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ABSTRACT

This article presents a method for safety performance evaluation in construction projects by using a technique data envelopment analysis (DEA) which is linear programming model. The evaluation was comparisons of efficiency where means inputs and outputs in the safety performance of 12similar construction projects. In this case, the inputs were expenses in health care, expenses in safety training, expenses in up-gradation of process-related tools, instruments, machines, materials leading to safe and healthy environment, and expenses on safety equipment and tools. The outputs were accident that do not cause any disability and do not involve any lost work days, accident that do not cause any disability but involve lost work days, accident that cause temporary disability, accident that cause permanent partial disability, and accident that cause permanent full disability or fatality. Results found the technique was applicable. The efficiencies of 12 construction projects were ranked between the highest efficiency (1.000) to the lowest (0.533). The results could be lead to a making decision in defining an appropriate safety budget for construction contractors or project owners in the future projects.

KEYWORDS: Safety Performance, Construction Project, Data Envelopment Analysis

1. Introduction

Presently, Thai construction industry has several used and adopted modern technology in construction tools and equipment for earlier construction completion and reducing construction costs. In the other hand, we found that trend of accidents in the construction industry are increasing. However, Thai government sector has defined a policy related to safety budget for contractors who join bidding in the government projects have to prepare the safety budget in the bidding documents. In practice, we found that the contractors or the project owners have not prepared the appropriate safety budget because they might not attend in the construction safety or they would reduce the total construction cost as low as possible. Another reason, they have not known or cleared that the outputs/outcomes of the budget would have benefit to their projects. These reasons lead to a problem that how the contractors and the project owners would prepare and estimate the appropriate safety budget for construction estimation of their projects in the future. This article presents a method for safety performance evaluation in construction projects by using a technique data envelopment analysis (DEA) which is a linear programming model. The evaluation was comparisons of efficiency where means inputs and outputs in the safety performance of 12 construction projects (case study).Results of the study have shown efficiency of safety performance for each project case study. The results could be lead to a making decision of construction contractors or project owners in defining an appropriate safety budget for the most construction safety in the future projects.In this article studied the safety performance evaluation in the construction projects. The main objectives were:

- To study inputs and outputs this could be indicators for the safety performance evaluation in the construction project.
- To analysis and evaluate the safety performance of the construction project case study.

Scope of this research was study of safety performance evaluation of construction projects in Thailand where the construction was completed. The case studies were 12 selected construction projects where the 12 projects have similarity in the project characteristics.

- Scope of sample: 12 construction projects where the construction was completed. The selected projects have similarity in the project characteristics such as the projects were RC. Buildings, location in downtown, private owners, etc.
- Scope of time: the data collection period was during August – November 2013 (4 months)
- Scope of place: the construction project case studies were located in Bangkok and surrounding areas Thailand.

2. DEA and Its Applications

Data envelopment analysis (DEA) is a mathematical method which is non-parametric approach was initialed by Farrell (1957). Principal of the analysis is a linear programming model was developed by Charnes, Cooper, and Rhodes (1978) [1] for measuring efficiency of multi-inputs and outputs in operating units with the same goals and objectives. DEA is concerned with evaluations of performance of organizations (i.e., business units, hospitals, government departments, construction projects, etc.), where the presence of multiple inputs/outputs make comparison difficult. The organization under study is called a decision making unit (DMU). A DMU is regarded as the entity responsible for converting inputs in to outputs and whose performance is to be evaluated. In this research, a DMU was a construction project.

Charnes, Cooper, and Rhodes, CCR (1978) [1] presented a mathematical model for measuring efficiency score of each unit by comparing the score of each unit with that of its peers. The model was used for measuring efficiency of n units, m inputs, and s outputs. The model as follows:

$$\text{Max} \quad h_0 = \sum_{k=1}^{s} u_k y_{k0} \tag{1}$$

$$\text{subject to} \quad \sum_{i=1}^{m} v_i x_{i0} = 1, \tag{2}$$

$$\sum_{r=1}^{s} u_k y_{kj} - \sum_{j=1}^{m} v_j x_{ij} \le 0, \tag{3}$$

$$i = 1,\ldots,m;\; j = 1,\ldots,n;\; k = 1,\ldots,s \tag{4}$$

$$v_k, v_i \ge 0 \tag{5}$$

Where:

h_0 the measure of efficiency for DMU_0 (the DMU under evaluation), which is a member of the set j = 1,..., n DMUs

u_k the output weight. It is determined by the solution of the model and is assigned to the observed *k*th output

v_i the input weight. It is determined by the solution of the model and is assigned to the observed *i*th input

y_{k0} the known amount of the *k*th output produced by DMU_0

x_{i0} the known amount of the *i*th input used by DMU_0

y_{kj} the known amount of the *k*th output produced by DMU_j

x_{ij} the known amount of the *i*th input used by DMU_j

The model is called CCR output-oriented maximization DEA model. At present, the efficiency score of n DMUs is obtained by running DEA software. In this research, MaxDEA Version 6.3 (freeware) was used for data analysis. The software has been developed by Cheng Gang (2012) [2].

Beriha et al.(2011) [3] studied safety performance evaluation of three industrial categories such as 10 construction, 10 refractory, and 10 steel organizations (total 30 organizations) in India using DEA approach. The results shown comparisons of safety performance scores of the three industries were different which lead to improving the safety performance to be the best practice of the industries by benchmarking based on safety performance in the future.

Mohammad S. et al. (2010) [4] analyzed and compared safety performance of 45 construction contractors in the Jordanian Contractors Association. The DEA was used to benchmark safety performance by considering a safety budget (input parameter) and five types of accidents (output parameters) of each the contractor. The DEA approach could be utilized by a particular contractor to gauge its own safety performance over the time. The results shown the contractors could be ranked in term of efficiency scores and classified to be two groups, efficient and inefficient contractors.

Jinxian and Yuanlu (2011) [5] studied and applied the DEA to solve the construction safety management performance in China. Ten construction projects were selected to study as DMU. The three inputs as investments included on-site safety, civilized construction, and personal labor protection while their income factors: social and economic as two outputs.

Brenda et al.(2005) [6] presented a research related to contractor prequalification for ranking 15 contractors in bidding a construction project in Canada. The DEA was used in the study. The inputs were safety records, current capacity while the outputs were sales history, related experience, and employee experience.

Sunun and Thawatchai (2010) [7] researched the actual costs related to safety system during a building construction project in Thailand. The safety costs were categorized to two parts safety measure cost and safety program cost. The results found the safety measure cost was 1.85% and the safety program cost was 0.98% of total construction cost. The safety cost (safety measure and safety program cost) in the building construction project was 2.83%.

3. Research Methodology

Research methodology was classified to be steps, studying the research problems and related theories, data collection, data analysis, and research results.

3.1 Research Framework

Scope of this research related to safety in 12 construction projects where the construction completed. Inputs, researcher has focused on records of the safety expenses in the 12 projects comprise of four parts of safety expenses for each project (I1-I4). The safety expenses in this study would be recorded in term of percentage (%) to total construction cost. Outputs, in this research would be number of total accident during the construction duration for each project including five types of accident (O1-O5). The inputs and outputs for safety performance evaluation in this research were:

Inputs

1.) Expenses in health care (I_1)

2.) Expenses in safety training (I_2)

3.) Expenses in upgrading of process-related tools, instruments, machines, materials leading to the safety (I_3) and,

4.) Expenses on personal protective equipment; PPE (I_4)

Outputs

1.) Accident that do not cause any disability and do not involve any lost work days (O_1)

2.) Accident that do not cause any disability but involve lost work days (O_2)

3.) Accident that cause temporary disability (O_3)

4.) Accident that cause permanent partial disability (O_4) and,

5.) Accident that cause permanent full disability or fatality (O_5)

Research framework included the four inputs and the five outputs through the DMU which was the 12 construction projects as shown in Fig 1.

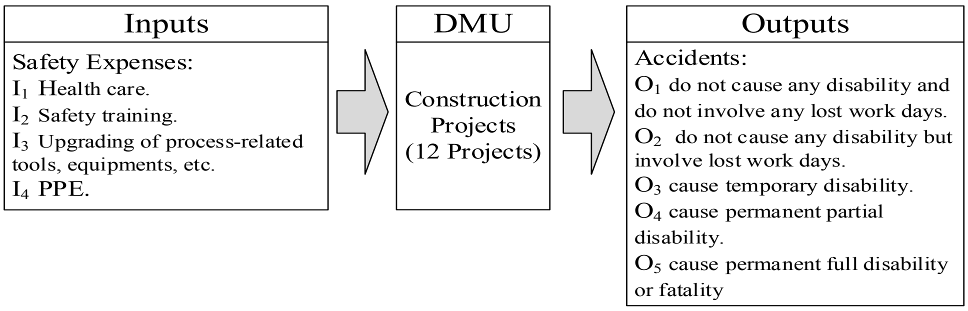

Figure 1 Research Framework

3.2 Data Collection

The 12 construction projects were selected by selecting the projects with have similarity in the project characteristics such as the projects were RC-Buildings, location in downtown, private owners, etc. The data collection period was during August - November 2014 (4 months). The project case studies were located in Bangkok and surrounding areas Thailand. The researcher had collected data the inputs and the outputs related to the research framework as shown in Table 1 and 2.

Table 1 Inputs, the expenses related to safety performance for each project case study (in term of percentage to total construction cost)

Project(DMU)	Inputs			
	I_1	I_2	I_3	I_4
1	2.00%	1.00%	2.00%	1.00%
2	1.50%	1.25%	2.25%	1.20%
3	2.25%	0.75%	2.10%	1.00%
4	2.15%	1.10%	2.20%	0.90%
5	1.65%	1.40%	1.75%	0.75%
6	1.75%	1.50%	2.05%	1.15%
7	1.90%	0.50%	1.90%	1.25%
8	1.60%	0.65%	2.50%	1.00%
9	1.40%	1.10%	2.40%	1.55%
10	1.55%	1.25%	2.00%	1.50%
11	1.70%	1.25%	2.20%	0.95%
12	1.80%	1.15%	2.15%	1.85%

Table 2 Outputs, number of each accident type during the construction duration for each project case study

Project(DMU)	Project Duration(Year)	Outputs					Project Duration / Number of Accident
		O_1	O_2	O_3	O_4	O_5	
1	1.50	10	7	2	1	1	0.0714
2	2.00	14	9	5	5	1	0.0588
3	1.75	11	4	0	4	2	0.0832
4	1.33	7	7	4	4	1	0.0578
5	1.67	12	8	8	5	1	0.0491
6	0.92	9	9	5	2	0	0.0368
7	0.83	8	5	6	3	2	0.0346
8	1.00	5	10	6	3	0	0.0417
9	1.79	10	11	7	1	1	0.0597
10	1.67	8	12	2	2	1	0.0668
11	1.50	13	5	4	4	0	0.0577
12	1.50	11	6	5	4	0	0.0577

In the Table 2, the researcher intended on number of total occurred accidents during the project duration for each project. Therefore, the last column in the Table 2 would be the ratio between the project duration over the number of total accidents.

4. Results

Evaluating safety performance in construction projects by using the DEA, the researcher has prepared the data (inputs/outputs) and a personal computer (PC) with the MaxDEA software (freeware). The data was inputted to the PC and RUN. The results were efficiency scores and rank for each the construction projects, shown in Table 3.

Table 3 Efficiency scores and rank

Project (DMU)	Efficiency Score	Rank
1	0.9495	4th
2	0.9534	3rd
3	1.0000	1st
4	0.7726	8th
5	0.8028	6th
6	0.5330	11th
7	0.6237	10th
8	0.6870	9th
9	0.9951	2nd
10	1.0000	1st
11	0.8859	5th
12	0.7832	7th

5. Conclusions and Recommendations

This research has presented a method for safety performance evaluation in construction projects by using a technique data envelopment analysis (DEA) which is a linear programming model. The four inputs (including expenses in health care, safety training, upgrading of process-related tools, instruments, machines, materials leading to the safety and personal protective equipment;PPE) and the five outputs (including accident that do not cause any disability and do not involve any lost work days, accident that do not cause any disability but involve lost work days, accident that cause temporary disability accident that cause permanent partial disability and accident that cause permanent full disability or fatality) were observed and collected as the data from the 12 construction project case studies in Thailand as shown in 3.1. Research found the DEA approach was applicable in the evaluation; the results could be ranked the safety performance of the 12 projects. The highest efficiency scores were the project no. 3 and no10. The next rank of efficiency scores were the project no. 9, 2, 1, 11, 5, 12, 4, 8, and 7 respectively. The lowest efficiency score was the project no. 6 (Table 3).

By this research, contractors, project owners, or project consults can use this approach for evaluating safety performance in their construction projects. The project with highest efficiency score will be bench mark for other projects in improving their safety policy and program. The results can lead to a making decision in defining an appropriate safety budget for the most construction safety in the future projects. Moreover, the DEA can be applied to other evaluations such as contractor prequalification (in bidding process), construction project performance, company performance, etc.

Acknowledgments

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