Teknik Dergi, 2019 8937-8959, Paper 529

Cost and Time Management Efficiency Assessment for Large Road Projects Using Data Envelopment Analysis

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ABSTRACT

Upon the completion of national road projects, their cost and time deviations are often reported. These deviations from the projected values are a result of complications in the time and cost management of such projects. Controlling the cost and time overrun of projects is important for successful implementation and efficient project management. However, few studies have attempted to measure the project cost and time management efficiency in civil engineering. Thus, this issue requires further investigation. In this study, large road projects that had poor cost and time management were selected. The chosen projects were configured as Decision Making Units (DMUs) in a Data Envelopment Analysis (DEA). It is a non-parametric modern mathematical tool for measuring relative managerial performance and determining efficient DMUs. The cost and time management efficiency of the projects was calculated using this tool, and the resulting values were ordered according to importance. The identified results demonstrate that additional works, inaccurate initial project scope, increase or change in the scope of the project, and design changes are four common critical causes that strongly impact both time and cost management efficiency.

Keywords: Data envelopment analysis, management performance evaluation, project management efficiency, project management, cost and time overrun.

1. INTRODUCTION

Cost and time overruns are common phenomena in large civil engineering projects. These variables are defined as discrepancies between predicted cost and duration with actual total cost, and time taken at project completion. Exceeding the budget and running over the

Note:

- This paper has been received on January 08, 2018 and accepted for publication by the Editorial Board on November 12, 2018.
- Discussions on this paper will be accepted by May 31, 2019.

• https://dx.doi.org/10.18400/tekderg.375664

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schedule for the implementation of projects is a significant problem. This has encouraged researchers to conduct detailed studies on the causes that impact the contracted cost and schedule.

Arditi et al. [1] investigated the sources of cost overrun in public projects. In the first statistical treatment of the problem, Flyvbjerg et al. [2] studied the frequency and magnitude of cost overrun in transport infrastructure projects. They concluded that transport infrastructure projects generally exceed their time and/or cost, and also identified the cost as a highly uncertain criteria. They also found that 90% of transportation infrastructure projects experience cost escalation, indicating that cost overrun is a pervasive phenomenon. Assaf and Al-Hejji [3] studied the sources of extensions in the duration of large construction projects and identified the causes leading to delay. It was found that approximately 2/3 of large projects experience different degree of time overruns. In other studies, the cost overrun causes impacting projects were identified and categorized [4]. Ahsan and Gunawan [5] inspected and analysed the cost and time variation of 100 international development projects. They identified the major causes of time extension and cost overrun. Ahbab and Celik [6] proved the existence of time and cost overrun by obtaining the critical causes affecting time and cost criteria in large road projects. Cheng [7] studied the important causes impacting on the cost of a project, and developed new methods to control and avoid cost overrun. The aim of these investigations is to assist project managers by highlighting critical causes and directing their efforts to complete the project successfully [8, 9, 10, 11].

There are different criteria for benchmarking a completed project as successful. The parties involved in a project (Investor, client, contractor, consultant, and end-consumer) may assess the outcome differently. For instance, the success of a project was traditionally compared to the output and interrelation of time, cost, and quality through the Barnes' Iron Triangle [12].

Empirical and academic research has revealed that project managers play a vital role in delivering projects within the specified timeframe, and budget of the contract. This starring role in large projects is of high importance. Olsen [13] defined successful project management as the delivery of a project within the time, cost, and quality constraints. Munns and Bjeirmi [14] noted the importance of good project management leading to a higher possibility of project success. It is obvious that the extent to which the project manager controls the budget and schedule will affect the probability of success. The importance of applying project management, and project management methods has been widely researched by Besner and Hobbs [15], Chou and Yang [16], de Carvalho et al. [17], and Joslin and Muller [18]. Based on these studies, it can be concluded that the role of efficient project management is particularly important.

Efficiency can be defined as the extent of the deviation between actual performance and anticipated performance, and should be compared with an objective function [19]. Investing in building organizational project management expertise will lead to greater efficiencies in projects [20].

Serrador and Turner [21] have demonstrated that project efficiency and project success correlates moderately strongly with the overall project success. Project management efficiency can be characterized as utilization of effective project administration techniques to accomplish the clearly defined project scope and goals with minimum possible deviation.

Iyer and Banerjee [22] measured and ranked managerial efficiency in terms of the schedule during project execution.

Investors and project owners are attentive to ensuring a successful project through efficient project management, mostly in terms of time and budget variables. Project Management Efficiency can be affected by different causes, leading to cost deviations and delays in the project.

It is believed that there is a vital need for greater focus on extracting the causes that critically reduce the efficiency of project managers. To achieve this goal and obtain reliable results, mathematical methods can be applied to compute management efficiency or make a comparison between project management efficiencies.

The comparison of projects in terms of management efficiency can be undertaken by different parametric and nonparametric methods. Nonparametric methods do not consider the studied data as following a certain distribution, and place no (or very restricted) assumptions on the data. Nonparametric methods are mostly used for nominal or ordinal datasets, whereas parametric methods are applied to data sets with interval or ratio scales [23].

Common nonparametric techniques are Data Envelopment Analysis and Free Disposable Hull analysis. The Distribution-Free Approach, Stochastic Frontier Approach, and Thick Frontier Approach are parametric methods for efficiency measurement [24].

Data Envelopment Analysis is a powerful tool and is extensively used because of its advantages in determining efficiency, such as the ability to handle multiple inputs and outputs in a model, no assumptions about the input weights, and the ability to relate the resources expended on a certain activity to the level of success for that particular action [25] and [26].

Thus, due to advantages of this tool as an effective mathematical model for determining project efficiencies, authors consider it feasible and reasonable to apply this technique. Another incentive for using this tool is the ability to compare project management efficiencies based on the multiple defects influencing the time and cost criteria. To the best knowledge of the authors, this is the first time that Data Envelopment Analysis has been applied to large transportation projects to assist decision makers in efficient project management.

In this study, 63 large transportation projects with cost and time deviations were selected from the projects sponsored and financed by the Asian Development Bank. The selected projects are large in terms of cost criteria, with estimated total cost in between 12 and 1566 million dollar. Through project completion reports, Bank evaluates and rates the success of its projects according to relevance, effectiveness, efficiency, and sustainability [27]. On average, each report is about 60 pages and contains the project description, evaluation of the bank in design and execution of the project, performance, and overall assessment and recommendations at the end. Detailed Information about outputs of the project including scope and objectives, authorized and actual costs detected responsible causes for overruns, disbursements, schedule and extension causes, and implementation arrangements are also provided.

The identified causes of time and cost overruns were extracted from project completion reports and sorted in terms of the number of replications. Then, using Data Envelopment Analysis as a robust tool, the relative efficiency scores of project management for the selected projects were computed and sorted accordingly. Using this methodology, the causes that negatively impacted the efficiency of project management and led to unsuccessful project status were recognized and extracted. These causes should be considered and addressed by policy and decision makers as critical negative efficiency causes. Additionally, more attention to these causes will help to improve the project management efficiency, and increase the likelihood of project success.

The first objective of this paper is to compute and compare the time and cost management efficiency of projects (Decision making units) regarding their contributing causes using Data Envelopment Analysis. Then, the importance of causes that adversely affect the management efficiency in terms of time and cost is quantified by applying sensitivity analysis. In this way, policy and decision makers in Asian Development Bank, government transportation departments, contract affairs units, project managers, and contractor companies will be able to improve their management efficiency. It is believed that the developed analytical tool can be used to benchmark the managerial efficiency through mitigation of the seriously continuing problems of time delays and cost overruns and objectively recognize management efficiency gaps. The rest of article is organized as follows. First, Data Envelopment Analysis methodology is illustrated. Second, Data aggregation, selection and preparation is described. Then, achieved results are discussed. As a final point, conclusions are provided.

2. DATA ENVELOPMENT ANALYSIS

Data Envelopment Analysis (DEA) is a powerful service management and benchmarking technique developed by Charnes, Cooper, and Rhodes (CCR) in 1978 to evaluate non-profit, and public-sector organizations [28]. Since its inception, this method has been used to identify ways of improving services that are not visible using other techniques. It is an evaluation tool for a set of entities called decision making units (DMUs) with multiple inputs and multiple outputs. It is also a decision-making tool that measures the relative efficiency of comparable units. The CCR model is the first and most fundamental DEA model to evaluate the relative efficiency of DMUs.

Consider a set of homogenous DMUs as DMU_j $(j=1,\dots, n)$. Each DMU consumes m inputs to produce r outputs. Suppose that $X_j=(x_{1j},\dots,x_{mj})$ and $Y_j=(y_{1j},\dots,y_{rj})$ are vectors of input and output values for DMU_j, respectively, and let $X_j \geq 0$ and $Y_j \geq 0, Y_j \neq 0$. The Production Possibility Set (PPS) T_C can be constructed by considering the following postulates.

The observed activities (X_j, Y_j) $\quad j=1,2,\dots n$ belong to T_C;

If an activity (X, Y) belongs to T_C, then activity (tX, tY) belongs to T_C for any positive scalar t. This property is called the constant returns-to-scale assumption;

For any activity (X, Y) in T_C, any semi-positive activity $(\overline{X}, \overline{Y})$ with $\overline{X} \geq X$ and $\overline{Y} \leq Y$ is included in T_C;

Any convex combination of activities in T_C belongs to T_C;

T_C is the smallest set that satisfies the above four properties.

With respect to the above assumptions, T_C can be defined as follows:

$$T_C = \{(X,Y) \mid X \geq \sum_{j=1}^{n} \lambda_j X_j ,\ Y \leq \sum_{j=1}^{n} \lambda_j Y_j , \lambda_j \geq 0, \forall j\} \tag{1}$$

Now, for the evaluation of DMUs, DMU_o with (X_0, Y_0) as the input–output vector is written from an input orientation with some free value θ such that $(\theta X_0, Y_0)$ belongs to PPS. Thus,

$$\begin{aligned} &Min \quad \theta \\ &S.t \quad (\theta X_0, Y_0) \in T_C \end{aligned} \tag{2}$$

Based on the definition of T_C, the following linear programming problem is obtained:

$$\begin{aligned} &Min \quad \theta \\ &S.t \quad -\sum_{j=1}^{n} \lambda_j X_j + \theta X_0 \geq 0 \\ &\qquad \sum_{j=1}^{n} \lambda_j Y_j \geq Y_0 \\ &\qquad \lambda_j \geq 0,\ j = 1,\ldots,n. \\ &\qquad \theta \ free \end{aligned} \tag{3}$$

The dual of the above linear programming problem is used to obtain values for the input weights v_i and the output weights u_r:

$$\begin{aligned} &Max \quad \theta = \sum_{r=1}^{s} u_r y_{ro} \\ &s.t \quad \sum_{i=1}^{m} v_i x_{io} = 1 \\ &\qquad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \quad j = 1,2,\ldots,n \\ &\qquad v_i \geq 0 \quad i = 1,2,\ldots,m \\ &\qquad u_r \geq 0 \quad i = 1,2,\ldots,s \end{aligned} \tag{4}$$

In vector format, this can be written as follows:

$$\begin{aligned} &Max \quad \theta = UY_o \\ &s.t \quad VX_o = 1 \\ &\qquad UY_j - VX_j \leq 0 \quad j = 1,2,\ldots,n \\ &\qquad U \geq 0 \\ &\qquad V \geq 0 \end{aligned} \tag{5}$$

DMU_o is said to be CCR-efficient if $\theta^* = 1$ and there exists at least one optimal (V^*, U^*) with $V^* > 0$ and $U^* > 0$. *DMU_o* is said to be CCR-weak efficient if $\theta^* = 1$ and there exists $V^* \geq 0$ and $U^* \geq 0$ where at least one of V^* or U^* is equal to zero. Otherwise, *DMU_o* is CCR-inefficient, that is, $\theta^* \neq 1$.

Clearly, the optimal solution for both (3) and (4) is the same, which shows the efficiency value of the evaluation of *DMU_o* (X_0, Y_0). The optimal solutions of these models give us other useful information about *DMU_o*.

Assume that *DMU_o* (X_0, Y_0) is evaluated by model (3) and $\lambda^* = (\lambda_i^*, \ldots, \lambda_j^*, \ldots \lambda_n^*)$ with an objective function value of θ^* as its optimal solution. In vector λ^*, $\lambda_j^* > 0$ shows the effect of *DMU_j* in θ^* toward the efficiency value of *DMU_o*. Then, *DMU_j* can be considered as a benchmark in the efficiency improvement process of *DMU_o*. Alternatively, if it is assumed that (U^*, V^*) with an objective function of θ^* is the optimal solution of model (4) for *DMU_o* (X_0, Y_0), u_r^* $(r = 1, \ldots, s)$ and v_i^* $(i = 1, \ldots, m)$ can be considered as the weight or degree of importance of the r^{th} output and i^{th} input, respectively, in the efficiency value. Similarly, models based on variable returns-to-scale [29] may be used for this purpose.

Obviously, if u_r^* or v_i^* are equal to zero, the associated output or input has no effect on the efficiency of *DMU_o* [30].

One of the proposed methods for understanding the importance of inputs and outputs in the DMU efficiency values is to compute the average of the optimal weight values for u_r^* and v_i^* and compare these average values. Another significant method for the sensitivity analysis is to eliminate the inputs and outputs one by one, and compute the efficiency of the DMUs with the remaining inputs and outputs. Any decrement in the average efficiency value of a DMU shows the degree of importance of the eliminated input or output [31].

Furthermore, the sensitivity analysis for individual efficient DMUs may be employed to retain their efficiency against small changes in input or output values [32].

In this study, constant returns-to-scale are assumed for the evaluation of the observed DMUs. This is because the inherent nature of the construction industry means that increasing the number of contributing causes will increase the potential cost and time overrun.

3. DATA AGGREGATION, SELECTION, AND PREPARATION

International organizations and government departments routinely collect records and provide reports about national and international projects. The World Bank, Asian Development Bank, and the US Department of Transportation are among several organizations that frequently publish project data. Sometimes, researchers use the published data as secondary data. The advantages over primary data include the reduced time and expense of obtaining the data, the higher quality of the data, and the enhanced objectivity, accuracy, validity, and reliability of the data [33].

In this research, the Project Completion Reports published by Asian Development Bank were used as secondary data. Afterward 63 projects that suffered time and/or cost overruns were selected (See Appendix2). Quantity of time and cost deviations in percentage from authorized duration and budget reported in each document were carefully computed and obtained. In the next step of this research, the documents were carefully scanned to find the causes that had adverse effects on time and cost criteria in the projects. As a result, 66 causes were identified as having an adverse influence leading to either time or cost overrun. To identify the most significant causes for each criterion, the number of repetitions of each cause was counted and sorted. Tables 1 and 2 list the affecting causes that were repeated 10 times or more within the projects. (See Appendix 1 for full list of adverse time and cost causes and their number of replications.)

Table 1 - Ranking of the first twenty critical causes influencing the time of the project

Code	Causes of Delay	No. Repetition	Rank
19	Long period between time of bidding and contract award	16	1
33	Delay in mobilization by contractor	13	2
43	Severe weather problems (heat, cold, snow, rain, cyclone)	12	3
58	Poor procurement procedure	11	4
21	Design changes	10	5
31	Poor performance of contractor	10	5
14	Slowness of the owner's decision-making process	10	5
20	Increase in quantity of work (Additional works)	9	6
7	Poor project management, construction management and supervision	8	7
52	Increase or change in scope of the Project	8	7
63	Delay in Land Acquisition	8	7
35	Slow or Delayed material or equipment delivery to project site	7	8
2	Inaccurate initial project scope and cost estimate	7	8
64	Delay in appointment of consultant	7	8
17	Delay in Approval of feasibility study, drawings and material	6	9
50	Complicated administrative and governmental procedures (institutional problems)	6	9
18	Financial difficulties of owner/Client	5	10
44	Political issues-Changes	5	10
42	Poor and unforeseen site conditions (Location, ground, geological, events, security, ETC)	5	10
36	Unavailability or shortage of required materials in the local market on time	5	10

In the next step, the data were prepared and modelled using the Performance Improvement Management software [34]. A total of 51 projects were input related to the 20 most frequent causes of time overruns and 38 projects with the 10 most frequent causes of cost overruns were also modelled. This combinations of selection was considered because the number of selected projects has to be higher than the maximum between (m × s) and [3 × (m+ s)], being m and s the number of input and output criteria [35]. The output from each model was the inverse time and cost overrun percentage.

Table 2 - Ranking of the first ten critical causes influencing the cost of the project

Code	Causes of Cost Overrun	No. Repetition	Rank
37	Fluctuation and escalation in prices	21	1
47	Change in exchange rate	13	2
53	Underestimated and inaccurate appraisal	12	3
52	Increase or change in scope of the project	11	4
62	Increase in the amount of land acquisition, price, and Compensation	11	4
21	Design changes	10	5
2	Inaccurate initial project scope and cost estimate	7	6
20	Increase in quantity of work (Additional works)	7	6
42	Poor and unforeseen site conditions (Location, ground, geological, events, security)	7	6
61	Additional project management, consultancy and administration costs	6	7

4. RESULTS AND DISCUSSIONS

The main purpose of this paper is to draw attention to the performance and managerial efficiency of large road projects in terms of time and cost criteria. Therefore, in this step, the project management efficiency of the projects was measured using the Performance Improvement Management software [34]. This was done by applying the CCR model considering the causes affecting each of the time and cost criteria. The relative managerial efficiency measurement is provided as an efficiency score by the software. The results are summarized in Tables 3 and 5 for time and cost, respectively.

Time and cost management efficiency can be defined as a set of management techniques which minimizes the overall effect of adverse causes leading to time and cost overrun. In other word, managing tasks by reducing the effect of adverse causes and reach to the best output, which is the completion of the project in specified time and budget. Managerial efficiency can be expressed as a relative measure. Different project management teams have different efficiency in taking decisions and controlling cost and time criteria in presence of affecting causes. Their ability in prioritizing the tasks, taking actions against causes and minimizing defects of causes will show the extent of their success in efficient time and cost management.

Table 3 - Managerial relative efficiency score for time criteria of 51 projects

Project	Efficiency Score	Project	Efficiency Score	Project	Efficiency Score	Project	Efficiency Score
01	39.40	16	17.13	32	100	48	12.93
02	100	18	16.13	33	100	49	98.39
03	15.45	19	67.12	34	23.04	50	100
04	100	20	16.90	35	100	51	100
06	100	21	100	36	100	52	6.54
07	100	22	100	37	100	53	30.93
08	100	23	100	39	100	55	100
09	6.83	24	60.37	41	14.55	56	100
10	100	25	100	42	90.97	59	12.06
12	60.65	26	15.81	43	100	61	14.70
13	36.30	29	100	44	100	62	100
14	100	30	4.15	46	6.09	63	36.17
15	100	31	50.60	47	100		

As can be seen in Table 3, the relative managerial efficiency in terms of time for 27 out of 51 projects is 100%. This can be interpreted as follows:

1) Despite presenting various difficulties and delays, the different parties involved in the management of these projects succeeded in accomplishing the project efficiently. For instance, project 29 partially and efficiently overcame seven causes that affected the project time. Those causes were the long-time gap between project preparation and real start date of construction, the lack of knowledge in regional owners and local contractors with the circumstances of the Fédération International des Ingénieurs-Conseils (FIDIC), delays in the approval of some changes by the owner, the unavailability or shortage of required materials in the local market, equipment and manpower shortages, unforeseen events, and a tsunami. Those unexpected issues resulted in a time overrun of only 15% (See Appendix 2).

2) In project 49, the relative efficiency score in time management is 98.39%. Project managers faced with only two causes in this project including unforeseen events and the unavailability or shortage of required materials in the local market which are in common with project 29. This project was accomplished with 33% of time overrun (See Appendix 2).

This evidence shows that the project managers of this project could not able to efficiently overcome the common causes in compare with other project which overcome more causes with less time overrun.

In the second step, the focus was on the causes that critically influenced and impacted the managerial efficiency. Therefore, projects with less than 100% efficiency were investigated. A table was prepared based on the number of repetitions of causes in the selected inefficient projects. The causes were then sorted and those having the most critical effect on time criteria, leading to inefficient project management, are presented in Table 4.

Table 4. Number of repetitions of causes influencing time management efficiency in the inefficient projects

Code* / Project	33	21	7	43	31	19	14	58	2	52	17	35	18	20	23	63
01							x	x								
03		x			x				x				x			
09		x				x		x		x	x					x
12						x		x								
13		x	x		x											x
16						x		x	x	x				x		x
18	x			x					x	x		x				
19																
20			x	x	x								x			
24									x	x			x	x		
26	x	x		x									x	x		x
30	x	x	x		x											
31	x				x	x	x				x				x	
34			x	x	x		x				x					
41	x		x				x	x							x	
42							x					x				
46		x	x									x				
48	x	x				x		x			x				x	
49																
52	x	x	x	x		x						x		x	x	
53	x															
59	x	x		x						x						
61				x			x									
63	x								x							
Repetition	10	9	7	7	6	6	6	6	5	5	4	4	4	4	4	4
*	Refer to Appendix 1															

Based on Table 4, it can be concluded that delays in mobilization by the contractor, project design changes, and poor project management and supervision are the three main causes that severely affect the time management of projects.

Simultaneously, the efficiency of cost management was also studied, and Table 5 summarizes the managerial cost efficiency score for the investigated projects. This table clearly implies that 11 of the 38 projects are efficient in terms of cost management criteria. It clarifies that project managers could able to accomplish those 11 projects with efficient cost management despite presence of adverse causes that impacts the authorized cost. The other 27 project managers could not fully succeed in managing the cost against causes efficiently in comparing with successful project managers. For example, the US$ 465 million project represented by project 36 is an efficient project. The different parties responsible for the management of this project dealt with inaccurate cost estimates in appraisal, changes in the scope of the project, changes in land acquisition prices, and design changes to complete the project with a cost overrun of just 2.2%. Meanwhile project 37 was affected by three causes which are common with project 36. Effect of causes and inefficient cost management led this project to 75% of cost overrun from $762 million to $1,333 million. In this point, in line with the reasons in time management efficiency part, the importance of efficient cost management is concluded. However, 27 out of the 38 projects investigated are inefficient projects.

Table 5 - Managerial relative efficiency score for cost criteria of 38 projects

Project	Efficiency Score	Project	Efficiency Score	Project	Efficiency Score	Project	Efficiency Score
01	96.95	24	7.94	36	100	51	21.17
02	35.54	25	51.69	37	5.14	52	100
04	100	27	100	38	15.26	54	48.70
06	100	28	95.03	39	7.40	55	3.42
10	100	29	100	40	4.49	57	100
14	6.27	30	47.61	41	4.74	58	13.96
15	100	32	22.95	44	54.98	59	100
16	1.87	33	19.90	45	23.22	63	14.56
20	11.85	34	38.82	46	4.02		
21	13.02	35	100	47	21.79		

Parallel to time management efficiency calculation, Table 6 lists the main causes observed in projects with cost management efficiency scores of less than 100%. This table indicates that fluctuations and escalations in the prices of material, equipment, and labour have the most impact on the cost managerial efficiency score. As the projects being studied are international road projects, changes in the US dollar exchange rate also impacted the efficiency. Underestimated and inaccurate appraisals and increases in the land acquisition price and compensation were other influential causes.

Another point that needs more attention is that there are four common critical causes in Tables 4 and 6. These are the increased quantity of work by additional works (20), inaccurate initial project scope (2), increases or changes in the scope of the project (52) and design changes (21). These causes strongly impact the management efficiency of both time and cost criteria.

Table 6 - Number of repetitions of causes influencing cost management efficiency in inefficient projects

Code* / Project	37	47	53	62	52	20	21	42	2	10	61
01	x										
02	x						x	x		x	
14		x			x				x		
16	x		x		x	x					
20	x									x	
21	x	x				x				x	
24			x	x	x	x	x	x			
25		x							x		
28					x		x	x			
30	x										
32	x										
33		x			x	x		x			
34	x					x		x	x		
37			x	x			x				
38	x	x									x
39	x	x	x	x							
40	x		x	x	x	x	x				x
41	x								x		
44		x									
45	x	x		x							
46	x		x							x	
47	x				x						x
51	x			x							
54	x			x							
55	x	x	x	x				x	x		
58	x	x	x				x				
63		x	x								
Repetition	19	11	9	8	7	6	6	6	5	4	3
*	Refer to Appendix 1										

In order to investigate the significance of the aforementioned 10 cost causes on the cost management performance, and effect of previously defined 20 time causes on time management performance, sensitivity analysis tool was adopted. With the help of sensitivity analysis, authors verified the influence of every single cause on the overall efficiency of the management team assigned for projects. This specific analysis enabled the identification of the degree of deviation in other words, the magnitude of impact of each cause in terms of effect on the efficiency of project management of construction projects. The sequential steps followed in this study for identifying the magnitude of impact of each cause on management efficiency are; (1) Elimination of each cause as input from the critical causes list one by one, (2) Computation of the efficiency value of project managers subsequent to execution of step (1), (3) calculation of the rate of declines in value from previous efficiency average in order to determine the level of significance for each cause.

For each project, decrease in management efficiency score compared to original one reflects the importance of eliminated cause in that project management performance. As performed by Montoneri et al [31], amount of deviation in the new efficiency average of all projects from the original efficiency average indicates the level of significance for the eliminated cause.

Tables 7 and 8 present the results of sensitivity analysis and the change in the new efficiency average compared with the original efficiency score average for the time and cost criteria.

According to the results summarized in Table 7, the deviations given by omitting design changes (cause 21), delay in mobilization by contractor (cause 33), and poor project management (cause 7) from the original average value are greater than for the other inputs. Thus, it can be concluded that these causes have a greater impact on the efficiency of the time management of projects. (See Appendix 1)

Table 7 - Results of sensitivity analysis and deviations in time criteria

Cause Code	New Efficiency Average	Cause Code	New Efficiency Average	Cause Code	New Efficiency Average	Cause Code	New Efficiency Average
2	67.71	19	67.71	35	67.71	50	66.74
7	52.04	20	65.75	36	67.71	52	67.71
14	57.34	21	24.27	42	58.74	58	63.02
17	67.54	31	67.49	43	61.35	63	63.78
18	67.71	33	42.09	44	62.56	64	66.66
Average of efficiency scores in Table 3: **67.71**							

As can be seen from Table 8, the studied projects are most sensitive to underestimated and inaccurate appraisals (cause 53), changes in the exchange rate (cause 47), and an increase in the quantity of work (cause 20). Based on the results, these causes have a greater impact on the cost management efficiency than other causes.

Table 8 - Results of sensitivity analysis and deviations in cost criteria

Cause Code	New Efficiency Average	Cause Code	New Efficiency Average
2	37.96	47	37.07
20	37.35	52	44.77
21	47.64	53	29.66
37	41.63	61	42.56
42	46.42	62	47.17
Average of efficiency scores in Table 5: **47.17**			

The results obtained by the sensitivity analysis using the Performance Improvement Management software are in line with the results in Tables 3 and 5. In the same way, these results confirm that the causes investigated here not only impact on the final cost and time of projects, but also influence the efficiency of time and cost management.

4.1. Importance of time and cost management efficiency

An awareness of the extent of the interaction between time and cost management efficiency is an important point. This may help decision makers and project managers to undertake countermeasures to reduce the probability of time and cost overruns. Consequently, in the last part of the current study, projects that suffered both time and cost overruns were selected.

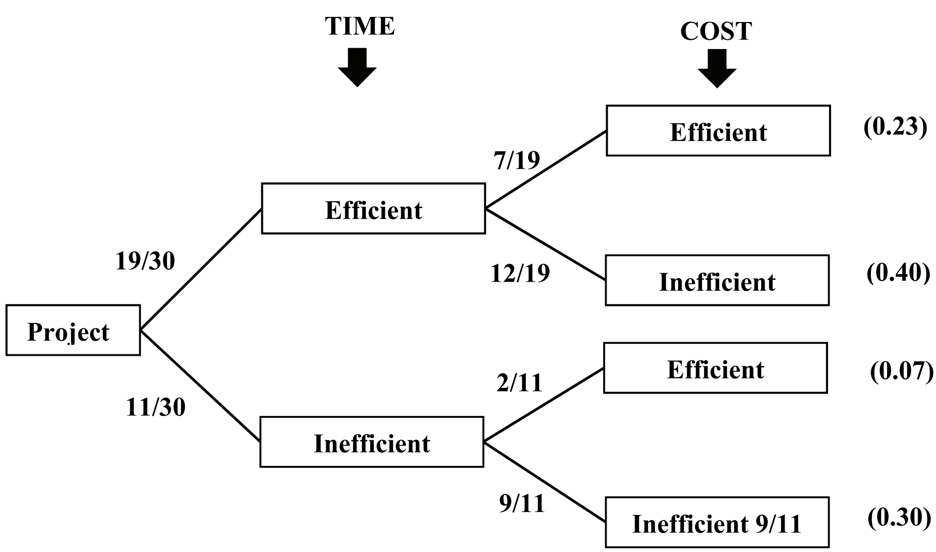

Figure 1 - Probability tree diagram of efficiency for time management criteria

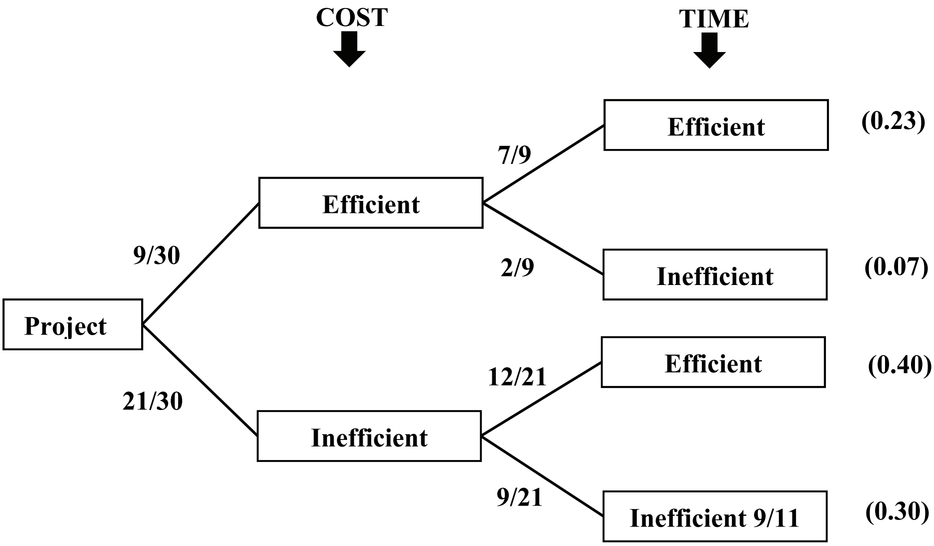

Figure 2 - Probability tree diagram of efficiency for cost management criteria

Based on Table 3 and 5, only 7 out of the total of 30 projects succeeded in managing both the time and cost criteria separately to achieve 100% efficiency. Projects 11 and 21 have inefficient management in terms of time and cost criteria, respectively. Figures 1 and 2 depict probability tree diagrams of the projects in terms of time and cost management efficiency.

Figure 1 plainly shows that, in the case of inefficient time management, the likelihood of inefficient cost management is approximately 4 times higher than that of efficient cost management. Therefore, time management is much more critical than cost management.

According to Figure 2, it can be concluded that the observed projects were mostly unsuccessful in terms of cost management efficiency. Moreover, efficient cost management is more likely to lead to efficient time management than to inefficient time management.

4.2. Impact of Different Elements of Project Management

It is believed that resulted cost and time overrun in the studied projects are a consequence of adverse causes that are rooted from other project management elements at the same time. Causes 3, 5, 8, 16, 24, 28, 45, 52 and 58 in Appendix 1 have direct relation with Communication Management, Contract Management, Quality Management, Procurement Management, Health and Safety Management, and Scope Management. Therefore, it can be concluded that not only time and cost management, but also existence of some other project management elements affects the time, and cost management efficiency. In other word, time and cost management efficiency is a portion of most of other project management elements combination.

5. CONCLUSIONS

The purpose of this article was to fill a gap in the literature concerning time and cost management efficiency for completed large transportation projects. By applying the CCR model in Data Envelopment Analysis, the authors have measured, scored, and benchmarked the schedule and budget supervisory efficiency of the studied projects. After benchmarking the efficient and inefficient projects in terms of time and cost management, a sensitivity analysis was conducted to examine the causes impacting these efficiencies.

The results obtained in this study reveal that design changes during the execution phase, delays in mobilization by the contractor, and poor project management have a significant effect on time management efficiency. Additionally, cost management efficiency is more sensitive to underestimated and inaccurate appraisals, changes in the exchange rate, and increases in the quantity of work. This article shows that this methodology can be widely and effectively applied to evaluate the managerial efficiency of project managers or project management teams in terms of time and cost or any other criteria. Moreover, using this methodology, the most significant causes impacting a project can be recognized, and these may be used as a guide for practitioners and decision makers to take the necessary countermeasures.

Another significant finding in this study is that inefficient time management of projects increases the chance of inefficient cost management to four times that of efficient cost management. Therefore, project managers should objectively pay more attention to controlling the time of the project.

The limitation of this investigation is that, this research was conducted based on projects implemented in Asia region. Also selected projects were among Asian Development Bank road projects. Moreover total number of studied projects were constrained by the number of projects that experienced time and cost overrun. Finally, the evaluated completion reports provides information, reason, and results of the problems for time and cost overrun.

It should be noted that, the obtained conclusions in this study are restricted to the selected project's data and considered criteria for those projects only.

Acknowledgements

The authors gratefully acknowledge the Asian Development Bank for providing the data used in this research through access to publicly disclosed Project Completion Reports. The data analysis phase detailed in this research would not have been possible without obtaining the data within these reports.

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APPENDICES

Appendix 1. Full List of Causes Affecting Time & Cost Criteria and their Repetition in Studied Projects, respectively

Code	Affecting Cause	# Repetition	
		in Time	in Cost
1	Inadequate front-end planning of project	1	0
2	Inaccurate initial project scope and cost estimate	7	7
3	Inadequate communication between design and construction parties	1	1
4	Poor site management	1	0
5	Not communicating with all parties dealing with the budget	1	1
6	Owner interference in the project	1	1
7	Poor project management, construction management, and supervision	8	0
8	Poor contract management (inexperience of following contract condition)	2	1
9	Poor provision of information to project participants	1	1
10	Inflation	2	4
11	Failure to resolve change orders and prevent them from becoming claims/disputes	1	1
12	Too many construction activities going on at the same time	1	1
13	No financial incentive to contractor to finish the project ahead of schedule	1	1
14	Slowness of the owner's decision-making process (approval of activities)	10	1
15	Slow financial and payment procedures adopted by the client	4	2
16	Contract modifications and variations (replacement, addition, and change)	0	2
17	Delay in approval of feasibility study, drawings, and material	6	0
18	Financial difficulties of owner/client	5	0
19	Long period between time of bidding and contract award (initial delay)	16	2
20	Increase in quantity of work (additional works)	9	7
21	Design changes	10	10
22	Absence of consultant's staff on the project site	1	0

23	Lack of technical and managerial skills of consultant's staff (poor performance)	4	0
24	Lack of quality assurance, control	1	1
25	Poor documentation - incomplete drawings, poor drawings, design deficiencies	1	0
26	Slow inspection of completed works	1	1
27	Equipment and manpower shortage and bad distribution on site	4	0
28	Poor communication with consultant and owner	1	0
29	Financial difficulties of contractor	4	0
30	Low productivity of labour	0	2
31	Inadequate contractor experience (poor performance of contractor)	10	0
32	Rework and wastage of materials	1	1
33	Delay in mobilization by contractor	13	0
34	Inadequate and incompetent subcontractors	0	1
35	Slow or delayed material or equipment delivery to project site	7	2
36	Unavailability or shortage of required materials in the local market on time	5	21
37	Fluctuation and escalation in prices (materials, machinery, labour, equipment)	2	0
38	Monopoly of construction materials supply (steel, cement)	1	1
39	Equipment availability and failure	1	1
40	Lack of maintenance for the equipment	1	1
41	Skilled labour shortage	2	7
42	Poor and unforeseen site conditions (location, ground, geological, events, security)	5	1
43	Severe weather problems (heat, cold, snow, rain, cyclone)	12	1
44	Political issues, changes	5	0
45	Poor health and safety conditions on site	0	2
46	Changes in laws and regulations during the project, obstacles from government	1	13
47	Change in exchange rate	0	2
48	Inadequate design team experience	1	3
49	Extension of the construction phase (delay)	1	1
50	Complicated administrative and governmental procedures (institutional problems)	6	3

51	Damage of structure and equipment breakdown (flood, cyclone)	1	11
52	Increase or change in scope of the project	8	12
53	Underestimate and inaccurate appraisal (missing measures, cost adjustment)	2	2
54	Extension of consultant contract	0	1
55	Court cases (litigation)	2	3
56	Unexpected issues (public obstruction, earthquake, flood, security issues)	1	1
57	Quitting the work by contractor	3	1
58	Poor procurement procedure (longer period or procedures in bidding)	11	1
59	Change in quality of the work	1	1
60	Inaccurate estimation for duration of the project	0	6
61	Additional project management, consultancy, and administration costs	0	11
62	Increase in the amount of land acquisition, price, and compensation	0	0
63	Delay in land acquisition	8	0
64	Delay in appointment of consultant	7	0
65	Low contract bid	1	0
66	Repetition of tendering or bidding procedure	3	0

Appendix 2. Specifications of selected projects

Description /Project	Country	Estimated Cost $(Million)	Cost Overrun (%)	Estimated Duration (Months)	Time Overrun (%)
01	Bangladesh	15.60	10.71	624	92
02	New Guinea	15.34	29.20	528	41
03	Pakistan	178	-12.07	648	48
04	Laos	23.75	6.32	1369	49
05	Bangladesh	696	8.29	1581	0
06	Bangladesh	105.5	2.49	792	36
07	Nepal	50	-3	1613	7
08	Guinea	97	-57	1886	69

09	India	308.8	-2	1340	109
10	Tonga	12.5	6.48	1552	12
11	Nepal	16.9	-8	2190	33
12	Thailand	211	-30	2190	67
13	Viet Nam	237	-31	1742	20
14	Laos	44.8	101	1217	26
15	China	532	4	228	299
16	Sri Lanka	295.9	206	72	117
17	China	795.5	-8	2555	-7
18	Laos	50	21	60	80
19	China	360	-4	1490	49
20	Fiji	90	88	2283	148
21	Sri Lanka	123.3	48	1825	40
22	Cambodia	88.1	-1	40	65
23	China	345	-3.41	1798	40
24	China	770.3	28	1796	46
25	Cambodia	77.5	12	1200	58
26	Laos	37.5	-27	1551	47
27	Laos	39.2	26	96	-6
28	China	757	28	48	0
29	Sri Lanka	92.5	10	1824	15
30	India	378	21.80	1440	179
31	Pakistan	236	-17	2190	33
32	India	92	45	2371	62
33	China	582	32	1490	33
34	Bhutan	34.10	6	1825	35
35	Tajikistan	26.8	3	1460	29
36	China	455.2	2	1492	37
37	China	762	75	1643	50
38	China	611.8	41	1875	60
39	China	882	52	2010	36
40	China	2077	49	2190	0
41	India	649	53	1440	114

42	China	834	-3	1826	40
43	Tajikistan	23.6	-1	1216	28
44	China	726	11	1339	25
45	China	778.1	27	1825	-13
46	Mongolia	78.14	96	1642.5	122
47	Azerbaijan	93.2	47.64	1094	17
48	India	285.7	-1	1825	58
49	Pakistan	423.6	-29	1095	33
50	Kyrgyz	43.4	0	1065	18
51	China	745	49.03	1826	20
52	Afghanistan	80	3.11	940	114
53	India	400	-3.25	1186	54
54	China	1425	21.31	1642.5	0
55	China	519.51	73	2281	8
56	Tajikistan	64.5	-7.09	2100	13
57	China	524.55	2.60	1398	0
58	China	1566	27.60	1825	15
59	Afghanistan	140.9	24.41	1260	62
60	China	594	-4.97	1855	20
61	Kyrgyz	30.3	-30	1002	55
62	Kyrgyz	76.5	-7	2191	4
63	Honduras	64.6	26.47	1525	46