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A Safety Approach for Measuring Efficiency of Projects, Using Data Envelopment Analysis

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Abstract. One of the key issues in projects management is improvement of projects' efficiency. Efficiency subject in project management has been discussed from different aspects and one of the problems which influence efficiency of projects is the high rate of accidents at the workplace. So, it is clear that safety issue as a vital dimension of each activity can decline organizations' efficiency. Various approaches and indicators have been proposed in this context. One of the practical approaches in the field of operation research which examine efficiency of decision making units is data envelopment analysis. Therefore, in this paper a DEA method is applied to measure efficiency of project organizations taking into account safety factors. The criteria considered in this model are safety costs, number of accidents and lost days. This approach may help safety managers to effectively evaluate safety performance of each project concerning safety performance of the best project. Results of DEA model can be used in order to calculate and determine benchmark values to compare with inefficient projects.

Keywords: Projects, Safety, Data Envelopment Analysis (DEA), Efficiency

1. Introduction

Safety programs play a key role in eliminating work related accidents and injuries. However, labour associations and companies have launched sustainable promotion plans through facilitating and training in organizations. Yet, the accident occurrence rate in industry still remains at unacceptable levels [1]. Siriruttanapruk and Anuntakulnathi [2] stated that the poor levels of safety in organizations are primarily due to inadequate implementation of safety programs and weak enforcement of legislation.

A number of definitions for safety programs have been stated by various scholars. Anton [3] defined a safety program as an instrument for controlling working environment, equipments, processes and workers which can reduce accidental injuries and losses in a workplace. In another study by Oregon Occupational Safety and Health Devision [4], a safety program was described as a term that determine who is responsible to control injuries and illnesses at workplace. Dhillen [5] described safety as an important factor which preserve humans' life and effectiveness and prevent damaging materials and equipments which are interrelated with humans' needs. Since safety can influence companies' productivity, it has been viewed as an indispensible issue in development and developing countries. Therefore, safety department of organizations are responsible for identification, evaluation and control of factors which may damage work environment. Final goals of a safety system are improving safety culture in organizations and declining the number of accidents and their severity. Thus, these goals should be considered as important indicators for performance evaluation. Most safety performance evaluation approaches consider the number of accidents happening and their severity and calculate the ratio of the number of accidents happening to working hours as an indicator of performance measurement.

Scholars defined efficiency as a progressive and economical development factor in each country. Efficiency is an important and complicated subject and has been analysed in various area such as engineering, management and economy.

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Abbaspour et al. [6] developed an appropriate model to evaluate organizations' efficiency and environmental performance, regarding health, safety, and environmental management system principles. The model was examined on 12 oil and gas general contractors. Findings of this research denote that reduction of projects' costs and expenses, and number of international certificate received in the scope of HSE-MS are two important factors which can improve companies' efficiency. In another study by Beriha et al. [7] an appropriate structure based on data envelopment analysis was developed to benchmark occupational health and safety performance in 30 Indian organizations under three categories of construction, refractory and steel. Results of this study revealed that safety performance of construction industries is consistently low in comparison with other categories of industries.

In this paper, efficiency of five different projects is evaluated based on the safety items. Therefore, BCC model in data envelopment analysis is applied to assess projects comparatively. Factors considered in DEA model are safety costs as an input and number of accidents and lost days as outputs. To examine the DEA model, a numerical example is represented. The proposed methodology of this study can help managers to identify the efficiency of projects based on safety factors and determine a benchmark pattern to improve their safety system.

2. Data envelopment analysis

Efficiency measurement has been an important issue for organizations which have struggled to improve their own productivity and efficiency. Reasons for this consideration were comprehensively stated five decades ago by Farrell [8] in his classic paper on the measurement of productive efficiency. Farrell also affirmed that the main reason that leads to failure in problem solutions was referred to the unjustified combination of multiple inputs into any satisfactory measure of efficiency. DEA has been developed by Charnes et al. [9] as a generalization of the framework of Farrell [8] on the measurement of efficiency. Farrell's approach was based on the production possibility set consisting of the conical hull of input-output vectors. This framework was generalized to include multiple inputs and outputs and reformulated as a mathematical programming model to assess the comparative efficiency of Decision-Making Units (DMUs). DMUs refer to the collection of firms, departments, divisions or administrative units with the same goals and objectives, and which have common inputs and outputs. The DEA approach uses a linear programming model to construct a hypothetical composite unit based on all units in the reference group. The performance of each DMU measured, is relative to the performance of all other DMUs [10].

3. The DEA model for measuring project efficiency based on safety

Data envelopment analysis is a mathematical programming methodology. It has been employed successfully for assessing the relative performance of a set of firms, usually called decision-making units (DMU), which use the same inputs to produce the same outputs. Assume that there are n DMUs, and the DMUs under consideration convert i inputs to j outputs. In particular, let the m_{th} DMU produce outputs y_{jm} using x_{im} inputs. The objective of the DEA exercise is to identify the DMUs that produce the greatest amount of outputs by consuming the least amount of inputs. A DMU is deemed to be efficient if the ratio of weighted sum of outputs to the weighted sum of inputs is the highest. The DMU defined in this study with input and output criteria are as follows: (Figure 1)

Figure 1- DEA model based on safety factors

Safety costs which were considered as inputs include: Gas and Fire detector systems, automatic extinguishing, calibration personal protection equipment, signs, internal and external training, incidents reports, internal and external audit, maintenance, developing and standardizing documents, etc.

Number of accidents can be described as accidents frequency in a specified period of time. Number of lost working days is the number of days that a worker cannot attend his/her job due to the injuries. In some situations, number of lost working days is determined based on the type of injuries or disablements.

The DEA model used in this study takes the form of single input and multiple outputs. The single input and multiple outputs DEA modeling form measures the efficiency of DMUs by how well they minimize single input criterion to produce multiple outputs criteria. In the following the BCC model will be used in order to identify the most efficient project. BCC model is as follows: [11]

$$MaxZ_o = \sum_{r=1}^{s} u_r y_{ro} + w$$

$$St.$$

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

$$\sum_{i=1}^{m} v_i x_{io} = 1$$

$$u_r, v_i \ge \varepsilon$$

Where dual model is as follows:

$$Min\theta - \varepsilon [\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{s} S_r^+]$$

$$St.$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} - S_r^+ = y_{ro} \qquad ,r = 1,2,...,s$$

$$\sum_{j=1}^{n} \lambda_j x_{ij} + S_i^- = \theta\, x_{io} \qquad ,i = 1,2,...,m$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \ge 0 \qquad , j = 1,2,...,n$$

$$S_r^+, S_i^- \ge 0 \qquad ,r = 1,2,...,s \qquad ,i = 1,2,...,m$$

4. Numerical example

In this section, a numerical example is presented to examine the possibility of implementing the proposed approach. As it is demonstrated in Table 1, 12 DMUs with one input and two outputs are considered in numerical example. All the data should be normalized before solution process. Since Output 1 and 2 have negative nature, the values are converted into the inverse format and then are normalized. In the first step, BCC model of input oriented should be solved for all DMUs. So, efficient and inefficient DMUs can be determined (Table 2).

5. Results

In order to follow this model, linear programming solution is performed for all projects in numerical example. Results of DEA model are represented in table 3. It is clear that projects 5, 9, 10, 11 are efficient

with the rating of 1.000. The remaining projects are identified inefficient. These score may help managers of company to evaluate projects' safety condition comparatively. The efficiency of projects means that the higher outputs are achieved with lower inputs. Projects 5 and 10 with the number of lost days in a year equal to 440 and 382 are identified efficient however projects 9 and 11 the number of lost days in a year equal to 808 and 597 which are relatively high in comparison with others are classified as efficient projects too.

Table 1- Input and outputs of DEA model

DMU	Input	Output 1	Output 2
	Ratio of safety costs to total cost in a year	Number of accidents in a year	Number of lost days in a year
1	0.083	18	605
2	0.093	22	463
3	0.042	25	716
4	0.065	19	528
5	0.077	14	440
6	0.063	31	561
7	0.066	42	967
8	0.078	17	755
9	0.021	26	808
10	0.097	16	482
11	0.088	9	597
12	0.036	33	817

Table 2 - Outputs and inputs of DEA model in normalized form

DMU	Input	Output 1	Output 2
1	0.8557	0.5000	0.7273
2	0.9588	0.4091	0.9503
3	0.4330	0.3600	0.6146
4	0.6701	0.4737	0.8333
5	0.7938	0.6429	1.0000
6	0.6495	0.2903	0.7843
7	0.6804	0.2143	0.4550
8	0.8041	0.5294	0.5828
9	0.2165	0.3462	0.5446
10	1.0000	0.5625	0.9129
11	0.9072	1.0000	0.7370
12	0.3711	0.2728	0.5386

6. Conclusions

In this paper, a model through DEA approach was developed in order to evaluate the efficiency of projects. The paper also described how one firm can implement this method and use DEA modelling for measuring projects' efficiency based on safety factors. Regarding to results of this study projects which provide the lower number of accidents and lost working days through lower safety costs are efficient. Thus, managers of projects should consider multi criteria in evaluation of projects in terms of safety factors. This

approach allows safety managers to effectively evaluate safety performance of each project concerning safety performance of the best project. Results of DEA model can be used in order to calculate and determine benchmark values to compare with inefficient projects. Another advantage of this model is the simplicity of calculating factors of DEA model. Comparing to traditional subjective safety evaluation techniques, the proposed DEA approach provides an objective statement of how safety systems have been implemented. Further researches can be done with more critical factors. Sensitivity analysis can be applied for measuring the influence of each factor. Yet, it is possible to rank efficient DMUs.

Table 3- Units' efficiency

DMU	Efficiency	DMU	Efficiency
1	0.5581	7	0.3183
2	0.7614	8	0.5104
3	0.7048	9	1.000
4	0.8695	10	1.000
5	1.0000	11	1.000
6	0.8002	12	0.5841

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