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Utilizing data envelopment analysis to benchmark safety performance of construction contractors

Mohammad S. El-Mashaleh [a,*], Shaher M. Rababeh [b], Khalied H. Hyari [a]

[a] Department of Civil Engineering, The Hashemite University, P.O. Box 150459, Zarqa 13115, Jordan
[b] Department of Architectural Engineering, The Hashemite University, P.O. Box 150459, Zarqa 13115, Jordan

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Abstract

The purpose of this paper is to utilize data envelopment analysis (DEA) to benchmark safety performance of construction contractors. DEA has been recognized as a robust tool that is used for evaluating the performance of business organizations. The proposed approach is deployed based on empirical data collected from 45 construction contractors. On a scale of 0–1.0, DEA analysis assesses the relative efficiency of every contractor relative to the rest of the contractors in terms of safety performance. For inefficient contractors, DEA analysis provides quantitative guidance on how to become efficient.

Keywords: Organization resources; Safety and health; Benchmarking; Performance measurement; Data envelopment analysis

1. Introduction

The purpose of this paper is to utilize data envelopment analysis (DEA) to benchmark safety performance of construction contractors. DEA has been recognized as a robust tool that is used for evaluating the performance of organizations such as business firms, hospitals, government agencies, educational institutions, etc. DEA is well-deployed in other industries. DEA is a nonparametric linear programming approach that produces a single measure of efficiency for each unit relative to its peers. It enables firms to assess their relative efficiency compared to other firms in the industry.

Construction literature includes several methods for assessing safety performance of construction contractors. Two of the most commonly used ones are OSHA recordable incidence rates and experience modification rating (EMR) [27,28]. OSHA recordable incidence rates are based on the US Occupational Safety and Health Act (1970), which requires employers to record and report accident information. Incidents are recorded and a formula is used to compute the incidence rates.

EMR, on the other hand, is established by independent rating bureaus. It dictates the contractor's premium of the workers' compensation insurance. EMR formula is criticized for its complexity and because of the existence of different versions in practice [19]. It is also argued that EMR is sensitive to company size [12,23,33].

Ng et al. [31] develop a safety performance evaluation (SPE) framework for evaluating contractor's safety performance. The model includes a range of organization-related and project-related SPE factors. Based on a survey, the authors assign weights to the different SPE factors to calculate a weighted average safety performance score for each contractor. Generally, it is well-accepted that weighted average scores have an inherent weakness due to the biases introduced in the development of the weights and the additive assumptions utilized in the computations of the weighted score average.

* Corresponding author. Tel.: +962 5 390 3333x4829; fax: +962 5 382 6348.
E-mail address: mashaleh@hu.edu.jo (M.S. El-Mashaleh).

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Teo and Ling [37] develop a model to measure the effectiveness of safety management systems (SMS) of construction sites. The authors utilize surveys and experts interviews and workshops to collect the important factors affecting safety. The analytic hierarchy process and factor analysis are used to identify the most crucial factors and attributes affecting safety. Using the model, a construction safety index can be calculated. The authors indicate that the limitations of their model include the small number of experts and respondents involved in the study. The importance weights and attributes are developed within the context of Singapore. Another limitation is that their model includes 590 attributes that must be evaluated on the site.

Despite the limitations associated with some of the existing methods, they are useful measures of construction safety performance. However, new methods are still needed as they offer new insights to both researchers and practitioners. A point of departure for the DEA approach compared to existing methods is that DEA relates resources expended on a certain performance to the level of success for that particular performance. Under existing methods, two contractors that suffer the same numbers and types of accidents are considered of identical performance. This is clearly not the case if one contractor is expending more resources (i.e., money, etc.) on safety than the other contractor. It makes more sense to consider the contractor that commits fewer resources to arrive at a certain safety performance as a better performer.

The rest of the paper unfolds as follows: data envelopment analysis, data collection, results and analysis, future extension of the research, and conclusions.

2. Data envelopment analysis (DEA)

Data envelopment analysis (DEA) was initiated by Charnes et al. [3–5]. Since that time, many studies across different disciplines have utilized DEA [11]. In the construction domain, only few studies made use of DEA. El-Mashaleh et al. [17] propose the DEA methodology to measure and compare subcontractors' productivity at the firm-level. El-Mashaleh [14] and El-Mashaleh et al. [15,16] deploy DEA to evaluate the firm-level performance of construction contractors. Vinter et al. [39] compare project efficiency in a multi-project environment based on DEA. McCabe et al. [29] utilize DEA to prequalify contractors. Pilateris and McCabe [32] evaluate contractors' financial performance based on DEA.

El-Mashaleh [14] and El-Mashaleh et al. [18] makes use of DEA to quantify the impact of information technology on contractors' performance. Chiang et al. [8] combine DEA to the I–O tables to examine repercussions of consumptions placed on the construction sector. Cheng et al. [6] propose a DEA approach for credit scoring to evaluate borrowers with respect to certain types of projects.

DEA is concerned with evaluations of performance of organizations (i.e., business firms, hospitals, government agencies, universities, etc.), where the presence of multiple input, multiple output makes comparison difficult. In DEA, the organization under study is called a decision making unit (DMU). A DMU is regarded as the entity responsible for converting inputs (i.e., resources, money, etc.) into outputs (i.e., sales, profits, certain performance measures, etc.) and whose performance is to be evaluated. In this study, a DMU refers to a construction contractor.

DEA utilizes mathematical linear programming to determine which of the set of DMUs under study form an envelopment surface. This envelopment surface is referred to as the efficient frontier. DEA provides a comprehensive analysis of relative efficiency for multiple input-multiple output situations by evaluating each DMU and measuring its performance relative to this envelopment surface. Units that lie on (determine) the surface is deemed efficient in DEA terminology. Units that do not lie on the surface are termed inefficient and the analysis provides a measure of their relative efficiency.

Cooper et al. [11] and Coelli et al. [9] argue that DEA has gained its popularity from three inherent powerful features. First, its capability to incorporate multiple inputs and multiple outputs as a result of the use of linear programming. Linear programming can handle large numbers of variables and relations (constraints). Second, DEA has no priori assumptions. There is no need to assign weights to the different inputs and outputs. The weights are derived directly from the data relaxing the user from arbitrary subjective weighting. DEA provides a set of weights, which optimize a unit's performance subject to the weights not leading to any other unit violating the bounds of the frontier. Third, the measurement units of the different inputs and outputs need not be congruent. Some may involve number of persons, or areas of floor space, money expended, etc.

2.1. Charnes–Cooper–Rhodes (CCR) DEA model

This study makes use of the Charnes–Cooper–Rhodes (CCR) model of DEA to benchmark safety performance of construction contractors. The mathematical form is shown below (Eqs. (1),(2),(3),(4),(5). Interested readers may refer to Cooper et al. [11] for details.

$$\max \quad h_0 = \sum_{r=1}^{s} u_r y_{r0} \tag{1}$$

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

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leqslant 1 \tag{3}$$

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

$$u_r, v_i \geqslant 0 \tag{5}$$