Available online at http://ijdea.srbiau.ac.ir

Int. J. Data Envelopment Analysis (ISSN 2345-458X)

Vol.8, No. 4, Year 2020 Article ID IJDEA-00422, 16 pages
Research Article

International Journal of Data Envelopment Analysis

Science and Research Branch (IAU)

Combination of Data Envelopment Analysis and Non-Linear Programming: A Novel Hybrid for Optimizing the Allocation of the Fixed-Cost in the Project Portfolio

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Received 9 November 2020, Accepted 25 June 2020

Abstract

Resource allocation is one of the most complicated managers' concerns, which forces them to seek novel methods and approaches. The fixed-cost (FC) allocation among different decision-making units is one such problem. That has led to considerable research in this regard. Numerous methods have been proposed, that the most important of them is Data Envelopment Analysis (DEA). Fixed-Cost allocation problem is more reflected in project portfolio management. The management has to allocate a common cost between several different projects. However, due to the nature of the project, the previously proposed methods are insufficiently adapted to the project execution realities. In this research, a novel method is proposed to allocate FC aligned with project management methods. For this purpose, the current situation of projects is first evaluated using the Earned Values Management method. Then projects which are out of scope are identified. Inverse Data Envelopment Analysis estimates the required costs to keep them back into their scope on the assumption that the project's efficiency remains constant. Finally, by using non-linear programming, the fixed-cost allocates optimally. In order to illustrate the proposed method, a real case example is presented.

Keywords: EVM, DEA, InvDEA, Fixed-cost allocation, Resource optimization, Project scope management, Project performance.

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1. Introduction

Decision-making problems are becoming increasingly complex. Balancing the limited resources and high demand is a kind of these problems, forcing decision-makers (DMs) to seek new approaches and methodologies. Since resources are limited and scarce, resource allocation decisions are vital for organizations' success [1]. Also, the constrained resources must be balanced somehow to reflect the organizational strategies [2]. Therefore, numerous methods have been presented in previous research to find out a better solution. However, these methods cannot respond to some DMs' concerns all the time.

In some countries, projects face problems of time and cost overrun. [3]. Therefore, the executive managers try to successfully undertake projects by achieving time and cost scope [4]. It means that if a project is out of these scopes, managers concentrate all facilities and resources to lead it into the plan. Nevertheless, this feature has some issues in project-based companies. In such companies, various projects are being carried out simultaneously that managers should support their needs. However, resources are limited and make it impossible.

In other words, although some research, such as Khazaeli et al. and Kaveh et al. has provided models for scheduling resource allocation optimally [5,6], the performance of some projects disrupts this planning. Managers need to distinguish between the projects with poor performance versus the projects that have been performed better. These points force decision-makers to look for allocation methods with at least two abilities: 1. calculating the project efficiency in decision-making progress 2. optimizing limited resources.

According to the projects' performance, one of the well-known resource allocation methods is Data Envelopment Analysis (DEA) [7]. DEA is a nonparametric technique to measure relative efficiency for a set of decision-making units (DMUs) that use similar inputs to produce the same outputs [8]. This method was introduced by Charnes et al. for The first time that estimates the efficiency of each unit by solving a linear programming (LP) problem [9,10]. Although DEA's primary purpose is the efficiency measurement of DMUs, it is applied to input estimation and resource allocation to consider projects' performance. Much research has been pointed out to this method, such as [1, 11, 12, 13, 39].

For instance, Cook and Kress made the first attempt to use DEA for allocating a fixed cost [8]. Beasly presented a new DEA-based approach to solving the same problems [14]. Lozano and Villa illustrated a new centralized resource allocation approach by using DEA. They focused on the reduction of total input consumption while guarantees that the total output is not decreased [15]. Korhonen and Syrjanen struggled to maximize the individual units' produced outputs by allocating available resources [16]. Therefore, they used DEA and multiple-objective linear programming (MOLP) to find the most preferred allocation plan. Fang and Zhang explained their allocation approach to maximize both the total efficiency and each unites individually [17]. Moreover, Nemati and Matin proposed a new method in the DEA framework for resource allocation and efficiency estimation of production units. They tried to consider partial impacts among inputs and outputs of DMUs [18].

Subsequently, some researchers have proposed a developed DEA approach to allocate resources and set the output targets simultaneously in an equal environment. For instance, Amirteimoori and Tabar showed a novel method to define the target of outputs of all DMUs simultaneously as decisions are made for resource allocation [19]. Hemati-Marbini et al. used a Common Set of Weights (CSW) method based on the Goal Programming (GP) concept to improve the efficiency of the units in the resource allocation process [20]. Ghazi and Lotfi applied this concept and allocated the Iranian Gas Company's budget using CSW-DEA [1]. Recently, Yang et al. presented their model, tying to allocate less input that produces more output [21]. In most of the previous methods, the main goal is to improve the efficiency of DMUs by decreasing the use of input and increasing output simultaneously.

Despite their abilities, the previous methods have two significant issues in project management fields: The first issue observed is the value of efficiency. In the most proposed research, the efficiency of the units is improved because of DEA performance. However, in projects, this is more complicated. The projects' efficiency depends on many factors such as project type, workshop location, environment, or even the weather condition. For example, at the beginning of a road construction project, much cost is spent due to the work and workshop environment's nature while the progress is insufficient. Such a condition indicates the project's low efficiency; however, this issue is not related to the contractor's performance and cannot be improved. Therefore, performance improvement in some hypothetical conditions will be unattainable. The second one is that the project is ahead of the procedure. Hence, if the time and cost are considered the two most significant inputs, they increase throughout the project lifespan. So, it is not possible to reduce the input to improve performance.

To solve these issues, the assumption of efficiency improvement needed to change into assuming that the efficiency was constant, caused to suggest a new method of DEA entitled inverse DEA (InvDEA). This method, introduced by Wei et al. for the first time, tries to answer this question: If the outputs of DMUs need to be increased to a certain level and the unit's efficiency remains unchanged, how much more inputs should be provided to the unit [22]? Numerous researches have been done about InvDEA utilization, e.g., [23-27]. However, Hadi-Vincheh et al. pointed out some issues in Wie's model. They presented a new modified method that the needed input data could estimate by changing output, assuming that the efficiency was constant in each DMU. This kind of method can use to define the inputs to reach the project's targets [23].

Using InvDEA in the project management area initially needs a reliable method to define the output targets. One popular approach for monitoring and estimating projects' outputs is the Earned Value Management (EVM) method. EVM can integrate the project's scope, schedule, and resources; for objectively measuring project performance and progress; and forecasting project outcome [2]. This method gives the project, program, and portfolio managers the ability to measure project performance by integrating the three most essential elements: cost, schedule, and scope [28]. Because of high accuracy and reliability in cost performance and forecasting EVM has been regarded in numerous research like [29-34]. However, the main question is which measure should be considered as the output?

EVM utilizes different measures to monitor the project. Most of them are based on earned values and actual costs. Table 1 shows the general scheme of indices and metrics used in current research. The Cost Performance Index (CPI) and Schedule Performance Index (SPI) are two crucial indices that demonstrated the cost and schedule performance of projects. Suppose SPI and

CPI are less than unity. In that case, they will indicate the project's weak performance from schedule and cost points of view. Moreover, CPI and SPI equal to unity indicate projects on the budget and schedule plan [35].
The Budget at completion (BAC) and Estimated at Complete (EAC) are essential EVM metrics. They show the planned final budget and the budget that the project will likely be terminated, respectively. If *EAC* exceeds *BAC*, the project is out of the planned scope and forces managers to provide more funds. The Project Management Institute (PMI) introduced a new index entitled the To-Complete performance index ($TCPI_{BAC}$). This index specifies how much CPI should be changed in order to terminate the project in BAC [2]. So CPI and TCPI could answer the question of which output should be considered in InvDEA?

Table1: general scheme of indices and metrics used in EVM

Abbreviation	Description	Equation
BAC	Budget at complete	
AP	Actual progress (based on the work performance)	
EV	Earned value	$AP \times BAC$
PV	Planed value	$Planed\ progress \times BAC$
AC	Actual cost	
SPI	Schedule performance index	$\frac{EV}{PV}$
CPI	Schedule performance index	$\frac{EV}{AC}$
EAC	Estimated at complete	$AC + (\frac{BAC - EV}{CPI * SPI})$
$TCPI_{BAC}$	To-complete performance index	$\frac{BAC - EV}{BAC - AC}$

The combination of InvDEA and EVM models can be an appropriate way to allocate resources in project management. Using TCPI defines the projects' target, considered the new output in InvDEA, and estimates the inputs demand. This process is done while the efficiency of projects remains constant. However, there is a drawback to this combination. The resources are limited, and it is impossible to support all projects' input demands. Therefore, using an optimization method in this allocation approach is undeniable. Hence, the EVM-InvDEA hybrid needs to be developed by optimization methods.

This research presents a novel hybrid of EVM, InvDEA, and non-linear programming to allocate a fixed cost into a set of projects. The new model's main objective is that projects return into their cost scope or stay on it. For this purpose, initially, the current situation of projects and their targets are defined using EVM. Then, assuming the projects' efficiency remain constant, the needed inputs to reach the targets are estimated by InvDEA. Finally, by using non-linear programming, the fixed cost is allocated optimally.
The rest of the research is unfolded as follows. The methodology of the proposed

method is explained in section 2. For evaluating the performance of the method, a numerical real case example is illustrated in section 3. Section 4, the example, is discussed, and the research will be concluded in section 5.

2. Methodology

The approach presented in this paper is a hybrid approach for allocating the fixed cost in a portfolio of projects. This approach consists of six steps classified into three phases shown in Figure 1 and explains as follow:

Phase	Step	Description	Input	TOOLS	Output
I Target Setting	1	evaluating the current situation of projects	Projects' progress data	EVM	AC, AP, PV, EV, CPI & SPI
	2	comparing the current project situation and project scope and defining the targets	AC, AP, PV, EV, CPI & SPI	EVM	BAC, EAC &$TCPI_{BAC}$

Phase	Step	Description	Input	TOOLS	Output
II calculating new inputs	3	calculating the projects' efficiency	AC, AP, CPI & SPI	DEA	Projects' efficiency (θ)
	4	calculating new inputs by InvDEA	AC, AP, PV, EV, CPI,SPI, θ & $TCPI_{BAC}$	InvDEA	New AC & AP

Phase	Step	Description	Input	TOOLS	Output
III optimizing the allocation	5	calculating the required cost	New AC & BAC	-	Requested cost (B_i)
	6	optimizing the final cost	Available fixed-cost & B_i	CAOM	Final budget (B_o)

Figure 1: The flowchart of the cost allocation model

2-1 Phase I: Target Setting

In this phase, initially, a set of ongoing projects are considered. Then, by using EVM, the current projects' situation is evaluated, and targets are set according to step 1 and 2 as follow:

Step 1: evaluating the current situation of projects

In this step, using project progress data gathered by the project management office (PMO) and EVM systems, the current situation of projects is evaluated. AC, AP, PV, EV, CPI, and SPI are calculated in this stream according to Table 1 equations. These indices help managers for monitoring the projects' procedures.

Step 2: comparing the current project situation and project scope and defining the targets

Here, *BAC* and *EAC* are calculated and compared for each project to determine that the projects are out of scope or not. If the *EAC* of each project is more than *BAC*, it is considered out of scope. So $TCPI_{BAC}$ of these projects is calculated and considered as the targets for the next steps.

2.2 Phase II: calculating new inputs

In this phase, by considering $TCPI_{BAC}$ as the new target of projects, costs required for them to remain in their scopes are calculated by InvDEA. This phase has two steps, as follow:

Step 3: calculating the efficiency of projects

It is essential to compute the efficiency of projects initially. For this purpose, a set of projects is selected, and each project is considered a Decision-Making Unit (DMU). Then the percentage of the actual cost ($AC_i(\%)$) and the percentage of the actual progress ($AP_i(\%)$) are considered as the input resources. The indices SPI_i and CPI_i are supposed as the outputs. In order to calculate the efficiency of projects, a CCR input-oriented DEA model, according to the model $P_{I,}$ is used. This kind of DEA model has been used in many studies, such as Hadi-Vincheh et al. [23].

$$(P_I)\ \min \theta \quad (1)$$
$$s.t.\ \ \sum_{j=1}^{n} X_j\lambda_j \le X_o\theta, \quad (2)$$
$$\sum_{j=1}^{n} Y_j\lambda_j \le Y_o, \quad (3)$$
$$\lambda > 0 \quad (4)$$

The model P_I is linear programming that the inputs and outputs of DMU_j (j=1,…,n) are illustrated as $X_j = [AC_j, AP_j]$ and $Y_j = [SPI_j, CPI_j]$ respectively. Also X_o, Y_o And θ explain the input, output, and efficiency of DMU_o, respectively. λ is the auxiliary coefficients obtained by the equation.

Step 4: calculating new inputs by InvDEA

Here, it is supposed that the CPI of DMUo changed into the $TCPI_{BAC}$ calculated at step 2. For this purpose, different models of the InvDEA method were examined. Finally, the input-oriented InvDEA model proposed by Hadi-Vincheh et al. [23] has been used due to its simplicity in application. The model is presented according to model V_I

$$(V_I)\ \min \sum_{i=1}^{m} w_i\alpha_{oi} \quad (5)$$
$$s.t.\ \ \sum_{j=1}^{n} X_j\lambda_j^V \le \alpha_o\theta, \quad (6)$$
$$\sum_{j=1}^{n} Y_j\lambda_j^V \le \beta_o \quad (7)$$
$$\alpha_o \ge 0 \quad (8)$$
$$\lambda_j^V > 0 \quad (9)$$

where β_o is the new CPI of DMUo and α_{oi} illustrates the new inputs (AC&AP) calculated by the model. Also, w_i is the value weight of α_{oi} defined by the managers and λ_j^V & θ are definite as before. The model's result illustrates that the managers can terminate the project DMUo at its BAC if they allocate the new actual cost resulting from the model.

2.3 Phase III: optimizing the allocation

In phase II, each project's required cost is calculated to remain projects in their scope. However, it may be impossible to cover all of these costs. In this phase, the available fixed-cost will be optimally allocated to the projects; somehow, projects receive the maximum possible cost. This phase consists of two steps as follow:

Step 5: calculating the required cost

In this step, the required costs of projects are calculated using Eq. 10. These values are computed based on the new actual costs percentage obtained from step 4.

$$B_i = \alpha_{1i} \times BAC_i, \ \ i = 1 \dots n. \qquad (10)$$

where, B_i is the required cost of project *i* and α_{1i} is the new AC(%) of project *i*.

Step 6: optimizing the final cost

In this research, a non-linear model is proposed for cost optimization. Before discussing the model, let to introduce γ_j the fuzzy logic membership degree of the optimized cost of project i (Boi) illustrates how much B_i is provided. This variable is presented based on Zimmerman's approach as an adequate fuzzy set [36]. Fig 2 represents the membership function of γ_j. Moreover, it is computed by Eq.11 as follows.

$$\gamma_i = \frac{B_{oi} - AC_i}{B_i - AC_i}, \ \ i = 1 \dots n. \qquad (11)$$

Where B_{oi} is the final optimized cost.

Fig 2 explains that when no cost allocated to project *i*, the cost of the project will remain constant and equal to AC_i; γ_j is equal to zero. However, if B_i is allocated entirely or more, γ_j will become 1.

According to the definition of γ_j the cost allocating optimization model (CAOM) is represented as follows. In this novel model, using the Prod function $\prod$ at Eq.12 allows all γ_j to involve in maximization and the best result will reach when all γ_j become 1.

CAOM:

$$Max\ Z = \prod_{i=1}^{n} \gamma_j, \qquad (12)$$

$$\text{s.t.} \sum_{i=1}^{n} \gamma_j (B_i - AC_i) - AC_i \leq B_{total} \qquad (13)$$

$$0 \leq \gamma_j \leq 1 \qquad \forall_i, \qquad (14)$$

The allocated cost should not exceed the available fixed-cost announced by managers. Eq.13 guarantees it. Also, All B_o must be less than or equal to B_i and more than or equal to AC_i. Eq.14 provides this constraint.

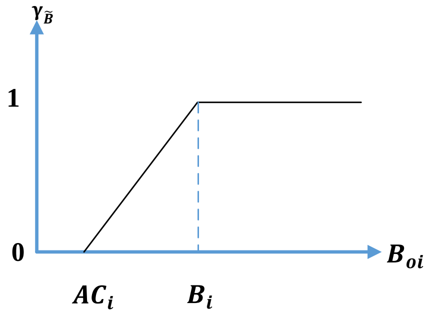

Figure2: membership function of optimized budget

3. Numerical illustration

3.1 Real case study

In order to illustrate the performance of the new proposed model, a real case project portfolio consists of 12 projects of Khuzestan Steel Company was considered. As step 1, the current situation of projects measured by the portfolio management office (PMO). Then, the $TCPI_{BAC}$ of each project was calculated based on Table 1 equations as step 2. The results are shown in Table 2.

Table 2 demonstrated significant non-conformity between BAC and EAC and explained that projects could not be terminated at the planned budget. Therefore, it was essential to improve *CPI* by $TCPI_{BAC}$. For this purpose, as the third step, the efficiency of projects was calculated. A CCR input-oriented DEA was used, as explained in phase II. The result of the DEA is shown in Table 3.

Table 2: Project portfolio metrics

Project	BAC	Planed progress (%)	AP (%)	PV	EV	AC	CPI	SPI	EAC	$TCPI_{BAC}$
1	54.828	61.734	54.042	33.84	29.630	32.200	0.920	0.875	63.481	1.114
2	10.000	62.466	54.500	6.247	5.450	6.500	0.838	0.872	12.720	1.300
3	8.000	64.384	70.895	5.151	5.672	6.200	0.915	1.101	8.512	1.294
4	342.974	42.700	36.000	146.45	123.47	145.000	0.852	0.843	450.753	1.109
5	19.600	61.644	51.000	12.082	9.996	11.250	0.889	0.827	24.315	1.150
6	12.000	64.658	55.000	7.759	6.600	7.500	0.880	0.851	14.714	1.200
7	30.200	47.595	45.000	14.374	13.590	14.000	0.971	0.945	32.098	1.025
8	22.194	65.000	85.000	18.000	18.865	19.000	0.993	1.048	22.199	1.042
9	15.000	50.546	60.000	8.530	9.000	9.230	0.975	1.055	15.062	1.040
10	2.469	38.000	37.000	0.938	0.913	0.980	0.932	0.974	2.694	1.045
11	17.000	69.863	65.863	11.877	11.200	11.800	0.949	0.943	18.280	1.115
12	47.634	80.952	80.952	38.560	38.560	40.000	0.964	1.000	49.412	1.189

*The amount of BAC, PV, EV, AC, and EAC is the currency unit

Table 3: The efficiency of projects calculated by DEA

Project	Input		Output		θ
	AC%	AP%	SPI	CPI	
1	58.7	54	0.857	0.920	0.676
2	65	54.5	0.872	0.838	0.611
3	77.5	70.9	1.101	0.915	0.590
4	42.3	36	0.843	0.852	0.939
5	57.4	51	0.827	0.889	0.692
6	62.5	55	0.851	0.880	0.635
7	46.4	45	0.945	0.971	0.892
8	85.6	85	1.048	0.993	0.499
9	61.5	60	1.055	0.975	0.699
10	39.7	37	0.974	0.932	1.000
11	69.4	65.9	0.943	0.949	0.582
12	84	81	1.000	0.964	0.489

In step 4, by improving output *CPI* to $TCPI_{BAC}$ and assuming that each project's efficiency would have remained constant, the new inputs were estimated by InvDEA. For this purpose, the weight of $AC_i(\%)$ & $AP_i(\%)$ were considered 0.75 and 0.25, respectively, based on senior managers' opinions. In step 5, by multiplying the new estimated $AC_i(\%)$ to BAC_i, each project's B_i was computed. The results of the calculations are illustrated in Table 4.

Table 4: The estimated input by InvDEA

Project	θ	$\beta=TCPI_{BAC}$	α_1=AP (%)	α_2=AC (%)	B_i	Net demand=B_i-AC
1	0.676	1.114	0.654	0.702	38.492	6.292
2	0.611	1.300	0.845	0.907	9.066	2.566
3	0.590	1.294	0.870	0.933	7.467	1.267
4	0.939	1.109	0.469	0.503	172.483	27.483
5	0.692	1.150	0.660	0.708	13.873	2.623
6	0.635	1.200	0.750	0.805	9.656	2.156
7	0.892	1.025	0.456	0.490	14.787	0.787
8	0.499	1.042	0.86	0.889	19.739	0.739
9	0.699	1.040	0.60	0.634	9.503	0.273
10	1.000	1.045	0.415	0.445	1.098	0.118
11	0.582	1.115	0.760	0.816	13.867	2.067
12	0.489	1.189	0.965	1.036	49.336	9.336
					Total	55.7

The result represents that the portfolio needed to provide 55.7 currency units to stabilize all projects into their budget scope. However, PMO stated that the organization could provide up to 35 currency units in this portfolio lifetime. It means that allocation should be optimized aligned with the inputs extract from the InvDEA method. So all projects are assumed to have the same weight, and CAOM was utilized. CAOM is more complicated than solving by ordinary methods. Thus, a meta-heuristic algorithm was suggested. In this research, Evolutionary Programming (EP) was considered as the appropriate method.

EP is an evolutionary algorithm for solving complex problems introduced by Fogle in 1960 [37] for the first time. In this stream, initially, a population is selected randomly. The objective function evaluates the population, and new offspring are generated based on the best fitness. The offspring are muted by the Gaussian method. A tournament is held, and the fitness of all muted offspring is compared with each other randomly. These steps are repeated till the best fitness or number of iteration reaches the tolerable level.

For solving CAOM, an exclusive EP algorithm was coded by authors in MATLAB v2019. The tournament number was considered 4 to increase the competition possibility of all population against each other. The initial population was assumed 40, and the Gaussian number was selected as the mutation method. The main issue in EP was the termination creation. The code was run for 7500 iterations for this problem, and the output is shown in Fig 3. It seems that after 4700 iterations, the objective function remained constant; the termination criterion can be set on iteration over 5000. The results of the EP are illustrated in Table 5.

Table 5: The optimized cost by EP

Project	AC	B_i	Net allocated cost	Bo_i	γ
1	32.200	38.492	6.264	38.464	0.996
2	6.500	9.066	2.566	9.066	1.000
3	6.200	7.467	1.267	7.467	1.000
4	145.000	172.483	8.129	153.629	0.296
5	11.250	13.873	2.623	13.873	1.000
6	7.500	9.656	2.156	9.656	1.000
7	14.000	14.787	0.787	14.787	1.000
8	19.000	19.739	0.739	19.739	1.000
9	9.230	9.503	0.273	9.503	1.000
10	0.980	1.098	0.118	1.098	0.997
11	11.800	13.867	2.067	13.867	1.000
12	40.000	49.336	8.010	48.010	0.858
		Total	35.000	$\prod_{i=1}^{n} \lambda_i$	0.252

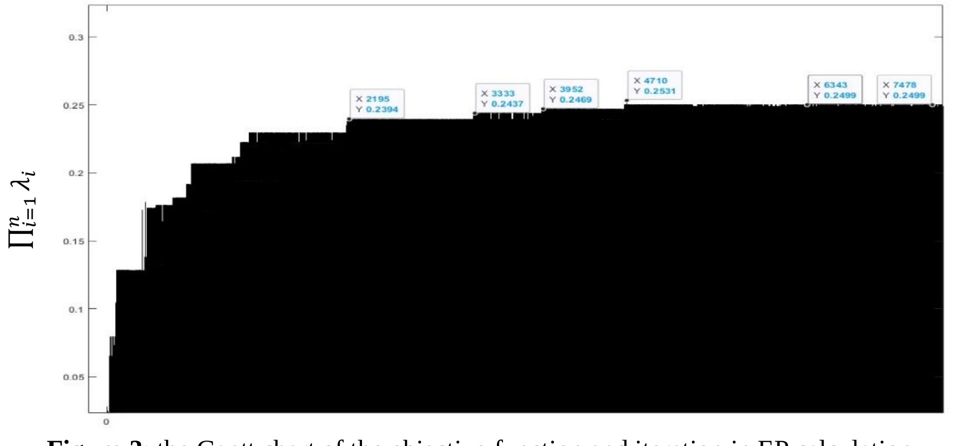

Figure 3: the Gantt chart of the objective function and iteration in EP calculation

3.2 Sensitive analysis

According to Table 5, all γ_j except γ_4 and γ_{12} are equal or semi-equal to 1. For evaluating the result of CAOM, a sensitivity analysis is implemented. In this way, two scenarios are considered by changing λ_4 and λ_{12}:

a) if B_{o12} increases to B_{12} (γ_{12}=1), then B_{o4} should be decreased to 151.804 (γ_4 =0.248).

b) if B_{o12} decreases to 47.51 (γ_{12} =0.804), then B_{o4} should be increased to 153.623 (γ_4 =0.314).

The results of the analysis are illustrated in Table 6. The decrease/increase of any project causes a considerable reduction in objective function fitness, proving the model's performance.

Table 6: The sensitive analysis

Project	Scenario a		Scenario b	
	γ	Bo_i	γ	Bo_i
1	0.996	38.464	0.996	38.464
2	1.000	9.066	1.000	9.066
3	1.000	7.467	1.000	7.467
4	0.248	151.804	0.314	153.623
5	1.000	13.873	1.000	13.873
6	1.000	9.656	1.000	9.656
7	1.000	14.787	1.000	14.787
8	1.000	19.739	1.000	19.739
9	1.000	9.503	1.000	9.503
10	0.997	1.098	0.997	1.098
11	1.000	13.867	1.000	13.867
12	1.000	49.336	0.804	47.510
$\prod_{i=1}^{n} \lambda_i$	**0.246 < 0.252**		**0.251 < 0.252**	

4. Discussion

The new method proposed in this paper can be utilized in any project-based firm efficiently. The proposed method's contribution combines three different well-noun methods, i.e., EVM, InvDEA, and non-linear programming. Also, the main objective is that the projects return to their planned scope. The EVM method can monitor the projects' performance and predict the future with reliable accuracy. Using DEA helps the managers compare the portfolio's efficiency and determine which project has the best. The indices derived from EVM can guide decision-makers to detect any non-conformity in projects' scope. InvDEA finds out how much inputs need to improve this issue. Finally, the proposed optimization model helps the managers to optimize the fund in the defined targets.

The result of the actual case illustrates the performance of the proposed method. The deviation between BAC and EAC in all projects indicates that projects cannot finish within the planned budget. Therefore, CPI should be increased to $TCPI_{BAC}$ to keep the project in planned lines. The results of InvDEA express that project *i* will be terminated by BAC_i at progressive α_1. For example, if project 1 receives 38.5 currency units before progressive 65%, it may be completed by 54.8 currency units at the end. Also, all projects' efficiency remains constant, which proves the performance of InvDEA. According to Table 4, improving the scope of all projects needs at least 55.7 currency units, which are not available on that specific period of the portfolio's cash flow. Therefore, it was undeniable to use an optimization method. Implementation CAOM helped managers to allocate fixed-cost optimally. Using λ and Eq.12 caused most of the projects to receive the maximum possible cost. On the other hand, the maximization of the objective function never obtains until all λs being the highest. This feature helps all projects to be considered substantially regardless of their size.

The study of previous DEA methods in resource allocation shows some ambiguities that have been answered in the present model. Previous resource allocation and target setting methods (e.g., Beasley [14], Amirteimoori and Tabar [19], Hemati-Marbini et al. [20], Ghazi and Lotfi [6], and Yang et al. [21]) try to improve each unit's efficiency by decreasing the value of inputs and increase the outputs simultaneously. This aspect caused two problems: in some DEA evaluations, estimated inputs are less than previous, and outputs remain constant for some units. These results cannot be aligned with the principle of resource allocation in project management; the project's inputs such as time and cost are certainly increased during the project lifespan. Furthermore, improving project efficiency is a complicated procedure in the natural environment that may be impossible due to many factors such as weather conditions or workshop environments. So, these issues should be considered in our suggested model by using InvDEA.

Although InvDEA tries to allocate the resources so that the unit's efficiency remains constant, this model needs an accurate supplement method to identify the goals. For this purpose, we suggested the EVM method as an appropriate approach. Formerly, most of previous EVM research such as Anbari [30], Bagherpour et al. [31], Aliverdi et al. [28], Salari et al. [34], Salari and Khamooshi [35], and Andrade et al. [38] have just concentrated on predicting the project performance on a precise way. They have not suggested any specific methods in order to correct any deviation between planned and actual situations. The current study tries to use EVM abilities for supporting InvDEA by calculating the desired output as $TCPI_{BAC}$. This feature helps managers to find out how they can return projects to their scope. Moreover, how much this correction cost needs. Finally, which time the cost should be allocated during the projects' lifespan.

Besides, using InvDEA-EVM hybrid alone is possible when the required budget for the output of these methods is available. Therefore, when there is a budget deficit, the use of the optimization method will be undeniable. That is a point that has not been found out in any previous studies based on our research. For instance, Hadi-Vincheh et al. [23] suggested just estimated the minimum inputs needed to reach some defined output. This issue can cause some problems. For example, when the managers face cash deficiency and it is impossible to supply all projects' demands, they need to use an optimization tool. The current study tries to solve this issue by proposing CAOM as a non-linear programming optimization method. In collaboration with the other two methods (i.e., EVM and InvDEA), this step can develop the approach to be more practical in a natural environment.

5. conclusion

Project performance evaluation and resource allocation are considered separate categories in most research. In this paper, we integrated them to assume that the project's performance can affect the allocation. This method provides a new approach to estimate a project portfolio's required cost according to its performance and scope management. Furthermore, by adding a novel optimization model, the allocation has become more practical. Reducing project scope deviation is the objective that managers and decision-makers can consider the most significant feature of this method.

The results of the numerical example explain the method's performance. Moreover, sensitive analysis reveals that the optimization model has the appropriate accuracy. However, the method has some limitations. This method can be implemented in an organization with reliable project monitoring systems based on EVM, e.g., Project Management Information System (PMIS). Also, InvDEA needs to be run for each project exclusively that can be a problem in an extensive project portfolio.

On the other hand, solving non-linear programming needs heuristic or meta-heuristic methods that is complicated for users. Furthermore, the projects' scopes are modified by $TCPI_{BAC}$. However, other measurement metrics of EVM, like "To Scheduling Performance Index" (*TSPI*), can be considered with *TCPI* simultaneously in future studies. Moreover, in this study, any priority is not considered for any project. Then it is suggested to use the priorities factor in other studies.

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