
Construction Project Success ranking through the Data Envelopment Analysis

Mazyar Zahedi- Seresht¹, Mohammadreza Akbarijokar², Shahrzad Khosravi^{2*}, Hamidreza Afshari³

(1) Department of mathematics, kharazmi university, Tehran, Iran.

(2) Department of Industrial Engineering, Sharif University of Technology, Azadi Ave, Tehran, Iran.

(3) Newspars company Chief Executive Office.

Copyright 2014 © Mazyar Zahedi- Seresht, Mohammadreza Akbarijokar, Shahrzad Khosravi and Hamidreza Afshari. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Abstract

The purpose of this paper is to rank construction projects' success in a post delivery phase. To attain this objective, a data envelopment analysis (DEA) approach is used. The model's output is a project success index which is calculated based on five project success criteria. These criteria which are determined by a two-round Delphi questionnaire survey are time performance, cost performance, quality, HSE, and customer satisfaction. The input factors which have effects on the output measures are Organizational Sponsorship, Project Manager Competency, Customer Organization, Project Operational Environment and Organizational Experience. The tool adopted to determine these factors is questionnaire. This model is applied for 9 projects with different importance of output and input factors and the reasonable result is achieved for ranking these projects.

Keywords: Project management, Efficiency, Construction industry, Project evaluation, Data envelopment analysis

1 Introduction

Project management peers still do not come to an agreement regarding what project success is and how it should be measured. Murray et al. and Klagegg et al. De Wit and Pinto and Slevin noted that as project stakeholders understand success factors differently, it is still not clear how to measure project success [1], [2], [3], [4]. Lim and Mohamed believed that project success should be considered from different angles of the individual owner, contractor, end user, general public and so on [5]. In other word, the project success has different meanings by different project stakeholders as attitude of each of them could be different due to their different objective.

This paper aims to provide a basis for measurement of construction project success in one of the Iranian construction company. This company has worked in the field of power plant, utility and cogeneration construction industries. This survey focused on developing a project success measurement model leading

* Corresponding Author. Email address: Khosravi.shahrzad@gmail.com, Tel: +982123151670

to project success ranking by applying DEA model to generally compare the finished projects and rank them. In addition, the model developed in this paper can be used as a guideline for other project-based organizations to initiate their own model.

The paper is organized as it follows. First, in literature review section, a clarification of project success, project success model and DEA is presented. Then research methodology is explained in the next section followed by experimental result. In the experimental result, Output and input factors, weight restriction, data and result are discussed. Finally, in conclusion, the paper concludes with a brief summary of findings, implications, and some recommendations for the future researches.

2 Literature review

Kerzner discusses definitions of Project success in his book, *In Search of Excellence in Project Management*, and provides a list of critical success factors that can affect project performance at different stages of a project life cycle [6]. In his book, he indicated that the definition of project success has changed over the years. Project success was measured entirely in technical terms in the 1960. In the 1980s, Kerzner defined project success in terms of meeting three objectives: 1) on-time completion, 2) within budget completion, and 3) completed at the desired level of quality. Project quality was commonly defined as meeting technical specifications. Note that all three of these measures are internal to a project, and do not necessarily indicate the preferences of the end user or the customer. In the late 1980s, a project was considered to be a success by not only meeting the internal performance measures of time, cost and technical specifications but also assuring that the project is accepted by the customer; and customer allows the contractor to use him as a reference.

It is necessary to distinct between project success and project management success. Previous studies [3], [7], [8] clarified that project success is measured against the overall objectives of the project while project management success is measured against cost, time and quality/performance. However, Baccarini insists that project success is measured both in terms of product success and project management success [9]. Munns and Bjeirmi separate project success from project management success, where the former is oriented towards long-term goal and the latter is oriented towards short-term goal [7]. Ashley identified six success criteria: budget performance, schedule performance, client satisfaction, functionality, contractor satisfaction, and project manager/team satisfaction [10]. Sanvido et al. defined project success, for a given participant such as owner, planner, engineer, contractor, or operator, as the degree to which project goals and expectations are met [11]. They mentioned that these goals and expectations may include technical, financial, educational, social, and professional aspects. Functionality, profitability to contractors, absence of claims and objections, and "fitness for purpose" for end user have also been used as measures of project success [12].

Based on the literature review there are some different project success models which are briefly explained here. Atkinson divides success criteria into delivery and post-delivery stages [13]. He provides a "square route" to understanding success criteria: iron triangle, information system, organizational and community benefit. The 'iron triangle' includes cost, time and quality. These criteria are applied for delivery stage. The post delivery stages includes 1) the information system with criteria such as maintainability, reliability, validity, and quality; 2) organizational benefit with criteria such as improved efficiency, improved effectiveness, increased profits, strategic goals, organizational learning, and reduced waste; and 3) community benefit with criteria such as satisfied users, social and environmental impact, personal development, professional learning, contractors profits, capital suppliers, content project team, and economic impact to local community. Lim and Mohamed modeled project success measurement into two categories 1) micro-view points and 2) macro-view points [5]. Patanakul and Milosevic grouped their measurement criteria into three categories 1) organizational criteria such as resource productivity and organizational learning, 2) project criteria such as time-to-market and customer satisfaction, and 3)

personal criteria such as personal growth and personal satisfaction [14]. Chua et al; proposed a hierarchical model for construction project success [15]. Budget, schedule, and quality objectives are key measures in this model which contribute to the goal of project success. Shenhar et al. [16] proposed a four-dimension model which is time-dependent 1) the period during project execution and right after project completion, 2) the period shortly afterwards, when the project has been delivered to the customer, 3) the period after a significant level of sales has been achieved (1-2 years), and 4) 3-5 years after project completion. Sadeh et al. modeled project success into four dimensions: 1) meeting design goals which are specified in the contract 2) the benefit to the end user, 3) benefit to the performing organization, and 4) the benefit to the technological infrastructure of the country and of firms involved in the development process [17]. Yeung et al. developed A Partnering Performance Index (PPI), which is composed of seven Key Performance Indicators (KPIs), to measure, monitor, improve, and benchmark the partnering performance of construction projects in Hong Kong [18]. A weighting system is applied for the project success criteria in order to integrate different success measures.

All the above stated model can be used to measure project success and then rank them. The most important drawback with all these method is that the input factors are not considered in these models and just the output factors are applied to measure the project success and rank the projects. Therefore in this paper, the input factors are incorporated through the application of DEA models to assess the project success and rank them.

DEA was introduced by Charnes, Cooper and Rhodes [19]. Their model is input oriented and assumed constant return to scale. Then several analytical models have been developed depending on the assumptions underlying the approach.

One of the main problems with DEA techniques is the correct selection of inputs and outputs. Other difficulties are the homogeneity assumptions and the flexibility of restrictions regarding the weights [20]. In the absence of restriction on the weights of input and output factors, DEA allows that each DMU to be assessed in its most favorable light. This flexibility may be confined by some information about the weight of input and output factor. So, in this paper first we define the input and output factors. Then we use restricted weight regard to the information we have obtained about the importance of each factors.

Further concerns arise from the distinction between inputs which can be controlled by the project manager under investigation such as project team competency, and those which cannot, such as environmental factors. There are two approaches to solve this problem. All inputs, whether controllable or not, are included in the first approach in the efficiency analysis [21], [22]. Two-stage model designed to consider input factors in the second approach. Efficiency scores are derived from a subset of controllable inputs in the first stage. Then these efficiencies are analyzed at a second stage in related to the non-controllable inputs applying an appropriate transformation and statistical technique [23]. Results from comparisons made in the context of other industry such as higher education suggest that there is little difference between the efficiencies derived from a two-stage approach and those from a one-stage DEA [24]. Therefore, in this paper, one stage DEA is used to compute the efficiencies of projects.

Industries such as banking, health care, agriculture and transportation industry practically adopt DEA for a variety of reasons, such as ranking DMUs, identifying sources of inefficiencies, evaluate the effectiveness of strategy, and etc. Application of DEA in project management area is less frequent. Some authors use DEA technique for project selection [26] and [27]. The discussion of DEA models presented in this paper is brief. More detailed review are presented by seiford and thrall [27], Lovell [23], Ali and Seiford [28], charnes et al [29], Seiford [30] and Tavares [31], Cook and Seiford [32].

3 Research Methodology

In this paper, a DEA approach for construction projects is used to find out how much the projects were successful after the closing phase. The model is based on project success criteria as an output factors and some input factors which have effects on the output factors.

Following assumptions have been considered:

The project success measurement is based on the perspective of performing organizations which are directly involved in project execution. It means the objectives of other project's stakeholders such as customer, owner, community, etc. are not considered to this model.

The model considers both product success (project quality performance) and project management success (such as project time and cost performance).

The model considers project success criteria and does not consider success factors. By project success criteria we mean the measures by which success or failure of a construction project will be judged such as project time performance, project cost performance, etc.

The project success measurement model should be applied for the projects which are handed over to the customer and are officially closed.

The output and input factors are independent items and there is no correlation among them.

The original DEA model referred to as the CCR model, optimizes the fractional output per input of each DMU through choosing optimal input/output-weights [19]. The optimization program is defined based on fractional linear CCR model and its linear forms [19] as follows:

Model 1:

$$U_k = \max_{u,v} \frac{\sum_{i=1}^s u_i y_{ik}}{\sum_{i=1}^m v_i x_{ik}}$$

Subject to

$$\frac{\sum_{i=1}^s u_i y_{ij}}{\sum_{i=1}^m v_i x_{ij}} \leq 1 \quad j=1, \dots, n$$

$$u_i, v_j \geq \varepsilon \quad \text{for all } i, j$$

where u_i ($i=1, \dots, s$) and v_j ($j=1, \dots, m$) are the weights for output and input factors, respectively. Also ε is a non-Archimedean infinitesimal and positive.

The above program can be translated into following linear program (model 2):

Model 2:

$$U_k = \max_{u,v} \sum_{i=1}^s u_i y_{ik}$$

Subject to

$$\sum_{i=1}^m v_i x_{ij} - \sum_{i=1}^s u_i y_{ij} \geq 0 \quad \text{for } j=1, \dots, n$$

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

$$u_i, v_j \geq \varepsilon \quad \text{for all } i, j$$

The relative DEA multiplier constraints are

$$\frac{v_i}{v_j} \leq b, \frac{u_i}{u_j} \leq a$$

Leading to the following constraints for LP to be added to the model 2:

$$u_i - a u_j \leq 0 \quad i, j = 1, \dots, s$$

$$v_i - b v_j \leq 0 \quad i, j = 1, \dots, m$$

As the relationships between the weights are different for each project, weight restrictions are not the same in each DMU models.

A two-round Delphi questionnaire survey, a questionnaire survey, a semi-structured interview with experienced project managers and DEA technique were employed as the research methods.

As different inputs/outputs combinations will produce different efficiency rankings of DMUs, an important decision in DEA modeling is the selection of inputs and outputs. In order to define output factors and input factor in success measurement model, a Delphi technique is used. Delphi technique produces useful results which are accepted and supported by the majority of the expert community. According to [33] two or three rounds are preferred for the Delphi questionnaire survey. Based on literature review and organizational experience in executing construction projects, a Delphi questionnaire consisting of two main parts was designed. In the first part of the questionnaire, 10 project success criteria and their definitions were listed and three questions were posed. In first question the respondents were asked whether they have any comments on the project success criteria regarding the modification of any of them. In second question, the respondents were asked to propose any other project success criteria which they believe that they are missed, to the end of the list. Finally, the respondents were asked to what extent they agreed to project success criteria on a five-point Likert scale where 1: totally disagree, 2: partially disagree, 3: indifferent, 4: partially agree and 5: totally agree. Based on DEA approach, in the second part of the questionnaire, 8 input factors were listed. The same questions were asked for the second part.

The interview with project sponsor is conducted in order to determine the relationship between weights of input factors and also output factors for each project.

A DEA technique is used to determine project success ranking. We referred the project efficiency in this paper as a project success. As the importance of each success measures is not equivalence in the project, we should have the sound relation between the Weights of output factors. For instance, in one project the schedule index is more important than the cost or vise a versa. According to the project management body of knowledge (fifth edition), in the project charter the priority of the goals should be defined. Base on this priority which is articulated by project sponsor in the project charter, the relationship between the weights of output factors should be determined. On the other hand, effects of input factors are different in the projects. In one project, team competency has more effects on the project output measures than the other input factors. In order to consider this fact, the restriction related to input weight factors are also developed as some constraints in DEA model. These constraints also have been checked by interview with project manager.

4 Research Findings

4.1. Output and input factors

21 persons who have had long-term experiences in execution of construction projects ranging from the middle managers to the project managers were selected as the panel of experts. A total of 20 respondents returned the questionnaires for the first round, giving a response rate of 95%. After the first round, 6 project success criteria and 3 input factors were suggested by the panel of experts. For the second round a new questionnaire was designed where the average score for the initial project success criteria and input factors were provided next to the respondents' first round score. In this part, considering the average score, the respondents were asked whether they would like to reassess their first score. In addition they once again were asked to what extent they agreed to the new project success criteria and input factors on the same five-point Likert scale. After the second round, the reassessed scores considered for the calculation of final average score for all project success criteria and input factors. Project success criteria and input factors were sorted by their average score. The ones having the average score equal or less than 4 were deleted. By using Statistical Package for the Social Sciences (SPSS) software, the Mean Rank method was

applied for the rest of them in order to select top five of project success criteria and input factors to be used for the model. The final results are summarized in Table 1 and Table 2.

Table 1: output factors

Project Success Criteria	Average Score	Mean Rank	Rank	Description	Result
Time Performance	4.94	13.72	1	Meeting time objectives for key milestones	Selected
Cost Performance	4.67	11.94	3	Meeting cost objectives for the project	Selected
Quality Performance	4.61	12.13	2	Meeting quality objectives for the project	Selected
HSE	4.44	10.77	4	Health, safety & environment of the project	Selected
Client Satisfaction	4.28	9.58	5	Customer overall satisfaction of the project	Selected

Table 2: Input factors

Input Factor	Average Score	Mean Rank	Rank	Description	Result
Organizational Sponsorship	4.50	7.77	1	Project's priority, funding, finalizing unresolved issues in time	Selected
Project Manager Competency	4.39	7.33	2	Experienced, knowledgeable, & competent project manager	Selected
Customer Organization	4.39	7.25	3	Experience, knowledge, & proficiency of the customer	Selected
Project Operational Environment	4.33	6.94	4	LC regulations, sanctions, economic situation, price shock	Selected
Organizational Experience	4.22	6.69	5	Availability of organizational process assets of the finished similar projects	Selected

To determine whether there is degree of agreement among the panel of experts with respect to their rankings of the project success criteria and input factors, Kendall's Coefficient of Concordance was used. The Kendall's Coefficient of Concordance says that the degree of agreement on a zero to one scale is:

$$W = \frac{12U - 3n(n - 1)^2m^2}{n(n - 1)^2m^2}$$

Where:

$$U = \sum_{j=1}^n \left(\sum_{i=1}^m R_{ij} \right)^2$$

And

n = number of project success criteria/input factors

m = number of experts

R_{ij} = significant degree allocated for ith project success criteria/input factor by jth expert

W = Kendall's Coefficient of Concordance

The calculated Kendall's Coefficient of concordance for project success criteria W = 0.3910. In order to know whether there is disagreement or agreement among the panel of experts on ranking the project success criteria, a test of hypothesis is needed.

Null hypothesis: H_0 : There is no agreement in ranking of project success criteria among the panel of experts.

Alternative hypothesis: H_1 : There is an agreement in ranking of project success criteria among the panel of experts.

Since $n = 16$ is too large for the table of critical values of Kendall's, chi-square approximation of the sampling distribution of W is computed with the following equation:

$$\chi^2 = m(n - 1)W$$

Therefore, $\chi^2 = 105.59$ and using a χ^2 critical table for $n = 16$ and $\alpha = 0.05$, the $\chi_{0.05}^{2(n-1)} = \chi_{0.05}^{2(15)} = 15.00$. Since computed value χ^2 is greater than critical table $\chi_{0.05}^{2(15)}$ null hypothesis H_0 is rejected and alternative hypothesis H_1 is accepted. Therefore, concluded that there is a significant degree of agreement among the panel of experts with respect to how they ranked the project success criteria.

The same approach used for input factors. The calculated Kendall's Coefficient of concordance for input factors $W = 0.2543$. The test of hypothesis for input factors would be:

Null hypothesis: H_0 : There is no agreement in ranking of input factors among the panel of experts.

Alternative hypothesis: H_1 : There is an agreement in ranking of input factors among the panel of experts.

Since $n = 11$ is large for the table of critical values of Kendall's, chi-square approximation of the sampling distribution of W is computed. Therefore, $\chi^2 = 45.77$ and using a χ^2 critical table for $n = 11$ and $\alpha = 0.05$, the $\chi_{0.05}^{2(n-1)} = \chi_{0.05}^{2(10)} = 18.31$. Since computed value χ^2 is greater than critical table $\chi_{0.05}^{2(10)}$ null hypothesis H_0 is rejected and alternative hypothesis H_1 is accepted. Therefore, concluded that there is a significant degree of agreement among the panel of experts with respect to how they rank the input factors. Although time, cost and quality are the basic criteria to project success, and they are identified and discussed in almost every article on project success, such as that of [34], [35], [36] and [37] other project success criteria may be required to be identified for each industries. The project success criteria identified in this research are close to those mentioned in project success definition provided by [38]. In addition to iron triangle (time, cost, & quality) and customer satisfaction, HSE has been identified due to its significant role in construction projects. Considering that we are developing a project success model for construction projects, it is obvious that a weak performance in HSE e.g. high rate of fatal and non-fatal injuries could significantly prejudice the iron triangle performance.

4.2. Weight restrictions

To define a relationship between weight factors for output, an interview is conducted with each sponsor and also the project charter is reviewed. In this interview, based on the context and goals of project, the relationship between the project success measures is defined. For instance, $u_1 \geq 2u_3$ means that in this project time index is twice more important than quality index.

For define the relationship between the input factors, interview with project manager are conducted. For instance, $v_2 \geq v_3$ means that team competency has more effects on the project success than knowledge and proficiency of the customer.

4.3.Data

In this section, the data which is used to compare nine projects in Mapna company is described. Following the input and output factors related to each DMU (project) is defined. then, weight restriction for each DMU is defined.

Table 3: input and output data

Project	Output factors					Input factors				
	Time Performance	Cost Performance	Quality Performance	HSE	Client Satisfaction	Organizational Sponsorship	Project Manager Competency	Client Organization	Project Operational Environment	Organizational Experience
1	0.52	0.16	0.78	1.07	1.18	5.00	5.00	5.00	5.00	5.00
2	1.054	1.44	0.99	0.24	0.88	3.00	3.00	3.00	4.00	3.00
3	1.09	0.31	1.37	0.29	1.21	4.00	4.00	4.00	4.00	5.00
4	0.89	0.49	1.12	0.92	0.90	4.00	3.00	3.00	4.00	4.00
5	0.99	0.20	1.01	0.95	1.03	5.00	5.00	4.00	5.00	3.00
6	0.96	0.34	1.19	0.97	0.90	5.00	3.00	4.00	2.00	5.00
7	0.52	1.44	1.11	1.54	0.90	5.00	5.00	3.00	5.00	5.00
8	1.11	1.79	1.52	3.43	1.121	3.00	3.00	2.00	2.00	3.00
9	0.70	0.28	1.22	0.80	1.10	4.00	4.00	4.00	2.00	4.00

DMU#1

$$u_2 \geq u_1, u_3 \geq 2u_2, u_4 \geq u_5$$

$$v_2 \geq 2v_3, v_4 \geq 2v_5$$

DMU#2

$$u_2 \geq 2u_3, u_1 \geq 2u_3, u_3 \geq u_5, u_3 \geq u_4$$

$$v_1 \geq 3v_2, v_2 \geq 2v_5$$

DMU#3

$$u_5 \geq 3u_1, u_5 \geq 3u_2, u_5 \geq u_3$$

$$v_1 \geq 2v_3, v_3 \geq 2v_5$$

DMU#4

$$u_1 = u_2, u_3 \geq 3u_2, u_4 \geq 2u_2$$

$$v_2 \geq 2v_3, v_4 \geq 2v_5$$

DMU#5

$$u_5 \geq 2u_3, u_4 \geq 2u_3, u_3 \geq u_2, u_3 \geq u_1$$

$$v_1 \geq 2v_3, v_4 \geq 2v_1$$

DMU#6

$$u_4 \geq 3u_1, u_4 \geq 3u_2, u_4 \geq 2u_3$$

$$v_1 \geq 2v_4, v_4 \geq 2v_5$$

DMU#7

$$u_1 \geq u_2, u_2 \geq 3u_3, u_3 \geq 2u_4, u_3 \geq 2u_5$$

$$v_1 \geq 2v_3, v_4 \geq 2v_1$$

DMU#8

$$u_5 \geq 3u_1, u_5 \geq 3u_2, u_5 \geq u_3$$

$$v_1 \geq 2v_2, v_2 \geq 2v_3$$

DMU#9

$$u_5 \geq 2u_3, u_4 \geq 2u_3, u_3 \geq u_2, u_3 \geq u_1$$

$$v_1 \geq 2v_4, v_4 \geq 2v_5$$

4.4. Results

At first time when we do not consider weight restrictions, the DMUs efficiency rank is as follows:

Table 4: project success ranking without considering weight restriction

DMU (Project)	1	2	3	4	5	6	7	8	9
Ranking	8	3	6	7	4	5	9	1	2

After using weight restrictions that mentioned above, the objective values and weights are calculated as follow. The construction of the models allows the investigation of relative efficiency scores. We use the GAMS software to obtain solutions of these formulations. The decision variables in these formulations represent weights associated with the formation of a project success.

Table 5: project success ranking considering weight restriction

DMU (Project)	1	2	3	4	5	6	7	8	9
Efficiency	0.31	0.95	0.81	0.80	0.91	0.80	0.41	1.00	0.79
Ranking	8	2	4	5	3	5	7	1	6

As illustrated in the above table, the ranking of the projects is different from the condition that the weight restrictions are not considered. In DEA, project with efficiency rating of less than 1 are considered relatively inefficient. Therefore in this example project No#8 become efficient. Data from DMU#8 indicates that the outputs have higher values than the other DMUs however the inputs have equal or lower values. So it is obvious that the performance of this project was better than the other projects. The lowest performance belongs to the first DMU. It sounds logical as the inputs are in best situation while the outputs, especially the third one, have lower values in comparison to the other DMUs.

Regarding the second DMU which has a relatively good performance, it can be said that considering the weight factors the first and the second output are more important than the rest of outputs. However the forth output, HSE performance, has a relatively low value; it makes no problem as its importance was also low. At the other hand as the first and the second input are more effective, considering the weight factors constraints, their lower values can be considered as an indicator for its performance. So it is reasonable that the second project ranked.

DMU#7 ranked 7 out of 9 projects. It is quite clear that considering the weight factors constraints, time performance which is more important than the other outputs, with the value of 0.52 has a lower value respect to the others. Furthermore, in the input factors, Project Operational Environment factor which is the most important factor compare to the others is in the most favorable situation. It seems logical that it became one of the low ranking projects.

5 Conclusion

This paper presented a usage of DEA approach for ranking construction project success. The model used five project success criteria as an output factors for measuring success of construction projects and five input factor as a factors have effects on the output factors. As core competency of project-based organizations is to execute projects in an effective and efficient way, measuring how much a project was successful can play a key role to improve project management competency. In summary, there are two

significant applications of the results we have obtained. First, we proposed one overall measure for success of the construction projects as an efficiency which can be applied for comparing construction projects. Second, this analysis can be used to improve the success of project based on setting the input factors. It means that the input factors measures of each project can be determined before starting the project to achieve the stated success measure ranking. The model presented here was from performing organization point of view and it could be developed for other project stakeholders' points of view for future studies. Another suggestion could be developing a project success model for other projects in different industries based on the conceptual framework proposed in this paper. Also the other proper DEA models such as BCC can be used to investigate the ranking of project.

References

- [1] M. D. Murray, J. E. Tookey, D. A. Langford, C. Hardcastle, Construction Procurement Systems: Don't Forget Murphy's Law, Paper submitted at the International Symposium of the Working Committee, CIB W92 (Procurement Systems) (2002).
- [2] O. J. Klagegg, K. Samset, O. M. Magnussen, Improving Success in Public Investment Projects: Lessons from Government Initiative in Norway to Improve Quality at Entry, Paper presented at the 19th IPMA World Congress, (2005).
- [3] A. De Wit, Measurement of project success, *International Journal of Project Management*, 6 (3) (1988) 164-70.
[http://dx.doi.org/10.1016/0263-7863\(88\)90043-9](http://dx.doi.org/10.1016/0263-7863(88)90043-9)
- [4] J. K. Pinto, D. P. Slevin, Project success: definitions and measurement techniques, *Project Management Journal*, 19 (3) (1988) 67-73.
- [5] C. S. Lim, M. Z. Mohamed, Criteria of project success: an exploratory re-examination, *International Journal of Project Management*, 17 (4) (1999) 243-48.
[http://dx.doi.org/10.1016/S0263-7863\(98\)00040-4](http://dx.doi.org/10.1016/S0263-7863(98)00040-4)
- [6] H. Kerzner, *In Search of Excellence in Project Management*, Van Nostrand Reinhold. New York, NY, (1998).
- [7] A. K. Munns, B. F. Bjeirmi, The role of project management in achieving project success, *International Journal of Project Management*, 14 (2) (1996) 81-87.
[http://dx.doi.org/10.1016/0263-7863\(95\)00057-7](http://dx.doi.org/10.1016/0263-7863(95)00057-7)
- [8] T. Cooke-Davies, The "real" success factors on projects, *International Journal of Project Management*, 20 (3) (2002) 185-90.
[http://dx.doi.org/10.1016/S0263-7863\(01\)00067-9](http://dx.doi.org/10.1016/S0263-7863(01)00067-9)
- [9] D. Baccarini, The logical framework method for defining project success, *Project Management Journal*, 30 (4) (1999) 25-32.
- [10] D. B. Ashley, New trends in risk management. paper presented at the Internet's 10th International Expert Seminar on New Approaches in Project Management, Zurich, 10-12 March, (1986).

- [11] V. Sanvido, F. Grobler, K. Parfitt, M. Guvenis, M. Coyle, Critical success factors for construction projects, *Journal of Construction Engineering and Management*, 118 (1) (1992) 94-111.
[http://dx.doi.org/10.1061/\(ASCE\)0733-9364\(1992\)118:1\(94\)](http://dx.doi.org/10.1061/(ASCE)0733-9364(1992)118:1(94))
- [12] R. Takim, A. Akintoye, A conceptual model for successful construction project performance, Paper presented the 2nd international Postgraduate Research Conference in Built and Human Environment, University of Salford, Salford, (2002).
- [13] R. Atkinson, Project Management: Cost, Time and Quality, Two Best Guesses and A Phenomenon, It's Time to Accept Other Success Criteria, *International Journal of Project Management*, 17 (6) (1999) 337-42.
[http://dx.doi.org/10.1016/S0263-7863\(98\)00069-6](http://dx.doi.org/10.1016/S0263-7863(98)00069-6)
- [14] P. Patanakul, D. Milosevic, The Effectiveness in Managing a group of Multiple Projects: Factors of influence and Measurement Criteria, *International Journal of Project Management*, 27 (2009) 216-233.
<http://dx.doi.org/10.1016/j.ijproman.2008.03.001>
- [15] D. K. H. Chua, Y. C. Kog, P. K. Loh, Critical success factors for different project objectives, *Journal of Construction Engineering and Management*, 125 (3) (1999) 142-50.
[http://dx.doi.org/10.1061/\(ASCE\)0733-9364\(1999\)125:3\(142\)](http://dx.doi.org/10.1061/(ASCE)0733-9364(1999)125:3(142))
- [16] A. J. Shenhar, O. Levy, D. Dvir, Mapping the dimensions of project success, *Project Management Journal*, 28 (2) (1997) 5-13.
- [17] A. Sadeh, D. Dvir, A. Shenhar, The role of contract type in the success of R&D defense projects under increasing uncertainty, *Project Management Journal*, 31 (3) (2000) 14-21.
- [18] J. F. Y. Yeung, A. P. C. Chan, D. W. M. Chan, L. K. Li, Development of a Partnering Performance Index (PPI) for construction projects in Hong Kong: a Delphi study, *Construction Management and Economics*, 25 (12) (2007) 1219-1237.
<http://dx.doi.org/10.1080/01446190701598673>
- [19] A. Charnes, W. W. Cooper, E. Rhodes, Measuring the Efficiency of Decision Making Units, *European Journal of Operational Research*, 2 (6) (1978) 429-444.
[http://dx.doi.org/10.1016/0377-2217\(78\)90138-8](http://dx.doi.org/10.1016/0377-2217(78)90138-8)
- [20] R. G. Dyson, R. Allen, A. S. Camanho, V. V. Podinovski, C. S. Sarrico, E. A. Shale, Pitfalls and protocols in DEA, *European Journal of Operational Research*, 132 (2001) 245-259.
[http://dx.doi.org/10.1016/S0377-2217\(00\)00149-1](http://dx.doi.org/10.1016/S0377-2217(00)00149-1)
- [21] J. Cubbin, G. Tzanidakis, Regression versus data envelopment analysis for efficiency measurement: An application to the England and Wales regulated water industry, *Utilities Policy*, 7 (1998) 75-85.
[http://dx.doi.org/10.1016/S0957-1787\(98\)00007-1](http://dx.doi.org/10.1016/S0957-1787(98)00007-1)
- [22] S. Grosskopf, Statistical inference and non-parametric efficiency: A selective survey, *Journal of Productivity Analysis*, 7 (1996) 161-176.
<http://dx.doi.org/10.1007/BF00157039>

- [23] C. A. K. Lovell, Production Frontiers and Productive Efficiency. In: Fried, H. O., C. A. K. Lovell and S. S. Schmidt (Eds.), *The Measurement of Productive Efficiency: Techniques and Applications*. New York & Oxford: Oxford University Press, (1993) 3-67.
- [24] T. A. McCarty, S. Yaisawarng, Technical Efficiency in New Jersey School Districts. in H. Fried, C.A.K. Lovell and S.S. Schmidt, eds, *The Measurement of Productive Efficiency: Techniques and Applications* (Oxford: Oxford University Press), (1993) 271-287.
- [25] P. T. Chang, J. H. Lee, A fuzzy DEA and knapsack formulation integrated model for project selection, *Computers & Operations Research*, 39 (1) (2012) 112-125.
<http://dx.doi.org/10.1016/j.cor.2010.10.021>
- [26] H. Eilat, B. Golany, A. Shtub, R&D project evaluation: An integrated DEA and balanced scorecard approach, *Omega*, 36 (5) (2008) 895-912.
<http://dx.doi.org/10.1016/j.omega.2006.05.002>
- [27] L. M. Seiford, R. M. Thrall, Recent Developments in DEA: The Mathematical Programming Approach to Frontier Analysis, *Journal of Economics*, 46 (1990) 7-38.
[http://dx.doi.org/10.1016/0304-4076\(90\)90045-U](http://dx.doi.org/10.1016/0304-4076(90)90045-U)
- [28] A. I. Ali, L. M. Seiford, The mathematical programming approach to efficiency analysis. in *The Measurement of Productive Efficiency*, eds H.O. Fried, C.A.K. Lovell & S.S. Schmidt, Oxford University Press, New York, (1993).
- [29] A. Charnes, W. W. Cooper, A. Y. Lewin, L. M. Seiford, *Data Envelopment Analysis: Theory, Methodology and Applications*. Boston, MA: Kluwer Academic Publishers, (1995).
- [30] L. M. Seiford, A Bibliography for Data Envelopment Analysis (1978 - 1996), *Annals of Operations Research*, 73 (1997) 393-438.
<http://dx.doi.org/10.1023/A:1018949800069>
- [31] G. Tavares, A Bibliography of Data Envelopment Analysis. (1978-2001). *Rutcor Research Report, RRR 01-02*, Rutgers University, (2002).
- [32] W. D. Cook, L. M. Seiford, Data envelopment analysis (DEA) – Thirty years on, *European Journal of Operational Research*, 192 (1) (2009) 1-17.
<http://dx.doi.org/10.1016/j.ejor.2008.01.032>
- [33] B. Green, M. Jones, D. Hughes, A. Williams, Applying the Delphi technique in a study of GP's information requirements, *Health and Social Care in the Community*, 17 (3) (1999) 198-205.
<http://dx.doi.org/10.1046/j.1365-2524.1999.00176.x>
- [34] W. Belassi, O. I. Tukul, A new framework for determining critical success/failure factors in projects, *International Journal of Project Management*, 14 (3) (1996) 141-51.
[http://dx.doi.org/10.1016/0263-7863\(95\)00064-X](http://dx.doi.org/10.1016/0263-7863(95)00064-X)

-
- [35] Z. Hatush, M. Skitmore, Evaluating contractor prequalification data: selection criteria and project success factor, *Construction Management and Economics*, 15 (2) (1997) 129-47.
<http://dx.doi.org/10.1080/01446199700000002>
- [36] D. H. T. Walker, An investigation into construction time performance, *Construction Management and Economics*, 13 (3) (1995) 263-74.
<http://dx.doi.org/10.1080/01446199500000030>
- [37] D. H. T. Walker, The contribution of the construction management team to good construction time performance – an Australian experience, *Journal of Construction Procurement*, 2 (2) (1996) 4-18.
- [38] D. B. Ashley, C. S. Lurie, E. J. Jaselskis, Determinants of construction project success, *Project Management Journal*, 18 (2) (1987) 69-79.