq 0, \quad i = 1, \ldots, m+s
\end{aligned} \tag{4}$$

where θ_j is the efficiency of the jth unit.

The normalization of weights in the BWM model is similar to the replacement of the equality constraint by the normalization weight constraint in the mentioned model. Thus, the following is a possible formulation of the hybrid multi-objective DEA-BWM model.

$$\begin{aligned}
& \max f_1 = \sum_{i=m+1}^{m+s} w_i y_{i_0} - \theta_0 \sum_{i=1}^{m} w_i x_{io} \\
& \max f_2 = -\xi \\
& \max f_3 = -\varepsilon \\
& s.t. \sum_{i=m+1}^{m+s} w_i y_{ij} - \theta_0 \sum_{i=1}^{m} w_i x_{ij} \leq 0, \quad j = 1, 2, \ldots, n \\
& \sum_{i=1}^{m+s} w_i = 1 \\
& \left| \frac{w_b}{w_i} - a_{Bi} \right| \leq \xi, \quad i = 1, \ldots, m+s \\
& \left| \frac{w_i}{w_W} - a_{iW} \right| \leq \xi, \quad i = 1, \ldots, m+s \\
& \left| \frac{w_b}{w_i} - a_{Bi} \right| \leq \varepsilon, \quad i = 1, \ldots, m+s \\
& \left| \frac{w_i}{w_W} - a_{iW} \right| \leq \varepsilon, \quad i = 1, \ldots, m+s \\
& w_i \geq 0, \quad i = 1, \ldots, m+s
\end{aligned} \tag{5}$$

The first objective function and the first constraint in the model (5) are taken from the DEA model (3). Inputs in the BWM include the second objective function and the third and fourth constraints. The BWM's outputs include the third objective function and the fifth and sixth constraints. The second constraint $\sum_{i=1}^{m+s} w_i$ belongs to DEA and also BWM. This constraint is the joint constraint between DEA and BWM parts. It is important to point out that both DEA and BWM parts use the same weight in the multiple objective programming model (5). Thus, the optimal weights should satisfy both DEA and BWM constraints, simultaneously. There exist a variety of techniques, including weighted sum, lexicographic, goal programming, etc., for solving the multiple objective programming models (5) that may be used based on the decision-maker's desires.

3. Assessing telecommunication contractor firms

In this section, 17 communication companies in Iran are evaluated using the proposed model. Evaluating communication companies from different aspects, especially services, is very important because it helps to find the strengths and weaknesses of these companies and provide better services to customers. The selection of input and output variables is very crucial in DEA applications. However, there is no firm consensus on which variables best describe the operation of distribution utilities. After reviewing the literature on contractor selection generally, we also asked the expert to determine the input and output data. Within this process, we of course consider the data availability for all firms. We finally consider four inputs including gross losses, sales cost, legal reserve, and fixed asset, and three outputs including operation income, operation profit, and retained earnings. Table 1 lists the statistical summary of the input and output data.

Table 1. Statistical summary for data of telecommunication contracting companies in 2019

Data	Inputs				Outputs		
	Gross losses	Sales cost	Legal reserve	Fixed asset	Operating income	Operating profit	Retained earning
Maximum	5,819,993	638,584	300,000	7,257,630	2,698,3601	5,134,275	6,558,654
Minimum	0	126	0	108	0	126	2909
Mean	658,449	154,011	50,240	994,096	485,8317	518,242	91,2421
Standard deviation	1410523	207750	83928	1939775	7520165	1228130	1,750,369

In Table 2, the result of weighting the best and the worst criteria using the expert team are given. After reviewing the literature on contractor selection, we asked the expert team including 35 seniors and managers who are relative experts working in the central organization of the telecommunication ministry, Khorasan province. All experts had at least ten years of experience in the field of telecommunication contractor firms.

For the set of criteria that the lower values are preferred, gross losses are determined as the best and fixed asset is found as the worst. We asked the experts to determine the best and the worst criteria first and then they were asked to rate other criteria from 1 to 9 compared with the best and the criteria. The rating of other criteria compared with the best and worst criteria is found based on the mean result of the expert's rating and reported in table 3. The same analysis is performed for the second set of criteria in which higher values are desired. For instance, the second row shows the rating values of all criteria between 1 to 9 compared with the best criteria which are gross losses (W1). Of course, W1 = 1 measuring gross losses has no preference compared with itself. W2 = 2 is the priority of sales cost compared with the gross losses, etc. The third row is the rating criteria based on the worst criterion which is fixed asset

(W4). We see that gross losses are rated 8 (from 1 to 9) compared with the worst criteria, namely, fixed assets. Sales cost is rated 5, etc.

Table 2. Preference of the best and worst criteria of inputs and outputs by experts

Criterion	W1 Gross Losses	W2 Sales cost	W3 Legal reserve	W4 Fixed asset
Best – W1	1	2	4	8
Worst – W4	8	5	3	1
	W5 Operation income	W6 Operation profit	W7 Retained earning	
Best – W5	1	7	5	
Worst – W6	7	1	3	

The efficiency of 17 communication contractor companies has been evaluated. Table 3 reports this result. According to the result of running the DEA model, eight companies were found efficient. In other words, these companies are located on the efficient frontier. On the other hand, the least effective at transforming inputs into outputs is PAK, which receives a score of 0.1102. The DEA model attempts to find the best combination of input and output weights to achieve an MDU at an efficient frontier. The average efficiency score using this method is 0.725 which shows a rather acceptable result.

Table 3. The efficiency level of contractor firms using classical DEA and hybrid DEA-BWM

Contractor firms	Efficiency score – DEA	Efficiency score – DEA-BWM
SEK	1	0.9813
SKK	1	0.9969
SAFGK	0.1596	0.1483
KVKHA	1	0.998
TAP	0.7423	0.4263
EMN	0.5682	0.5329
KRKHA	0.457	0.4456
PATM	0.899	0.8977
BPHSA	1	0.8926
MSSG	1	0.9315
DVFA	0.5839	0.5738
KAL	1	0.9935
NAK	0.6882	0.5231
RFG D	1	0.8951
PAK	0.1102	0.1067
GKS	0.1171	0.0182
BPM	1	0.9996

In the next analysis, we performed the hybrid DEA-BWM model and reassessed the performance of contractors. As we mentioned before the hybrid DEA-BWM model is a multiple objective model and does not have optimal solutions, but (weak and strong) efficient solutions. However, there exist several techniques for solving this type of programming model. We used the simple weighted sum method with the positive unity weights for solving the hybrid DEA-BWM model. This guarantees to find strong efficient solutions for this model. A strong efficient solution means there is no solution better (higher for maximization and lower for minimization) than this solution, managerially. In the first step, the best and the worst variables for inputs and outputs should be determined which is done and reported in Table 1. The best and the worst criteria, the preference for the best criterion of all criteria, and the preference of all criteria over the worst criterion for input and output variables are determined. First, using the BWM method and associated weights out of the experts' opinions, we obtained the weights of the desired criteria and then we ranked the companies using the hybrid method. According to the hybrid, the DEA-BWM model BPM with a score of 0.9996 is the best company among communication companies, and GKS with a score of 0.0182 has the worst performance among 17 communication companies. The average efficiency score using the hybrid method is 0.6683 which shows a difference of 0.0567 less than the average efficiency score using the classical method. This shows an important finding which is the higher discrimination power of the analysis by the hybrid model compared with the classical DEA model. This fact is supported in two ways. On one hand, there is no fully efficient firm using the hybrid method compared with the classical method. On the other hand, by the average value of the efficiency score of firms.

In Table 4, we determine the ranking order of contractor firms using the hybrid DEA-BWM method. BPM stands in the first ranking place. Please note that it is an efficient firm based on the DEA model and has a high efficiency level using the hybrid model as well.

Table 4. Ranking of companies based on the DEA-BWM model

Contractor firm	Rank DEA-BWM
SEK	5
SKK	3
SAFGK	15
KVKHA	2
TAP	14
EMN	11
KRKHA	13
PATM	7
BPHSA	9
MSSG	6
DVFA	10
KAL	4
NAK	12
RFG D	8
PAK	16
GKS	17
BPM	1

Another interesting outcome of the hybrid model is weighting criteria, considering both the performance of the contractors and the expert's opinions. The mean result of this result is reported in Table 5.

Table 5. Optimal weights out of the DEA-BWM model

Criteria's weight	W1	W2	W3	W4	W5	W6	W7
Optimal weight	0.2844	0.248788	0.2249	0.128024	0.003888	0.104006	0.005653

Observe the importance of input criteria vs output criteria that highlight the significance of input criteria in the performance evaluation of contractor firms. The lowest position is associated with W5 which is operation income and on the other side the gross losses (W1) stand in the highest position while considering the expert's preferences and the performance of the contractor firms. If we consider only the expert's desires then the result confirms the most important criterion which is gross losses. However, we did not find a consensus for the least important criteria and of course, the result that considers both the performance of firms and the expert's opinions is more reliable.

In the end, in Figure 2, we summarize the procedure that can help the decision-makers in the process of contractor selection.

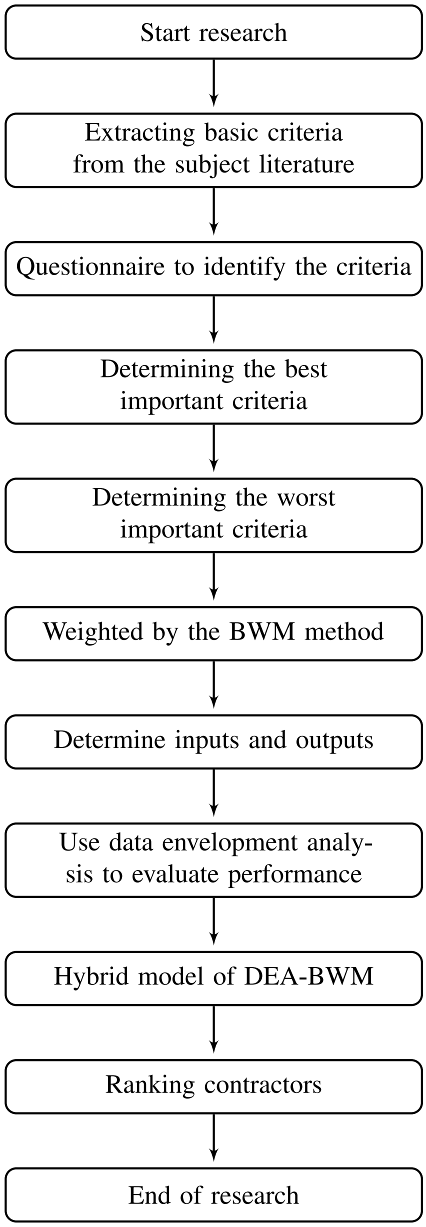

Figure 2. Procedure for contractor selection

4. Conclusion

Using a hybrid DEA-BWM model, We analyzed the performance of 17 contractor firms – telecommunication companies in Khorasan Razavi's in 2019. Ranking MCDM are methods just based on the decision-makers' desire may have some bias. However, non-parametric methods like DEA ignore the exogenous information in the process of the evaluation. Thus, a hybrid method based on the DEA and MCDM can overcome the aforementioned drawbacks and yield more reliable results. The result provides useful information for decision-makers in selecting contractor firms. Compared with other MCDM methods, the BWM method provides more reliable results due to more consistent comparisons. However, for the future research line, considering other MCDM techniques with the DEA model as an economic-based method could be interesting and reveals more interesting finding.

References

[1] Babaee, S., Toloo, M., Hermans, E., and Shen, Y. A new approach for index construction: The case of the road user behavior index. *Computers & Industrial Engineering 152* (2021), 106993.

[2] Charnes, A., Cooper, W. W., and Rhodes, E. Measuring the efficiency of decision-making units. *European Journal of Operational Research 2*, 6 (1978), 429–444.

[3] Cheaitou, A., Larbi, R., and Al Housani, B. Decision-making framework for tender evaluation and contractor selection in public organizations with risk considerations. *Socio-Economic Planning Sciences 68* (2019), 100620.

[4] Dahooie, J. H., Qorbani, A. R., and Daim, T. Providing a framework for selecting the appropriate method of technology acquisition considering uncertainty in hierarchical group decision-making: Case study: Interactive television technology. *Technological Forecasting and Social Change 168* (2021), 120760.

[5] Dehshiri, S. J. H., Emamat, M. S. M. M., and Amiri, M. A novel group BWM approach to evaluate the implementation criteria of blockchain technology in the automotive industry supply chain. *Expert Systems with Applications 198*, (2022), 116826.

[6] Dellnitz, A., Tavana, M., and Banker, R. A novel median-based optimization model for eco-efficiency assessment in data envelopment analysis. *Annals of Operations Research 322*, 2 (2023), 661–690.

[7] Gharedaghi, G., and Omidvari, M. A contractor selection model for gas and oil industries in safety approach using ANP-DEMATEL in grey environment. *Safety and Reliability 37*, 1 (2017), 25–47.

[8] Heydarpour, S., Seyyed Esfahani, S. H., and Khorshidvand, B. Providing a DEA and AHP hybrid model to evaluate contractors' performance (Case study: Zarand Iranian Steel Co. (ZISCO)). *Journal of Industrial Engineering and Management Studies 9*, 1 (2022), 1–10.

[9] Jain, V., Kumar, A., Kumar, S., and Chandra, C. Weight restrictions in Data Envelopment Analysis: A comprehensive Genetic Algorithm based approach for incorporating value judgments. *Expert Systems with Applications 42*, 3 (2015), 1503–1512.

[10] Kao, C., and Hung, H.-T. Data envelopment analysis with common weights: the compromise solution approach. *Journal of the Operational Research Society 56*, 10 (2005), 1196–1203.

[11] Khalili, M., Camanho, A. S., Portela, M. C. A. S., and Alirezaee, M. R. The measurement of relative efficiency using data envelopment analysis with assurance regions that link inputs and outputs. *European Journal of Operational Research 203*, 3 (2010), 761–770.

[12] Krishna Rao, M. V., Kumar, V. S. S., and Rathish Kumar, P. Optimal contractor selection in construction industry: The fuzzy way. *Journal of The Institution of Engineers (India): Series A 99*, 1 (2018), 67–78.

[13] Liu, S.-T. Restricting weight flexibility in fuzzy two-stage DEA. *Computers & Industrial Engineering 74* (2014), 149–160.

[14] Marović, I., Perić, M., and Hanak, T. A multi-criteria decision support concept for selecting the optimal contractor. *Applied Sciences 11*, 4 (2021), 1660.

[15] Morkunaite, Z., Podvezko, V., Zavadskas, E. K., and Bausys, R. Contractor selection for renovation of cultural heritage buildings by PROMETHEE method. *Archives of Civil and Mechanical Engineering 19*, 4 (2019), 1056–1071.

[16] Omrani, H., Alizadeh, A., Emrouznejad, A., and Oveysi, Z. A novel best-worst-method two-stage data envelopment analysis model considering decision-makers' preferences: An application in bank branches evaluation. *International Journal of Finance & Economics 28*, 4 (2023), 3593-3610.

[17] Omrani, H., Amini, M., and Alizadeh, A. An integrated group best-worst method – Data envelopment analysis approach for evaluating road safety: A case of Iran. *Measurement 152* (2020), 107330.

[18] Rezaei, J. Best-worst multi-criteria decision-making method. *Omega 53* (2015), 49–57.

[19] Saaty, T. L. *The Analytic Hierarchy Process*, McGraw-Hill, New York, 1980.

[20] Tajik, M., Makui, A., and Mansouri, N. Suppliers' evaluation and ranking in telecommunication infrastructure company using the TOPSIS method in an uncertain environment. In *Logistics and Supply Chain Management: 7th International Conference, LSCM 2020, Tehran, Iran, December 23-24, 2020, Revised Selected Papers* , (Cham, 2021), Z. Molamohamadi, E. Babaee Tirkolaee, A. Mirzazadeh and G. W. Weber, Eds., vol. 1458 of *Communications in Computer and Information Science* book series, Springer, pp. 84–99.

[21] Vaidya, O. S., and Kumar, S. Analytic hierarchy process: An overview of applications. *European Journal of Operational Research 169*, 1 (2006), 1–29.

[22] Wen, Y., An, Q., Xu, X., and Chen, Y. Selection of Six Sigma project with interval data: common weight DEA model. *Kybernetes 47*, 7 (2018), 1307–1324.

[23] Yang, H., Kim, S. Y., and Yim, S. A case study of the Korean government's preparation for the fourth industrial revolution: Public program to support business model innovation. *Journal of Open Innovation: Technology, Market, and Complexity 5*, 2 (2019), 35.

[24] Zhao, Z.-Y., Tang, C., Zhang, X., and Skitmore, M. Agglomeration and competitive position of contractors in the international construction sector. *Journal of Construction Engineering and Management 143*, 6 (2017), 04017004.

[25] Zohrehbandian, M., Makui, A., and Alinezhad, A. A compromise solution approach for finding common weights in DEA: An improvement to Kao and Hung's approach. *Journal of the Operational Research Society 61*, 4 (2010), 604–610.