Int. J. Res. Ind. Eng. Vol. 7, No. 3 (2018) 320–335

IJRIE

International Journal of Research in Industrial Engineering

www.riejournal.com

Investment Projects Ranking with DEA Method Considering Feasibility Study Results

M. V. Sebt [1*], M. N. Juybari[2], V. R. Soleymanfar[3]

[1]Department of Industrial Engineering, Faculty Technical-Engineering, Kharazmi University, Tehran, Iran.

[2]Department of Industrial Engineering, Faculty of Engineering, Kharazmi University, Tehran, Iran.

[3]Department of Industrial Engineering, Islamic Azad University, South Tehran Branch, Tehran, Iran.

A B S T R A C T

According to the increasing need of industry to financiers and investors in order to incorporate and encouraging them to invest in various fields of industry, the necessity of a method to help investors for making a decision has emphasized. We present a method which tries to omit to apply personally partial views in making a decision in order to make the results more reliable. This paper focuses on ranking investing opportunities. The strategy which has used is the Data Envelopment Analysis that the 4 main sub-models including Charnes, Cooper & Rhodes (CCR) model, Input Oriented Banker, Charnes & Cooper (BCC) model, Output Oriented BCC model, and Additive model have been utilized. The contribution of this research is using 4 DEA models for ranking projects in terms of feasibility whereas in the similar researches, as what found in the literature, the mentioned models have not been taken into account simultaneously. The developed model is applied in an Iranian investment company which has 15 investment opportunities that we have evaluated and ranked them based on 5 financial indices with DEA mechanism. Our approach can be performed by any investment company or financier to rank their investment projects considering feasibility study results of each investment opportunity.

Keywords: Data envelopment analysis, Investment opportunity, Feasibility study, Ranking.

Article history: *Received: 08 May 2018* *Revised: 09 November 2018* *Accepted: 30 November 2018*

1. Introduction

Investing in financial projects has become an important decision-making problem for financiers and investors in recent years. Based on enhancing advantages and providing safer investing while considering the tradeoff between risk and profit of a project, the most favorable ranking that aims to specify the best choice among several projects has long been an important subject in financial

* Corresponding author

E-mail address: vhd_sebt@yahoo.com

DOI: 10.22105/riej.2018.147016.1058

studies. Managers are always seeking to find a way to improve the performance of their managing organizations, but this improvement is out of reach of managers unless they recognize their own abilities and consider competitor’s strength and weakness points. Investors usually encounter several similar questions which are about the project's priority; they ask ‘what is the order of precedence in project ranking?’ or ‘which projects should be investigated and which not?’ Investors can have a reliable investment with lower risk and higher profit by answering these kinds of questions.

One of the common models for selecting portfolios is the Markowitz model [27]. In fact, this model does not sort projects in order of precedence. The purpose of this paper is to present a mathematical model that helps investors to find the best projects among available projects for investing in. Finally, by using this model they will achieve the maximum available profit. We focus on a subject that is ‘ranking various economic cases and industrial projects in order of precedence by considering the financial and economic indexes’. For achieving and collecting adequate information, fifteen feasibility studies have been checked in different industries that will be introduced in the next section. Furthermore, we consider five indexes to evaluate fifteen alternative choices. In this paper Data Envelopment Analysis (DEA) method is applied for ranking projects in order of precedence. By using this method and its mathematical model, all of the projects are compared with each other by the determined indexes and ranking. With this procedure, the investigator can easily make the decision and find appropriate project(s). Our fifteen sample projects are selected among Iranians economical and industrial projects that are analyzed between 2006 and 2016. Also, to simply visualize the performance of the projects, they are illustrated by a scatter plot and classified into two groups based on a statistical regression trend-line. Finally, an improvement plan is suggested for inefficient projects to enrich their performance. The remainder arrangement of this paper is as follows: Section 0 reviews the literature in both DEA and investing fields and introduces the fundamental and basic principles of model and presents a brief introduction. Section 0 describes the problem while formulating it. Section 0 applies the DEA model in order to rank Decision Making Units (DMU). Section 0 mentions the models deduction and provides a discussion about improvement plans. Section 0 presents the conclusions while recommending the future study suggestions.

2. Literature Review

Mutual funds represent one of the fastest growing types of financial intermediary in the American economy. The question remains as why mutual funds and in particular, actively managed mutual funds have grown so fast when their performance on average have been inferior to that of the index funds [17]. Murthi et al. [31] applied DEA to measure the performance of the mutual funds and they used CCR model to evaluate portfolio performance. In the next study, McMullen and Strong [29] continued Murthy's work and applied BCC model. Nowadays, while developing the prior versions of DEA, this model has been used in some cases, such as ranking and evaluating to help researchers to have a better comparison between alternatives. Galagedera et al. [16]

proposed a two-stage DEA model with leakage variables at stage 1 for assessing the relative performance of decision-making units. The applicability of the proposed model is demonstrated by assessing the performance of a sample of the US mutual fund families over the period 1999–2008 with operational management and portfolio management processes as the two stages of mutual fund operation. They considered Total Cash Flow (TCF) to investors as the leakage variable. Arazmuradov [3] proposed a model that is based on DEA to evaluate the feasibility of the technical efficiency to be used as an ex-ante predictor of debt default risk assessment. Diversified portfolios are recommended by Modern Portfolio Theory (MPT) to reduce an unnecessary risk of portfolios. In this way, Choi and Min [11] provided an alternative portfolio performance measure based on DEA to obtain the return from a portfolio. Wei and Zhijiang [41] analyzed the incremental cost and benefits of the multiple projects in combination with the DEA model in order to determine the efficiency of the decision-making units. Walczak and Rutkowska [40] described the application of fuzzy TOPSIS with a modification for a participatory budget based on an empirical example to order preference based on the similarity to an ideal solution for the personalized ranking of projects in a participatory budget. Aggelopoulos and Georgopoulos [1] and Stoica, et al. [38] applied DEA to measure the efficiency of the bank branches. Also, Ohsato and Takahashi [32] applied a slack-based measure network DEA model to measure the efficiency of bank branches. Hall et al. [19] used a modified slack-based model to examine the evolution of Hong Kong banks' efficiency and to identify factors that affect the banks' scores. Also Yin et al. [46] evaluated the technical efficiency of Chinese banks with stochastic frontier analysis. Tsolas and Charles [39] involved a new factor in measuring bank efficiency, they incorporated risk into bank efficiency by using DEA model.

Some researchers worked on portfolio selection area and used DEA. Wu [42] used a reliable method for evaluating the asset performance, and it was ranked from both self- and peer-evaluation perspectives. Azadeh and Kokabi [4] proposed a Z-number version of the CCR and BCC models that can be applied to a portfolio selection problem to tackle uncertainties. Rębiasz et al. [34] used both probability distributions and fuzzy numbers to propose a framework that enables to consider stochastic dependencies between model parameters and economic dependencies between projects. Also Chen et al. [10] applied fuzzy DEA to analyze bank performance and market risk. Eilat et al. [14] proposed a methodology that is based on DEA model and Balanced Score Card approach to analyze portfolios of R&D projects with interactions. Mashayekhi and Omrani [28] combined DEA cross-efficiency and Markowitz mean-variance model to propose a novel multi objective model for portfolio selection. Also, Lim et al. [25] used DEA cross-efficiency evaluation in portfolio selection. Amiri et al. [2] presented a new method which is integrated by DEA and TOPSIS to evaluate the risk of portfolios. Edirisinghe and Zhang [13] developed a generalized DEA model to analyze the financial statements of a specific firm.

Evaluating a set of alternatives, each defined by its scores on several criteria, is a problem that we commonly encounter in practice. Karasakal and Aker [23, 24] developed the multiple criteria sorting methods based on data envelopment analysis to evaluate Research and Development (R&D) projects. Wu et al. [44] proposed several secondary goal models for weights selection considering both desirable and undesirable cross-efficiency targets of all the Decision Making Units (DMU). Sadeghi and Mohammadzadeh Moghaddam [36] presented a multidimensional method for prioritizing safety retrofit projects. Data envelopment analysis with uncertainty assessment is described to help the decision makers to select the most cost effective projects. Hadad et al. [18] used multi-criteria methods (based on the Analytical Hierarchical Process (AHP), and data envelopment analysis for ranking project activities according to the several ranking indexes. Zhang [47] proposed a systematic decision-making method of bid evaluation based on the fuzzy DEA and gray relation for choosing proper bidders, and Yang et al. [45] used DEA to facilitate the criteria evaluations for each bidder.

The application of data envelopment analysis as a tool for efficiency evaluation has become widespread in the public and private-sector organizations [7]. Carrillo and Jorge [7] proposed a new method for ranking alternatives that use the common-weight DEA under a multi-objective optimization approach. Liu et al. [26] presented an equitable model for efficiency evaluation of decision-making units with undesirable outputs and introduced a technique for cross-efficiency evaluation considering undesirable outputs. Kádárová et al. [22] combined the balanced score card technique with DEA approach to obtain the efficiency management system for industrial companies. In a ‘big data’ environment, Zhu et al. [49] proposed an SBM-DEA model based on natural resource input orientation to evaluate the efficiency of natural resource utilization.

Mostafaeipour et al. [30] proposed a hybrid approach to perform a technical economic feasibility study on the construction of photovoltaic power plants in 14 areas of Khuzestan province in Iran by using a hybrid approach composed of data envelopment analysis, balanced score card and Game theory to rank the selected areas. Ramazankhani et al. [33] studied the potential of different provinces of Iran for producing hydrogen by a water electrolyzer using the electricity generated from a geothermal source. They used the data envelopment analysis method to rank and prioritize the provinces. In comparison between suppliers and selecting the most suitable one to the factory’s needs, Jalalvand et al. [21] developed a method to compare Supply Chains (SCs) of an industry in the scope of supplier’s supplier to customer’s customer. Their method uses data envelopment analysis and PROMETHEE II, a multiple criteria decision-making technique, as tools to compare SCs at the process level, business stage level, and SC level. Cui et al. [12] used DEA to analyze the impacts of the EU ETS emission limits on the airline performance.

To solve some shortages of DEA methods such as dealing with desirable outputs and undesirable outputs and its time consuming to solve lots of constraints when new data arrive, Hu et al. [20] provided an effective solution to overcome some shortages of traditional DEA method by modifying DEA methods and integrating data mining algorithm. Wu et al. [43] proposed a cross-efficiency evaluation approach based on Pareto improvement to resolve weakness of cross efficiency scores. Banker et al. [5] customized an additive DEA model to evaluate fund managers’ efficiency.

A company needs to audit and adjust its business process to improve its 'business of software' day by day. Siok and Tian [37] provided a way, using project metrics and data envelopment analysis for a software organization to perform a comparative analysis of software projects. For recognizing and controlling datasets of a company, the use of an applicable method is more needed because of the generation of a large amount of data. Zhang et al. [48] presented a novel feature selection method, which is based on Class-Separability (CS) strategy and DEA.

According to the reviewed articles, none of the papers considered the investment opportunities ranking. In the present paper, each investment opportunity is identified as a decision making unit. The gathered information is analyzed by applying DEA method. The paper's procedure is illustrated schematically in Figure 1.

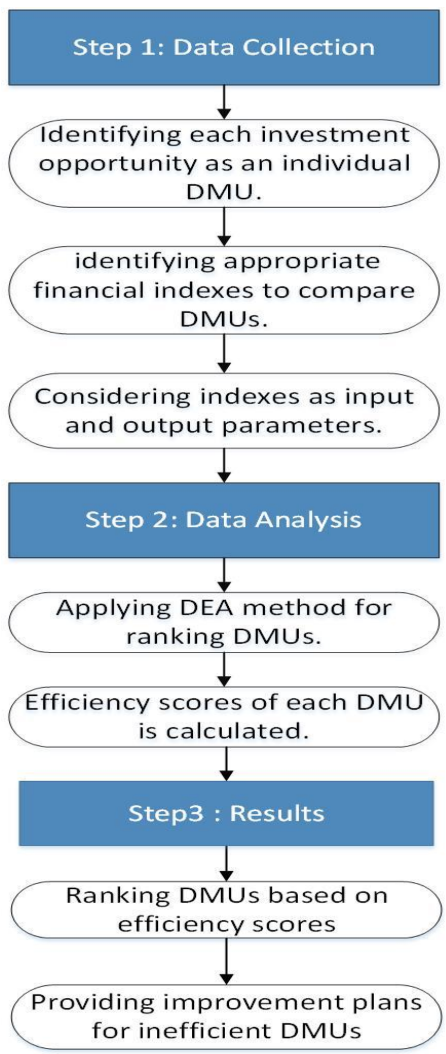

Figure 1. Procedure of Paper.

Researchers have been interested in measuring the efficiency of a production factory. Farrell [15] considered the ratio between one input and one output to measure the Technical Efficiency (TE) of a decision making unit according to Eq. (1).

$$\text{TE}=\frac{output}{input}\,. \tag{1}$$

In some cases, in the real world, there are some DMUs with multiple inputs and outputs as shown in Figure 2, in order to measure the efficiency of these kinds of DMUs. Rhodes [35] and Charnes et al. [9] extended this concept and proposed a new model which consists of the multiple inputs and outputs. The presented model is in Eq. (2).

Figure 2. Role of Inputs and Outputs.

$$\begin{aligned}
&\text{Max } Z_0=\frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}}\\
&\text{s.t.}\\
&\frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}\leq 1 \qquad \forall J=0,1,\dots,n\\
&u_r, v_i \geq 0\,.
\end{aligned} \tag{2}$$

Here, the y_{rj} and x_{ij} are the known outputs and inputs of the jth DMU and the u_r and v_i are the variable weights to be determined by the solution of the model, and Z_0 is the efficiency of DMU under evaluation. The above model is known as CCR model. It tries to maximize the efficiency by calculating the variable weights of special DMU.

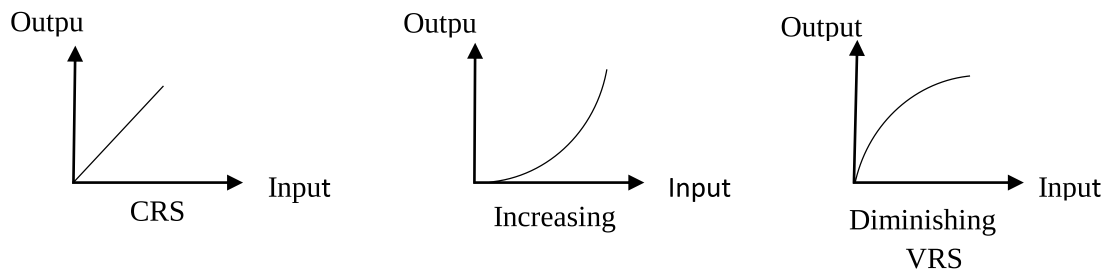

Figure 3. Diagram of Different Kinds of Return to Scale.

'Returns to scale' is one of the most important factors in the comparative assessment of producers. There are two kinds of returns to scale: Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS). In CRS model, inputs and outputs are linearly related to each other and any changes in one of them will not affect DMU's efficiency, but in VRS mode the correlation between inputs and outputs in some cases increases and in other cases diminishes as shown in Figure 3.

Banker et.al [6] developed CCR model and proposed a new model that is known as BCC model. The BCC model is applicable to measure the efficiency of DMU with variable returns to scale:

$$\begin{aligned} & \text{Max } Z_0 = \sum_{r=1}^{s} u_r y_{r0} + w \\ \text{s.t.} \quad & \\ & \sum_{i=1}^{m} v_i x_{i0} = 1 \\ & \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + w \le 0 \qquad \forall j = 1,2,\ldots,n \qquad (3) \\ & \text{W=free variable} \\ & u_r, v_i \ge 0. \end{aligned}$$

Where *w* shows the mode of returns to scale. *w*=0 shows that the model is in CRS mode and negative *w* means that the model is in diminishing VRS mode, and positive *w* indicates that the model is in increasing VRS mode.

The above model tries to maximize the outputs by fixing the inputs, thus this model is known as input oriented BCC model. In our case, by applying this model, we fixed the costs in order to maximize the revenues.

Another approach is to evaluate the efficiency of DMU from outputs viewpoint by fixing the outputs and minimizing the inputs based on Eq. (4).

$$\min\ Z_0 = \sum_{i=1}^{m} v_i x_{i0} + w$$

s.t.

$$\sum_{r=1}^{s} u_r y_{r0} = 1 \qquad (4)$$

$$\sum_{i=1}^{m} v_i x_{ij} - \sum_{r=1}^{s} u_r y_{rj} + w \le 0 \qquad \forall j = 1,2,\dots,n$$

W= free variable

$$u_r, v_i \ge 0.$$

Charnes, et al. [8] proposed an additive model that is also called slack-based model which integrates both input and output orientations. This model tries to reduce inputs and increase outputs simultaneously as follows:

$$\text{Max } Z_0 = \sum_{r=1}^{s} y_{r0} u_r - \sum_{i=1}^{m} x_{i0} v_i + w$$

st:

$$\sum_{r=1}^{s} y_{rj} u_r - \sum_{i=1}^{m} x_{ij} v_i + w \le 0 \quad \forall j = 1,2,\dots,n$$

$$\sum_{r=1}^{s} u_r \ge 1 \qquad (5)$$

$$\sum_{i=1}^{m} v_i \ge 1$$

W= free variable

$$u_r, v_i \ge 0.$$

3. Problem Description and Formulation

Checking and studying the feasibility of financial investment in firms has become a major problem for industrial investors. For this reason, investors are attempting to find a mathematical model to help them to introduce the best opportunities among available choices. Analyzers can’t reach sufficient information by analyzing each investment projects separately, so to find the adequate financial information and projects ranking, a comparative analysis could be a solution of the problem.

To compare DMUs with DEA method, the model needs some indices. We considered five main financial indices among available indices, two as input and three as output indices, which are described below:

- Total investment: The definition of the phrase is the total amount of financial resources that a person or entity either has in a project or must put into a project, including the fixed investment + Networking Capital.
- Annual production cost: Production cost refers to the cost incurred by a business when manufacturing a good or providing a service. Production costs include a variety of expenses including, but not limited to the labor, raw materials, consumable manufacturing supplies, and general overhead. Additionally, any taxes levied by the government or royalties owed by the natural resource-extracting companies are also considered production costs.
- Internal Return Rate (IRR): Internal rate of return is a discount rate that makes the Net Present Value (NPV) of all cash flows from a particular project equal to zero.
- Break-even point: A point in time (or in "number of units sold") when forecasted revenue exactly equals the estimated total costs; where loss ends and profit begins to accumulate.
- Annual profit: Profit is a financial benefit that is realized when the amount of revenue gained from a business activity exceeds the expenses, costs, and taxes needed to sustain the activity. Any profit that is gained goes to the business's owners, who may or may not decide to spend it on the business.

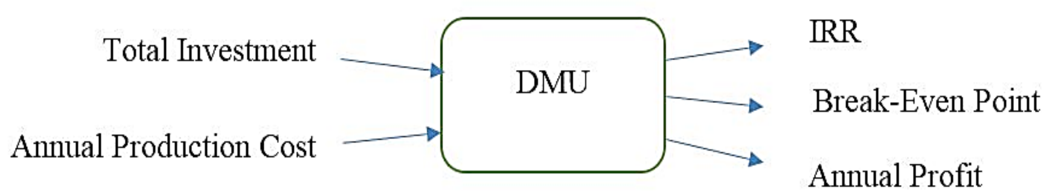

Figure 4. Input and Output Indices.

4. Case Study

DEA method is applied to an Iranian investment company with 15 Iranian investment projects (as investment opportunities) to compare them with each other with some selected indices as inputs and outputs. The projects appear as DMUs of DEA method which are selected from Iran industrial environment. The information of projects is presented in Table 1.

.

Table 1. Raw Data of DMUs.

Code	Scope of Investment project	Input indices		Output indices		
		Total Investment *10^6 (Rials)	Annual Production Cost *10^6 (Rials)	Invest Return Rate (IRR) (%)	Break-even point (%)	Annual Profit (%)
DMU1	Food industries	6175.00	4825.00	51.00	27.70	34.60
DMU2	Food industries	149350.00	354181.00	39.06	24.00	7.20
DMU3	Food industries	423112.61	452278.10	63.75	14.95	28.74
DMU4	Food industries	39581.04	61159.41	66.95	18.50	18.70
DMU5	Food industries	59788.33	660970.60	51.70	48.35	4.14
DMU6	Civil industries	126450.00	106000.00	25.00	45.44	7.83
DMU7	Food industries	123153.40	194327.00	66.30	12.30	28.00
DMU8	Agriculture industries	225306.50	99045.50	0.00	0.00	0.00
DMU9	Piping industries	447748.00	246836.00	36.62	33.91	30.00
DMU10	Agriculture industries	1476.00	218.00	15.80	27.74	45.98
DMU11	Industrial zone	1792078.00	96790.00	35.89	6.00	58.00
DMU12	Agriculture industries	752039.00	95880.00	84.00	1.62	54.00
DMU13	Piping industries	73900.00	179999.00	44.27	12.20	12.70
DMU14	Plastic industries	117115.34	94203.10	30.93	76.00	22.26
DMU15	Piping industries	157291.22	55443.36	45.00	29.81	40.50

We used MATLAB software to solve the model and to find the most efficient investment opportunity. The result of solving the DEA model by all 4 approaches (CCR, Input Oriented BCC, Output Oriented BCC, and Additive Model) is presented in Figure 5.

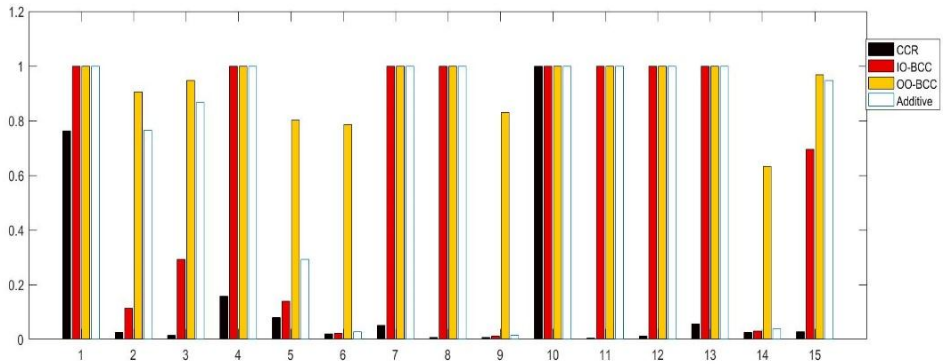

Figure 5. Efficiency of DMUs.

One of the most significant issues in investment project selection is comparing choices with each other. A statistical solution for this issue is using a trend line. A trend line is a straight or curved line on a graph that represents the current general direction of variables seems to be heading. We select 'annual profit' as output factor and 'total investment' as input factor to analyze DMUs in single input and single output mode. Figure 6 shows DMUs' general pattern in a trend chart.

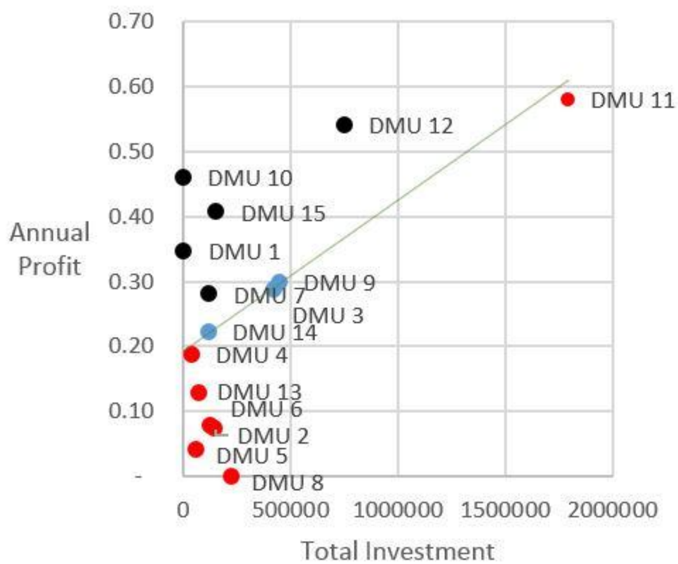

Figure 6. Trend Chart of DMUs.

According to Figure 6, DMUs are categorized into two classes: Inefficient DMUs are below the trend line and efficient DMUs are top of the trend line. Each DMU's position is comparable and we can suggest improving plans for inefficient DMUs.

6. Results and Discussions

Thus, for making a decision, the average of each DMU's efficiency based on four approaches is shown in Figure 7. According to Figure 7 'DMU10' is the most efficient opportunity for investor. DMUs ranking is presented in Table 2.

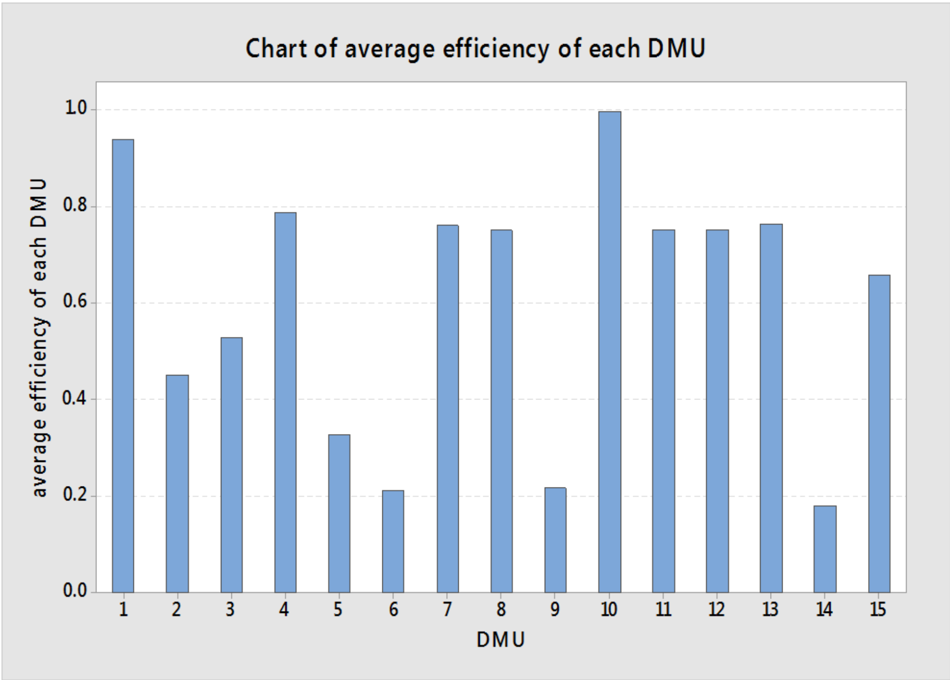

Figure 7. Average Efficiency of each DMU.

Table 2. Ranking of DMUs.

Rank	Name of DMU	Average of efficiency
1	DMU10	1.0000
2	DMU 1	0.9405
3	DMU 4	0.7891
4	DMU 13	0.7637
5	DMU 7	0.7623
6	DMU 12	0.7530
7	DMU 8	0.7520
8	DMU 11	0.7513
9	DMU 15	0.6587
10	DMU 3	0.5301

Rank	Name of DMU	Average of efficiency
11	DMU 2	0.4522
12	DMU 5	0.3282
13	DMU 9	0.2162
14	DMU 6	0.2132
15	DMU 14	0.1812

As we mentioned in the previous section, by considering Figure 6, we can propose an improved plan for inefficient DMUs. The novelty of this article comes in Figure 8, where an improvement plan is devised for those inefficient DMUs. For example, for DMU 11 there is two improve plans: First is to increase its annual profit by fixing total investment and second is decreasing its total investment by fixing annual profit to reach the trend line as shown in Figure 8.

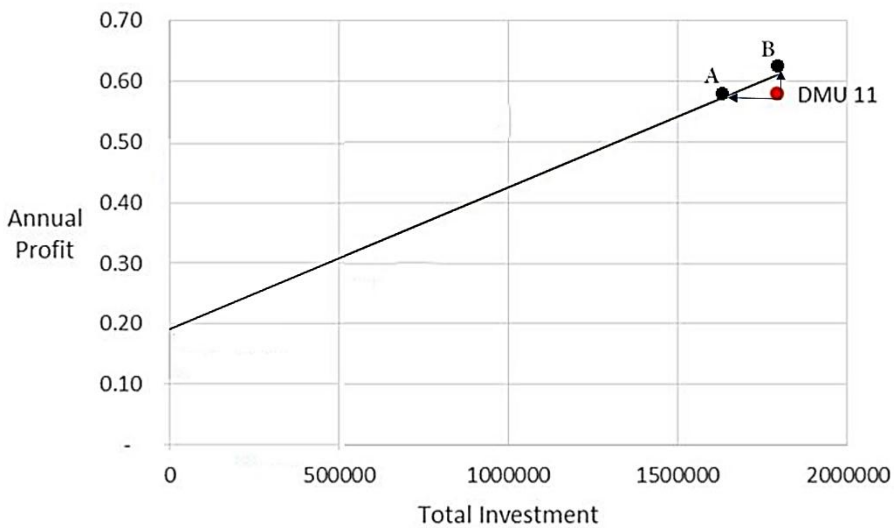

Figure 8. Improved State of DMU 11.

In a case of improvement, ‘A’ or ‘B’ would be the improved state of DMU 11.

Data envelopment analysis is a mathematical linear programming model which is a powerful tool in helping managers for making the decision. DEA is capable in rating and ranking organizations and finding their weakness and strength points by measuring technical efficiency. Hence we used this mathematical model to compare investment projects by considering several factors to guide investors to the best choice.

7. Conclusion

In this paper, we attempted to invent a new model to solve decision-making problems in financial investment field by DEA mechanism. According to the presented financial indices, investment opportunities are ranked based on preference. The 15 investment opportunities which were selected from an Iranian investment company were considered as Decision Making Units (DMU) and ranked by four different methods of DEA mechanisms such as (CCR, input oriented BCC, output oriented BCC, and additive model) and based on five indices (including total investment, annual production cost, internal return rate, break-even point, and annual profit). As a result, the 10th DMU was identified as the most efficient opportunity to invest in. This study was based on the particular decision-making units and specific decision factors but in general, this paper's approach can be applied for any investment projects selection problems to have a unique investment model for each special investment company or financier. The presented idea can be a foundation for investors who want to select the most desirable investment opportunities among several feasible studies and can guide them to the best choice. By illustrating pattern graph of DMUs in trend chart, each DMU's position was determined and according to inefficient DMU's position, some improve plans were offered to convert them into an efficient one. Our suggestion for future study is a mathematical model which considers budget and time limitations and handling them while trying to rank investment projects in order to offer sufficient projects.

References

[1] Aggelopoulos, E., & Georgopoulos, A. (2017). Bank branch efficiency under environmental change: A bootstrap DEA on monthly profit and loss accounting statements of Greek retail branches. *European journal of operational research*, *261*(3), 1170–1188.

[2] Amiri, M., Zandieh, M., Vahdani, B., Soltani, R., & Roshanaei, V. (2010). An integrated eigenvector–DEA–TOPSIS methodology for portfolio risk evaluation in the FOREX spot market. *Expert systems with applications*, *37*(1), 509–516.

[3] Arazmuradov, A. (2016). Assessing sovereign debt default by efficiency. *Journal of economic asymmetries*, *13*, 100–113.

[4] Azadeh, A., & Kokabi, R. (2016). Z-number DEA: A new possibilistic DEA in the context of Z-numbers. *Advanced engineering informatics*, *30*(3), 604–617.

[5] Banker, R., Chen, J. Y. S., & Klumpes, P. (2016). A trade-level DEA model to evaluate relative performance of investment fund managers. *European journal of operational research*, *255*(3), 903–910.

[6] Banker, R. D., Charnes, A., & Cooper, W. W. (1984). Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Management science*, *30*(9), 1078-1092.

[7] Carrillo, M., & Jorge, J. M. (2016). A multiobjective DEA approach to ranking alternatives. *Expert systems with applications*, *50*, 130–139.

[8] Charnes, A., Cooper, W. W., Golany, B., Seiford, L., & Stutz, J. (1985). Foundations of data envelopment analysis for Pareto-Koopmans efficient empirical production functions. *Journal of econometrics*, *30*(1), 91–107.

[9] Charnes, A., Cooper, W. W., & Rhodes, E. (1979). Measuring the efficiency of decision-making units. *European journal of operational research*, *3*(4), 339.

[10] Chen, Y. C., Chiu, Y. H., Huang, C. W., & Tu, C. H. (2013). The analysis of bank business performance and market risk—applying fuzzy DEA. *Economic modelling*, *32*, 225-232.
[11] Choi, H. S., & Min, D. (2017). Efficiency of well-diversified portfolios: Evidence from data envelopment analysis. *Omega*, *73*, 104-113.
[12] Cui, Q., Wei, Y. M., & Li, Y. (2016). Exploring the impacts of the EU ETS emission limits on airline performance via the dynamic environmental DEA approach. *Applied energy*, *183*, 984–994.
[13] Edirisinghe, N. C. P., & Zhang, X. (2007). Generalized DEA model of fundamental analysis and its application to portfolio optimization. *Journal of banking & finance*, *31*(11), 3311–3335.
[14] Eilat, H., Golany, B., & Shtub, A. (2006). Constructing and evaluating balanced portfolios of R&D projects with interactions: A DEA based methodology. *European journal of operational research*, *172*(3), 1018–1039.
[15] Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the royal statistical society. Series A (General)*, *120*(3), 253-290.
[16] Galagedera, D. U., Watson, J., Premachandra, I. M., & Chen, Y. (2016). Modeling leakage in two-stage DEA models: An application to US mutual fund families. *Omega*, *61*, 62-77.
[17] Gruber, M. J. (2011). Another puzzle: The growth in actively managed mutual funds. *Investments and portfolio performance* (pp. 117-144).
[18] Hadad, Y., Keren, B., & Laslo, Z. (2016). Multi-criteria methods for ranking project activities. *Yugoslav journal of operations research*, *26*(2), 201–219.
[19] Hall, M. J. B., Kenjegalieva, K. A., & Simper, R. (2012). Environmental factors affecting Hong Kong banking: A post-Asian financial crisis efficiency analysis. *Global finance journal*, *23*(3), 184–201.
[20] Hu, Z., Yang, J., Wang, S., & Yang, Q. (2016). A hybrid modified DEA efficient evaluation method in electric power enterprises. *3rd international conference on informative and cybernetics for computational social systems (ICCSS)*(pp. 283–287). Department of Enterprise Management, Guangdong Power Grid Corporation, Guangzhou, China: Institute of Electrical and Electronics Engineers Inc.
[21] Jalalvand, F., Teimoury, E., Makui, A., Aryanezhad, M. B., & Jolai, F. (2011). A method to compare supply chains of an industry. *Supply chain management*, *16*(2), 82–97.
[22] Kádárová, J., Durkáčová, M., Teplická, K., & Kádár, G. (2015). The proposal of an innovative integrated BSC – DEA model. *Procedia economics and finance*, *23*, 1503–1508.
[23] Karasakal, E., & Aker, P. (2017). A multicriteria sorting approach based on data envelopment analysis for R&D project selection problem. *Omega*, *73*, 79-92.
[24] Köksalan, M., & Bilgin Özpeynirci, S. (2009). An interactive sorting method for additive utility functions. *Computers & operations research*, *36*(9), 2565–2572.
[25] Lim, S., Oh, K. W., & Zhu, J. (2014). Use of DEA cross-efficiency evaluation in portfolio selection: An application to Korean stock market. *European journal of operational research*, *236*(1), 361–368.
[26] Liu, X., Chu, J., Yin, P., & Sun, J. (2017). DEA cross-efficiency evaluation considering undesirable output and ranking priority: A case study of eco-efficiency analysis of coal-fired power plants. *Journal of cleaner production*, *142*, *Part*, 877–885.
[27] Markowitz, H. (1952). Portfolio selection. *The journal of finance*, *7*(1), 77-91.
[28] Mashayekhi, Z., & Omrani, H. (2016). An integrated multi-objective Markowitz–DEA cross-efficiency model with fuzzy returns for portfolio selection problem. *Applied soft computing*, *38*, 1–9.
[29] McMullen, P. R., & Strong, R. A. (1998). Selection of mutual funds using data envelopment analysis. *The journal of business and economic studies*, *4*(1), 1.
[30] Mostafaeipour, A., Qolipour, M., & Mohammadi, K. (2016). Evaluation of installing photovoltaic plants using a hybrid approach for Khuzestan province, Iran. *Renewable and sustainable energy reviews*, *60*, 60–74.
[31] Murthi, B. P. S., Choi, Y. K., & Desai, P. (1997). Efficiency of mutual funds and portfolio performance measurement: A non-parametric approach. *European journal of operational research*, *98*(2), 408-418.

[32] Ohsato, S., & Takahashi, M. (2015). Management efficiency in japanese regional banks: A Network DEA. *Procedia-social and behavioral sciences*, *172*, 511–518.
[33] Ramazankhani, M. E., Mostafaeipour, A., Hosseininasab, H., & Fakhrzad, M. B. (2016). Feasibility of geothermal power assisted hydrogen production in Iran. *International journal of hydrogen energy*, *41*(41), 18351-18369.
[34] Rębiasz, B., Gawel, B., & Skalna, I. (2017). Hybrid framework for investment project portfolio selection. *Studies in computational intelligence*.
[35] Rhodes, E. (1978). *DEA and related approaches for measuring the efficiency of decision making units with an application to program follow through in US education* (Doctoral dissertation, Ph. D. Thesis, Carnegie Mellon University).
[36] Sadeghi, A., & Mohammadzadeh Moghaddam, A. (2016). Uncertainty-based prioritization of road safety projects: An application of data envelopment analysis. *Transport policy*, *52*, 28–36.
[37] Siok, M. F., & Tian, J. (2011). Benchmarking embedded software development project performance. *13th IEEE international symposium on high assurance systems engineering (HASE)* (pp. 277–284). Lockheed Martin Aeronautics Company, Fort Worth, TX, United States.
[38] Stoica, O., Mehdian, S., & Sargu, A. (2015). The impact of internet banking on the performance of romanian banks: DEA and PCA approach. *Procedia economics and finance*, *20*, 610–622.
[39] Tsolas, I. E., & Charles, V. (2015). Incorporating risk into bank efficiency: A satisficing DEA approach to assess the Greek banking crisis. *Expert systems with applications*, *42*(7), 3491–3500.
[40] Walczak, D., & Rutkowska, A. (2017). Project rankings for participatory budget based on the fuzzy TOPSIS method. *European journal of operational research*, *260*(2), 706–714.
[41] Wei, L., & Zhijiang, W. (2016). Cost - benefit analysis of green building based on input - output theory. *Revista de la facultad de ingenieria*, *31*(10), 213–221.
[42] Wu, D. (2017). Robust decision support system for asset assessment and management. *IEEE systems journal*, *11*(3), 1486-1491.
[43] Wu, J., Chu, J., Sun, J., & Zhu, Q. (2016). DEA cross-efficiency evaluation based on Pareto improvement. *European journal of operational research*, *248*(2), 571–579.
[44] Wu, J., Chu, J., Sun, J., Zhu, Q., & Liang, L. (2016). Extended secondary goal models for weights selection in DEA cross-efficiency evaluation. *Computers & industrial engineering*, *93*, 143–151.
[45] Yang, J. B., Wang, H. H., Wang, W. C., & Ma, S. M. (2016). Using data envelopment analysis to support best-value contractor selection. *Journal of civil engineering and management*, *22*(2), 199-209.
[46] Yin, H., Yang, J., & Mehran, J. (2013). An empirical study of bank efficiency in China after WTO accession. *Global finance journal*, *24*(2), 153–170.
[47] Zhang, Y. (2015). Research on decision-making method of bid evaluation for engineering projects based on fuzzy DEA and grey relation. *Open cybernetics and systemics journal*, *9*(1), 711–718.
[48] Zhang, Y., Yang, C., Yang, A., Xiong, C., Zhou, X., & Zhang, Z. (2015). Feature selection for classification with class-separability strategy and data envelopment analysis. *Neurocomputing*, *166*, 172–184.
[49] Zhu, Q., Wu, J., Li, X., & Xiong, B. (2017). China's regional natural resource allocation and utilization: A DEA-based approach in a big data environment. *Journal of cleaner production*, *142*, *part*, 809–818.