An efficient algorithm for project selection problem: An application on information system management

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Abstract
One of the many important decisions organizations must make is project selection. Every project includes an initial plan to run, but not every plan can be implemented as a project. In situations where they lack resources or funds, all different plans must first be able to assess profitability in an accurate way, leading to the selection of a combination of proposals to carry out as projects. In this paper, we develop a new project selection method based on a common set of weight Data Envelopment Analysis (DEA) model. An important advantage of our method is that by solving only one model, the most efficient bundle of plans is selected so that maximum use is made of resources, and the other is a non-computationally expensive method. Finally, the new method is applied to 18 Iranian Ministry of Commerce' data in 2014.
Keywords:
Data envelopment analysis, common set of weights, goal programming, project selection.

1. Introduction

In any organization, the utilization of the most appropriate method, or methods, of project selection is significant, especially when considering the goals of the organization. This process is what will ultimately define the projects that will be carried out. There are many different project selection methods used by modern organizations, all with different features and characteristics, it should be noted that the mathematical approaches commonly used for larger projects require several calculations in order to conclude whether or not a project should be selected. Considering limited available resources, such as equipment, human resources, budgets, and location, the strategy by which the optimal plan is selected is critical. Literature reviews show vast research on the topic of project selection that use widely different methods and criteria (see [1-9]).

Data envelopment analysis (DEA) is a data oriented, non-parametric technique, which is extensively adopted in the problem of evaluating a group of decision-making units (DMUs) [10]. In recent decades, this method has gained an extensive catalog of research in the mathematical programming field. Factually, the DEA method has become popular for efficient analyses in the practical projects of economy, management, education and many other fields. Despite the vast applicability of DEA, investigations have been made into various analysis problems, primarily in regards to location selection. [11] proposed a decision support system for the efficient location of offices offering government services. The proposed system incorporated numerous factors, such as branch office efficiencies, budget restrictions, capacity limitations for processing transactions, and demand requirements for designing an efficient service system. [12] presented a model which combines DEA and location analysis in order to maximize the accessibility, the utilization and the mean efficiency of the selected locations. In order to determine optimal and efficient facility location/allocation patterns, [13] proposed multiple objective models that considered tolerance variables using goal programming approach. [14] used a combination of DEA and knapsack models to propose a prioritization model for project evaluation and selection. In their method, it is assumed that individual projects are independent, neither synergistic nor interfering and that the total outputs and inputs of selected projects are the sum of the individual outputs and inputs. [15] discussed the specific problem of selecting a portfolio of projects that achieves an organization's objectives without exceeding limited capital resources.

Reviewing the customary project selection methods based on DEA, it can be seen that the most common primary goal is the selection of plans that maximize outputs without consideration of potentially inefficient output to input ratios. Due to this weakness, the main purpose of the current paper is to develop a new project selection DEA method which not only has a low operating volume but one that also selects the most efficient combination of plans.

The overall content of the paper is as follows: Section 2 presents the basics of the DEA method. In Section 3, the new model is presented (selecting the most efficient bundle of plans by a central organization where there are limited resources at hand). The applicability of the proposed model on data from the Iranian Ministry of Commerce is shown in Section 4, followed by conclusions and remarks in Section 5.

2. DEA preliminaries

To describe the DEA efficiency measurement, let there is a set of n peer DMUs, which each DMU$_j$; $j \in J = \{1, \dots, n\}$

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produces an output vector $\boldsymbol{y}_j = (y_{1j}, \ldots, y_{sj})$ by utilizing the input vector $\boldsymbol{x}_j = (x_{1j}, \ldots, x_{mj})$. Also, $\boldsymbol{x}_j \geq 0$ and $\boldsymbol{y}_j \geq 0$ for all $j \in J$. The efficiency measure for DMU_o; $o \in J$ is defined as

$$\mathrm{E}_o = \frac{u_1 y_{1o} + u_2 y_{2o} + \cdots + u_s y_{so}}{v_1 x_{1o} + v_2 x_{2o} + \cdots + v_m x_{mo}}$$

where the weights u_r and v_i are positive. To assess DMU_o, we solve the following DEA model [16]:

$$\begin{aligned} & max \quad \frac{\sum_{r=1}^{s} u_r\, y_{ro}}{\sum_{i=1}^{m} v_i\, x_{io}} \\ & s.t. \\ & \frac{\sum_{r=1}^{s} u_r\, y_{rj}}{\sum_{i=1}^{m} v_i\, x_{ij}} \leq 1 && \forall j \\ & v_i \geq \varepsilon && \forall i \\ & u_r \geq \varepsilon && \forall r \end{aligned} \tag{1}$$

where $\varepsilon > 0$ is an infinitesimal value to avoid vanishing the weights. This linear fractional programming problem can be reduced to a non-ratio format in the usual manner of [16]. Specifically, making the transformation $\sum_{i=1}^{m} v_i\, x_{io} = 1$, model can be expressed in the form:

$$\begin{aligned} & \max \quad \sum_{r=1}^{s} u_r\, y_{ro} \\ & \text{s.t.} \\ & \sum_{i=1}^{m} v_i\, x_{io} = 1 \\ & \sum_{r=1}^{s} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} \leq 0 && \forall j \\ & v_i \geq \varepsilon && \forall i \\ & u_r \geq \varepsilon && \forall r \end{aligned} \tag{2}$$

The efficiency ratio ranges between zero and one, with DMU_o being considered relatively efficient if it receives a score of one.

As can be seen by solving model (2), consideration of the initial weight is not required and, in the result, the best input and output weights of each DMU are achieved, garnishing a higher efficiency. In this way, the related efficiency of each DMU calculated is higher than the actual real value. To overcome this difficulty, the following model, which determines a set of optimal weights for all DMUs, is proposed:

$$\begin{aligned} & max \quad \left\{ \frac{\sum_{r=1}^{s} u_r\, y_{r1}}{\sum_{i=1}^{m} v_i\, x_{i1}}, \frac{\sum_{r=1}^{s} u_r\, y_{r2}}{\sum_{i=1}^{m} v_i\, x_{i2}}, \ldots, \frac{\sum_{r=1}^{s} u_r\, y_{rn}}{\sum_{i=1}^{m} v_i\, x_{in}} \right\} \\ & s.t. \\ & \frac{\sum_{r=1}^{s} u_r\, y_{rj}}{\sum_{i=1}^{m} v_i\, x_{ij}} \leq 1 && \forall j \\ & v_i \geq \varepsilon && \forall i \\ & u_r \geq \varepsilon && \forall r \end{aligned} \tag{3}$$

The aim of this model is to determine a common set of weights to get the highest efficiency of all DMUs simultaneously. Model (3) is a Multiple Objective Problem. There are various approaches to solving this model (see [17]). [18] introduced a common set of weight approach to linearize model (3) using a goal programming approach, which minimizes the sum of deviations from the efficiency level, is one applicable approach. This model is as follows:

$$\begin{aligned} & \min \quad \sum_{j=1}^{n} \varphi_j \\ & \text{s.t.} \\ & \sum_{r=1}^{s} u_r\, y_{rj} - \sum_{i=1}^{m} v_i\, x_{ij} + \varphi_j = 0 && \forall j \\ & \varphi_j \geq 0 && \forall j \\ & v_i \geq \varepsilon && \forall i \\ & u_r \geq \varepsilon && \forall r \end{aligned} \tag{4}$$

Suppose (u^*, v^*, φ^*) is an optimal solution of model (4), then the efficiency score of DMU_j can be calculated using the following expression:

$$\theta_j^* = \frac{\sum_{r=1}^{s} u_r^*\, y_{rj}}{\sum_{i=1}^{m} v_i^*\, x_{ij}} = 1 - \frac{\varphi_j^*}{\sum_{i=1}^{m} v_i^*\, x_{ij}},\ j = 1, \ldots, n \tag{5}$$

3. Proposed mathematical model

Organizations encounter numerous proposals for potential implementation and operation. Considering the aim of the organizations, not every proposal can be chosen as an operational project. In situations where there is a lack of resources or funding, all different plans must first be able to accurately assess profitability followed by a combination of the proposals selected to be carried out as projects. It is assumed that all proposals are homogeneous, i.e. all inputs and outputs of plans are similar in terms of type and number; in such, each proposal is assumed as a decision-making unit. Consider a set of n proposals as n DMUs, where each DMU_j; $j \in J$ produces the output vector $\boldsymbol{y}_j = (y_{1j}, \ldots, y_{sj})$ while consuming the input vector $\boldsymbol{x}_j = (x_{1j}, \ldots, x_{mj})$. In addition, a positivity assumption is also considered. project can be implemented with only the remaining resources. The integer variable is defined as $k_j \in \{0,1\}$, equating to 1 if the jth proposal is chosen to be run in the optimal solution. Next, it is assumed b_i is the available amount of ith resource. So, we consider $\sum_{j=1}^{n} k_j x_{ij} \leq b_i \; for \; all \; i = 1, \dots, m$ as the resource limitation constraints.

To exhibit the primary contribution of this paper, we first consider a simple example in two-dimension space. Input and output data corresponding to five DMUs are given in Table 1. Here, a set of appropriate projects must be selected among these five proposals so that, at most, 15 units of resources are used in total, i.e. $\sum_{j=1}^{5} k_j x_{ij} \leq 15$. Accordingly, there are four possible selections ($S_t; t = 1, \dots, 4$). In Table1, the selected DMUs and their corresponding relative efficiencies ($E_t; t = 1, \dots, 4$) are shown in columns entitled "S" and "E", respectively. The number 1 shows the selected DMUs.

Table1: Example in the two-dimensional space

			S_1		S_2		S_3		S_4	
	Input	Output	k_j	E_1	k_j	E_2	k_j	E_3	k_j	E_4
DMU_1	8	15	1	0.73	1	0.63	0	-	0	-
DMU_2	7	18	1	1	0	-	1	0.90	0	-
DMU_3	3	9	0	-	1	1	1	1	1	1
DMU_4	4	12	0	-	1	1	1	1	0	-
DMU_5	12	13	0	-	0	-	0	-	1	0.36
sum				1.73		2.63		2.90		1.36

After evaluating each specific set separately, the set having the highest total efficiency can be chosen. In this example, the set "S_3" is considered the optimal set. It can be seen that for cases with large data sets, due to the large number of possible selections, the process requires a large number of calculations.

To escape this difficulty, we present a method by which the most efficient bundle of plans is selected through solving only one MIP selection model.

As noted earlier, projects should be selected so that maximum use is made of resources. In Due to this, the remaining resources ($b_i - \sum_{j=1}^{n} k_j x_{ij} \; ; i = 1, \dots, m$) cannot be used to further project(s). Accordingly, for each DMU which is not selected in the optimality, i.e. $k_j = 0$, at least one of the following resource constraints must be violated:

$$b_i - \sum_{j=1}^{n} k_j x_{ij} \geq (1 - k_j) x_{ij}, \quad i = 1, \dots, m \qquad (6)$$

In other words, in expression (7) the value of free variables, s_{ij} , corresponds to at least one constraint being negative:

$$b_i - \sum_{l=1}^{n} k_l x_{il} - s_{ij} = (1 - k_j) x_{ij}, \quad i = 1, \dots, m, \; j = 1, \dots, n \qquad (7)$$

It should be noted that if $k_j = 1$, then all slacks of constraints (7) are non-negative. To guarantee the maximum use of resources, the two following constraints must be considered:

$$\bar{M}(f_{ij} - 1) \leq s_{ij} \leq \bar{M} f_{ij} - \bar{\varepsilon}, \quad i = 1, \dots, m, \; j = 1, \dots, n \qquad (8)$$

$$\sum_{i=1}^{m} (1 - f_{ij}) \geq 1 - k_j, \qquad j = 1, \dots, n \qquad (9)$$

where parameters $\bar{\varepsilon}$ and $\bar{M}$ are assumed infinitesimal and infinite, respectively, and f_{ij} ($i = 1, \dots, m; \; j = 1, \dots, n$) as binary variables.

As shown, expression (8) leads to $f_{ij} = 1$ and $f_{ij} = 0$ for every non-negative value and negative value of s_{ij} , respectively. Also, the constraints (9) satisfy at least one negative value of s_{ij} for every unselected DMU_j.

After primary explanations, in brief, the goal is to find $S^* = \{\mathrm{DMU}_j | k_j^* = 1\}$ as the most efficient set of all possible selections so as to maximize the use of the available resources. Thus, we modify model (2) and present the following model:

$$
\begin{aligned}
& max\left\{k_1\left(\frac{\sum_{r=1}^{s}u_r y_{r1}}{\sum_{i=1}^{m}v_i x_{i1}}\right), k_2\left(\frac{\sum_{r=1}^{s}u_r y_{r2}}{\sum_{i=1}^{m}v_i x_{i2}}\right), \dots, k_n\left(\frac{\sum_{r=1}^{s}u_r y_{rn}}{\sum_{i=1}^{m}v_i x_{in}}\right)\right\} && && \\
& s.t. && && \\
& k_j\left(\frac{\sum_{r=1}^{s}u_r y_{rj}}{\sum_{i=1}^{m}v_i x_{ij}}\right) \le 1 && \forall j && \\
& \sum_{j=1}^{n} k_j x_{ij} \le b_i && \forall i && (a) \\
& b_i - \sum_{l=1}^{n} k_l x_{il} - s_{ij} = (1-k_j)x_{ij} && \forall i, \forall j && (b) \\
& \bar{M}(f_{ij}-1) \le s_{ij} \le \bar{M} f_{ij} - \bar{\varepsilon} && \forall i, \forall j && (c) \qquad (10) \\
& \sum_{i=1}^{m}(1-f_{ij}) \ge 1-k_j && \forall j && (d) \\
& k_j \in \{0,1\} && \forall j && (e) \\
& f_{ij} \in \{0,1\} && \forall i, \forall j && (f) \\
& v_i \ge \varepsilon && \forall i && \\
& u_r \ge \varepsilon && \forall r &&
\end{aligned}
$$

In fact, four constraints (10.a) - (10.d) are regarded as possible selection constraints. Model (10), as a fractional model, can be converted to the following non-fractional model using the transformations used by [18].

$$
\begin{aligned}
& \min \ \sum_{j=1}^{n}\varphi_j && \\
& \text{s.t.} && \\
& \sum_{r=1}^{s} k_j u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} + \varphi_j = 0 && \forall j \\
& \varphi_j \ge 0 && \forall j \qquad (11) \\
& v_i \ge \varepsilon && \forall i \\
& u_r \ge \varepsilon && \forall r \\
& (10.a) - (10.f) &&
\end{aligned}
$$

Model (11) does not satisfy our goals because the binary variables, k_j, were found to multiply the output weights. So, in order to negate the effect of DMUs which are not selected on inputs weights, we alter model (11):

$$
\begin{aligned}
& \min \ \sum_{j=1}^{n}\varphi_j && \\
& \text{s.t.} && \\
& \sum_{r=1}^{s} k_j u_r y_{rj} - \sum_{i=1}^{m} k_j v_i x_{ij} + \varphi_j = 0 && \forall j \\
& \varphi_j \ge 0 && \forall j \qquad (12) \\
& v_i \ge \varepsilon && \forall i \\
& u_r \ge \varepsilon && \forall r \\
& (10.a) - (10.f) &&
\end{aligned}
$$

Model (12) is a nonlinear, mixed integer program. Solving these models is not straightforward, therefore the model is converted to a mixed integer programming model, defining the new variables u_{rj} and v_{ij} so that

$$u_{rj} = k_j u_r, \ \ v_{ij} = k_j v_i, \quad r = 1, \dots, s; i = 1, \dots, m; j = 1, \dots, n$$

Then, model (12) can be converted to the following MIP model,

$$
\begin{aligned}
& \min \ \sum_{j=1}^{n}\varphi_j && && \\
& \text{s.t.} && && \\
& \sum_{r=1}^{s} u_{rj} y_{rj} - \sum_{i=1}^{m} v_{ij} x_{ij} + \varphi_j = 0 && \forall j && \\
& \sum_{r=1}^{s} u_{rj} - \sum_{i=1}^{m} v_{ij} + \varphi_j \le M k_j && \forall j && (a) \\
& u_{rj} - u_{rl} \le (2 - k_j - k_l)M && \forall r, \forall j, \forall l && (b) \\
& v_{ij} - v_{il} \le (2 - k_j - k_l)M && \forall i, \forall j, \forall l && (c) \qquad (13) \\
& \varphi_j \ge 0 && \forall j && \\
& \varepsilon k_j \le u_{rj} \le M k_j && \forall j, \ \forall i && \\
& \varepsilon k_j \le v_{ij} \le M k_j && \forall j, \forall r && \\
& (10.a) - (10.f) && &&
\end{aligned}
$$

Where M is an adequate big number. Details on these constraints are stated in the next three cases:

i) Constraints (13.b) and (13.c) are written in order to assure similar weights for every selected DMUs, i.e.:

If $j \neq l$ and $k_j = k_l = 1$, then from constrains (13.b) we have $u_{rj} \le u_{rl}$ and $u_{rj} \ge u_{rl}$ therefore $u_{rj} = u_{rl}$.

ii) Constraints (13.a) convey that an unselected DMU couldn't affect the

input/output weights and also the objective function, i.e.:
If $k_j = 0$ and $k_l = 1$ then we have u_{rj}=0 from constrains (13.a) and redundant constraints $-u_{rl} \leq M$ and $u_{rl} \leq M$ are resulted from constraints (13.b). The case $k_j = 1$ and $k_l = 0$ is similar.

iii) If $j \neq l$ and $k_j = k_l = 0$, then constraints (13.a) and (13.b) result $M \geq 0$ and $u_{rj} = u_{rl} = 0$.

The same cases exist for constraints (13.c).

It must be noted that model (13) without possible selection constraints (13.a) - (13.f) are not able to select the desired bundle, since every k_j gets zero value.

4. Application

The task of project selection with consideration given to the intended budget is the responsibility of the manager of the information system (IS) at the Iranian Ministry of Commerce. The budgets of the various areas cannot be easily allocated to different sectors. Due to this limitation, the primary focus is on project selection and implementation that accounts for budgeting limits and resources utilization efficiency. To select the most efficient bundle of plans, different criteria, such as quality factor, must be included in the assessment. The IS department of Iranian Ministry of Commerce utilizes a group, consisting of several experts in the field of IS and software engineering. To ensure a comprehensive evaluation is performed, these experts develop a set of criteria and estimates for each project. Accordingly, Table 1 lists six criteria to consider in evaluating projects.

Table 2. The list of criteria as input and output index

	Variable
Inputs	x_1: Software Cost
	x_2: Training Cost
	x_3: Support Cost
	x_4: Potential Risk
Outputs	y_1: Time Reduction
	y_2: Improvement Management

Table 2 reports the amounts of inputs and outputs estimated by specialists in 18 under-investigation projects in 2014. Resource limitation and efficiency for each plan is computed by model (4) and expression (5), as shown in the last column. It should be noted that in this case there is no limit to the amount of potential risk, but given a sufficiently large upper bound, for example, the sum of numbers of risk column is acceptable.

Table3: Estimated criteria in evaluating of IS Projects

IS	Inputs				Outpu		Efficien
	x_1	x_2	x_3	x_4	y_1	y_2	
1	4764	40	98	8	2	7	0.36
2	3552	95	85	8	1	7	0.31
3	4813	154	7	8	2	8	0.33
4	2327	75	32	4	2	6	0.7
5	2864	83	56	5	8	9	0.31
6	1714	150	33	9	2	8	1
7	1020	57	16	4	1	7	1
8	2010	153	83	8	1	9	0.7
9	2834	197	92	8	2	9	0.57
10	2100	172	79	4	8	1	0.24
11	3436	39	68	6	3	8	0.67
12	5092	167	37	5	3	7	0.43
13	4585	57	50	4	1	3	0.18
14	1801	36	62	1	2	2	1
15	5478	34	62	5	1	6	0.18
16	1042	118	59	7	1	1	0.82
17	5175	197	52	7	3	6	0.41
18	3083	32	68	6	1	9	0.35
Availabl	1400	100	70	10			

Table 4. The computational results of the selection model (13).

IS	Inputs				Outpu		Efficien
	x_1	x_2	x_3	x_4	y_1	y_2	
1	-	-	-	-	-	-	-
2	-	-	-	-	-	-	-
3	-	-	-	-	-	-	-
4	-	-	-	-	-	-	-
5	286	83	56	5	8	9	0.31
6	171	15	33	9	2	8	1
7	102	57	16	4	1	7	1
8	201	15	83	8	1	9	0.7
9	-	-	-	-	-	-	-
10	210	17	79	4	8	1	0.24
11	-	-	-	-	-	-	-
12	-	-	-	-	-	-	-
13	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-
16	104	11	59	7	1	1	0.82
17	-	-	-	-	-	-	-
18	308	32	68	6	1	9	0.35

Remain	167	26	37	6

The results of selection model (13) are reported in Table3. Solving model (13) yields S*, including proposed projects {5,6,7,8,10,16,18} for resource allocation. The final row of Table3 shows the resulting remaining resources. By careful observation of Table 2 data, it is clear that none of the unselected projects could be run with the remaining budget. From this, the high efficiency of this process is shown. The final results are obtained by merely running one MIP model with 126 nonnegative variables, 90 binary variables, 72 free variables and 2430 constraints; while without using such a model, an analyst may examine about $2^{18} = 262144$ combinations and solve many DEA models in order to calculate the efficiencies of each possible selection in satisfying resource limitations. In fact, the manager of IS is able to select the most efficient bundle of projects by solving only one model so that maximum use is made of resources.

5. Conclusion

This paper discussed in detail the selection of a subset of projects with consideration of the existing resources to ensure efficient resource allocation and resources remnants. In order to achieve this, the primary goal was the selection of the most efficient set of plans, which has not been discussed so far in project selection methods based on DEA. To do so, we considered each proposal as a decision-making unit and developed a DEA model using the classic idea of the common weight model. The accuracy of the suggested model in selecting the most efficient bundle of plans was evaluated using data from the Iranian Ministry of Commerce. This method could be utilized in various other applications, such as in Research & Development, investment portfolios and with any issue in which the inputs and outputs are heterogeneous, and in which managers are faced with limited resources. Since the data envelopment analysis approach is retrospective, it is recommended that further research is performed as an investigation into this problem of imprecise data.

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