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A performance-based approach to project assignment and performance evaluation

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Abstract

Project assignment and performance evaluation have been addressed as two important and separate research issues in project management. This paper develops a new performance-based approach for integrating the project assignment and the performance evaluation processes in a project-based organization. An objective-oriented preference-based assignment process is developed to assign a project to a project manager. An optimal project assignment model is developed to maximize the total weighted contribution value of all new projects to the organizational objectives. An efficiency-based evaluation process is developed using data envelopment analysis to measure the relative performance efficiency of the completed projects and of the project managers. The approach provides a proactive mechanism for facilitating objective-focused management of projects. The outcomes of an empirical study conducted provide managerial insights in assigning projects to project managers and in evaluating the performance efficiency of both projects and project managers.

Keywords: Managing projects; Project assignment; Performance efficiency evaluation; Project-based organization; Optimization modeling

1. Introduction

Project-based organizations perform projects for achieving their business objectives (Project Management Institute, 2004). To ensure that projects can be best performed, assigning projects to project managers has been a critical process in project management (Avots, 1969; Belassi and Tukel, 1996; Ogunlana et al., 2002; Patanakul et al., 2007; Pinto and Slevin, 1989). This project assignment problem has been well addressed essentially by matching the abilities of project managers with the requirements of projects. For example, Adams et al., (1979) use a contingency approach to rate and choose the candidate project managers in terms of their capabilities to cope with the expected demands of projects. Hauschildt et al. (2000) use questionnaire surveys to classify project managers into five naturally occurring types in terms of their abilities to match various types of projects. Mian and Dai (1999) use the analytical hierarchy process to assign projects to project managers based on their administrative and supervisory skills, technical knowledge and personal skills. Patanakul et al. (2007) develop an integer programming model for project assignment by considering project priorities, project requirements, project managers' competencies, and organizational and personal limitations. With these assignment methods, a project can be assigned to a project manager who is likely to have the best performance on the project. The actual performance of the project manager and of the project is to be appraised by a formal evaluation process in order to examine how the stated objectives are achieved after the project is carried out.

Evaluating the performance of the completed projects will help establish benchmarks of high performance projects for cross-learning and identify inefficiencies of low performance projects for potential improvement (Cao and Hoffman, 2011; Farris et al., 2006; Stensrud and Myrtveit, 2003). Existing studies

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on project performance evaluation use different methods based on different sets of evaluation criteria and factors that affect the performance of projects. For example, in project management, earned value management is a conventional technique used to measure and report project performance from initiation to closure by integrating the project's scope, resources and schedule (Project Management Institute, 2004). In measuring the overall performance of projects, multicriteria decision making methods have been used to aggregate multiple performance measures under various application contexts (e.g. Barfod, 2012; Marques et al., 2011; Pillai et al., 2002). In evaluating the relative performance efficiency of the completed projects, data envelopment analysis (DEA) has been widely used as an effective tool by incorporating multiple input and output variables that impact the project performance (Busby and Williamson, 2000; Cao and Hoffman, 2011; Eilat et al., 2006, 2008; Farris et al., 2006; Linton and Cook, 1998; Revilla et al., 2003; Stensrud and Myrtveit, 2003; Verma and Sinha, 2002; Vitner et al., 2006).

The performance outcome of a project will be affected by the assignment outcome of the project, as different project managers will perform the same project differently and achieve the stated objectives to different degrees (Yang et al., 2011). Despite the fact that project assignment and project performance evaluation have been well addressed by existing studies, they are treated as two separate research problems in project management. To address these two research problems in an integrated manner for managing multiple projects in a project-based organization, this paper develops a new performance-based approach.

The rationale behind the conceptual development of this performance-based approach is that project managers will prefer to undertake a project that they expect to perform best and contribute most to the organizational objectives. The organization will prefer to assign a project to a project manager who is expected to perform best and contribute most to the organizational objectives. That is, the performance-based approach addresses two major issues raised by previous project assignment studies, such as Adams et al. (1979), Mian and Dai (1999), Hauschildt et al. (2000), and Patanakul et al. (2007). First, a project should be assigned to a project manager who is expected to have the best performance on the project. Second, the project assignment process should ideally help maximize the overall contribution of the projects to the organizational objectives. To this end, the performance-based approach maximizes the total expected contribution of the projects by considering the projects' expected contribution to the organizational objectives and the project managers' expected performance on the projects. To ensure that the expected performance specified by the project managers can be verified, the performance-based approach evaluates the relative performance efficiency of the project managers by considering the projects' expected contribution and the project managers' expected performance. That is, the performance-based approach uses the projects' expected contribution and the project managers' expected performance to integrate the project assignment and the performance evaluation processes.

In the subsequent sections, we first present the performance-based approach together with the key processes involved in project assignment and performance evaluation. We then develop methods and models for implementing these key processes, illustrated with an empirical study together with their managerial insights in supporting the assignment decisions and the subsequent performance evaluation results.

2. The performance-based approach to project assignment and performance evaluation

Fig. 1 shows the framework of the performance-based approach with the project assignment and performance evaluation phases. The project assignment phase begins with a set of new projects to be assigned to a group of available project managers for achieving their stated objectives, which are established in alignment with the organizational objectives. An objective-oriented assessment process with the weighted-sum method (Xu and Yeh, 2012) is used to assess the expected overall contribution value of a new project to the organizational objectives, given the project's stated objectives. The achievement level of the project's stated objectives is often affected by the performance of the project manager assigned. To measure how a project manager performs the job in managing a project and in helping achieve the project's stated objectives, a performance score is used.

A preference-based scoring process is used to allow all available project managers to self-assess and specify a performance score on each new project. This specified performance score given by a project manager on a new project indicates the project manager's preference on the project relative to others, after considering her own availability (e.g. commitments to other concurrent projects) and competence (e.g. managerial practices, knowledge and experience of similar projects). This specified score is the performance score expected by the company, if the new project is assigned to the project manager. That is, the specified score given by the project manager becomes the expected performance score of the project manager for performing the project.

Given the expected overall contribution value of the new projects and the expected performance score of the available project managers, a new objective-oriented preference-based assignment process is used to assign each project to a project manager. With special constraints formulated for accommodating actual project assignment settings, an optimal project assignment model is developed to maximize the total weighted contribution value of all projects to the organizational objectives. The weighted contribution value of a project is determined by multiplying the project's expected overall contribution value by the expected performance score of the assigned project manager. That is, the expected overall contribution value of a project is weighted by the expected performance score of the assigned project manager. This reflects the fact that the overall contribution value of a project is affected by the performance of the assigned project manager. The assigned projects will be completed after the project execution process, which provides the necessary assessment information for the performance evaluation phase. The project execution process, indicated using dashed lines in Fig. 1, is not covered in this study.

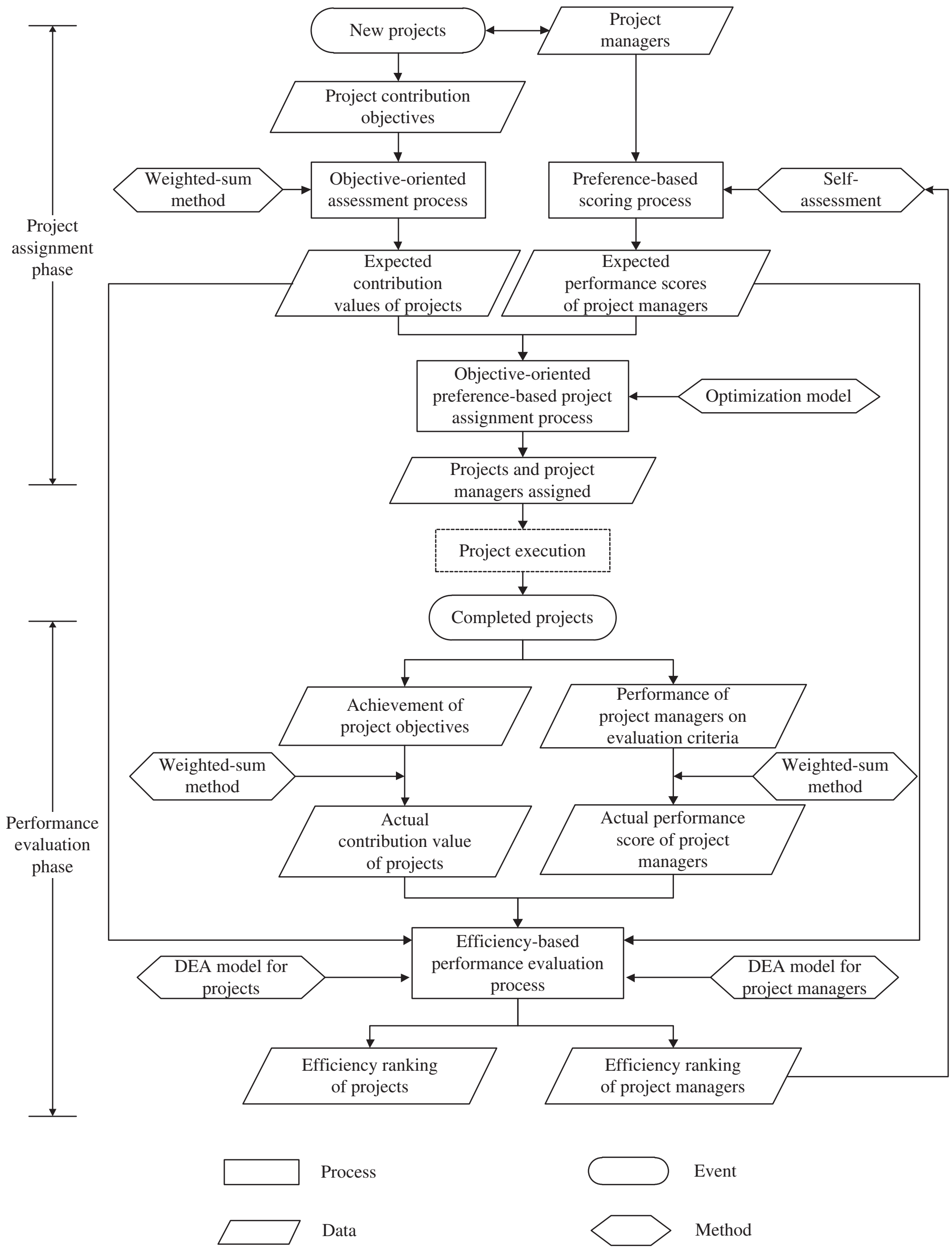

Fig. 1. The performance-based project assignment and evaluation approach.

The performance evaluation phase is carried out to assess the actual performance of the completed projects and of their responsible project managers against the expected performance. One purpose of this phase is to ensure that a project manager will specify a performance score rationally in the project assignment phase, as the score will be used as a baseline for the performance evaluation of the project manager. The achievement levels of the project's stated objectives by each completed project are to be assessed and subsequently aggregated by the weighted-sum method for obtaining its actual contribution value to the organizational objectives. For each completed project, the actual performance score of the responsible project manager is to be assessed with respect to a set of evaluation criteria and subsequently aggregated by the weighted-sum method. The evaluation criteria are used to reflect how the project manager performs the job in managing the project and in helping achieve the project's stated objectives.

Given the expected and actual performances of both the completed projects and the responsible project managers, an efficiency-based evaluation process is used to measure the relative performance efficiency of the projects and of the project managers by using DEA models. Developed by Charnes et al. (1978), DEA is a non-parametric method for evaluating the relative efficiency of a set of decision making units (DMUs) (Banker, 1984; Charnes et al., 1978; Coelli et al., 2005; Cook and Seiford, 2009). As a benchmarking approach, DEA has many advantages in evaluating project performance and exploring project efficiency. These advantages include (a) using a set of evaluation criteria from multiple dimensions for the relative performance evaluation of projects (Revilla et al., 2003), (b) incorporating multiple input and output variables with different units of measure to facilitate cross-project comparison (Cook et al., 1996; Farris et al., 2006; Mahmood et al., 1996), and (c) differentiating between efficient and inefficient projects (Mahmood et al., 1996).

The following sections present the methods and models developed for implementing the four key processes described in Fig. 1, which are the objective-oriented assessment process, the preference-based scoring process, the objective-oriented preference-based assignment process, and the efficiency-based evaluation process. An empirical example is given to illustrate how the four key processes work.

3. The objective-oriented assessment process

3.1. The overall contribution value of projects

In a project-based organization or company, new projects P_i (i = 1, 2, …, I) are to be assigned to a group of available project managers. The stated objectives of each project P_i, called the contribution objectives (CO_{iq}), are defined in terms of their expected overall contribution value to the organizational objectives O_q (q = 1, 2, …, Q). The expected contribution rating r_{iq} of each project P_i with respect to each organizational objective O_q is obtained as

$$r_{iq} = CO_{iq}/O_q \tag{1}$$

The weights of the organizational objectives, represented as w_q, are set to indicate their relative importance to the company's strategic goal. The expected overall contribution value c_i of each project P_i to the organizational objectives is obtained by multiplying its contribution ratings r_{iq} by the organizational objective weights w_q (i.e. the weighted-sum method) (Xu and Yeh, 2012) as

$$c_i = \sum_{q=1}^{Q} w_q r_{iq}; \quad i=1,2,\ldots,I. \tag{2}$$

3.2. Empirical illustration

As a project-based consulting company, ITCo provides information systems and consulting services to its clients in the form of projects. When new projects are available, the company assigns each new project to a project manager based on the potential contribution of the project and the expected performance of the project manager.

In this multi-project environment, the assignment of new projects and the performance evaluation of the completed projects are characterized by a high degree of managerial complexity. To deal with this complex decision making process, the company applies the performance-based approach with the objective-oriented preference-based project assignment phase and the efficiency-based performance evaluation phase. In its current strategic settings, the company has three objectives to achieve: \$4.5 million in profit (O_1), the employee development level of 80% (O_2), and the client satisfaction level at 80% (O_3). The weights of the company objectives O_q (q = 1, 2, and 3) are determined as w_q = (0.4, 0.3, 0.3).

The company has 10 new projects P_i (i = 1, 2, …, 10) to be assigned in its current planning run. The objectives-oriented assessment process is applied to assess the expected overall contribution values of these projects to the three annual company objectives. Take project P_1 as an example, the contribution objectives of P_1 are to achieve \$0.3 million in profit (CO_{11}), the employee development level of 80% (CO_{12}), and the client satisfaction level at 80% (CO_{13}). The employee development level of a project is measured by criteria such as professional learning and growth opportunities, the quality of training programs, and career advancement opportunities. The client satisfaction level is measured by criteria such as service quality, client complaints, and client partnership. Thus, the expected contribution ratings r_{1q} of project P_1 for the three company objective are 0.067, 1.000, and 1.000 respectively. Columns 2–4 of Table 1 show the expected contribution ratings r_{iq} of the 10 projects on the three company objectives O_q. The expected overall contribution value c_i of project P_i with respect to the company objectives is obtained by applying Eq. (2). The last column of Table 1 shows the result.

4. The preference-based scoring process

4.1. The expected performance score

The scoring process is used for project managers M_j to self-assess their expected performance score s_{ij} for each new project P_i on which the assignment of the project is based. The company may set a minimum expected performance score for a given project based on criteria such as importance and difficulty. The company may set a maximum performance score that the project managers can specify based on their past performance in order to reduce their opportunistic behavior of getting a project for unjustifiable reasons. The project managers can specify a score of zero for a project, if they are unavailable or incapable to

Table 1
Expected contribution rating and value of the projects to be assigned.

Project P_i	Expected contribution rating r_{iq}			Expected overall contribution value c_i
	O_1	O_2	O_3	
P_1	0.067	1.000	1.000	0.627
P_2	0.029	1.000	1.000	0.612
P_3	0.044	1.000	1.000	0.618
P_4	0.178	1.000	1.000	0.671
P_5	0.062	1.000	1.000	0.625
P_6	0.033	1.000	1.000	0.613
P_7	0.018	1.000	1.000	0.607
P_8	0.033	1.000	1.000	0.613
P_9	0.009	1.000	1.000	0.604
P_{10}	0.133	1.000	1.000	0.653

undertake the project when considering their own availability or competence.

This process encourages the project managers to take proactive attitudes towards the projects that they prefer to undertake, instead of being assigned passively. A project will be assigned to the project manager who specifies the highest expected performance score. To break the tie where two or more project managers specify the same highest expected performance score for a project, the project managers are given an assignment priority value by the company based on their past performance on the completed projects. This assignment priority value indicates the performance ranking of the project managers in the company, which can be derived from the result of the performance evaluation phase. In the case of a tie, the project will be assigned to the project manager with a higher priority value. To facilitate the formulation of this tie-breaker constraint for the optimal project assignment model (to be given as Constraints (6) in Section 5.1), all available J project managers are arranged by their assignment priority value and numbered as M_j (j = 1, 2, …, J).

4.2. Empirical illustration

The company has 12 project managers available to compete for the 10 new projects in its current planning run. Table 2 shows their self-assessed expected performance score on each project. Column 2 of Table 2 shows the minimum performance score set by the company for each project.

5. The objective-oriented preference-based assignment process

5.1. An optimal project assignment model

The assignment process maximizes the total contribution value of all new projects to the organizational objectives by assigning each project to a project manager who is expected to have the highest performance score. To this end, the expected overall contribution value of each project is weighted by the expected performance score specified by the assigned project manager. The following optimal project assignment model is thus developed to maximize the total weighted expected contribution values of all new projects.

Objective

Maximize

$$\sum_{j=1}^{J}\sum_{i=1}^{I} s_{ij} c_i x_{ij} \tag{3}$$

Subject to

$$\sum_{j=1}^{J} x_{ij} \le 1; i = 1, 2, \ldots, I. \tag{4}$$

$$x_{cj} + x_{dj} \le 1, \quad c, d \in \{1, 2, \ldots, I\}, c \neq d. \tag{5}$$

$$x_{ia} + Y(1-x_{ia}) + Y|s_{ia}-s_{ib}| > (a-b), \quad a, b \in \{1, 2, \ldots, J\}, a \neq b. \tag{6}$$

where

Decision variables:

$$x_{ij} = \begin{cases} 1, \text{if project } P_i \text{ is assigned to project manager } M_j \\ 0, \text{otherwise} \end{cases}$$

Parameters:

c_i = the expected overall contribution value of project P_i, obtained by Eq. (2).

s_{ij} = the expected performance score specified by project manager M_j for project P_i.

Y = a large constant.

The objective function (3) is to maximize the total weighted expected contribution values of all projects. Constraints (4) state that each project, if assigned, can only be assigned to one project manager. In situations where the number of available project managers is not sufficient to cover all new projects, some projects are not assigned. Constraints (5) state that some projects (e.g. P_c and P_d) cannot be assigned to the same project

Table 2

Expected performance scores specified by project managers.

Project P_i	Minimum performance score	Project manager M_j											
		M_1	M_2	M_3	M_4	M_5	M_6	M_7	M_8	M_9	M_{10}	M_{11}	M_{12}
		Expected performance score s_{ij}											
P_1	75	86	0	85	75	0	87	0	80	0	80	87	75
P_2	80	0	85	85	80	85	0	80	90	0	90	85	80
P_3	70	75	80	0	75	80	75	0	85	85	85	85	70
P_4	70	0	75	80	0	80	85	75	80	86	86	85	70
P_5	75	80	80	80	80	80	0	85	0	85	80	85	80
P_6	80	85	0	86	85	0	85	85	86	0	0	86	85
P_7	80	0	85	0	85	85	87	86	84	0	87	85	85
P_8	75	85	80	80	0	80	0	85	85	85	0	85	85
P_9	80	84	86	85	87	85	0	0	84	86	89	84	85
P_{10}	70	85	0	75	85	0	85	0	75	84	85	85	70

manager. This limitation can be specified by the company for two or more projects, due to project schedule feasibility, productivity requirement, or quality assurance requirements. This limitation can also apply to a project manager who gives an expected performance score to two or more projects, but can only take up one of them due to personal availability or project schedule feasibility.

Constraints (6) ensure that if two project managers (M_a and M_b) give the same highest expected performance score ($s_{ia} = s_{ib}$), the project will be assigned to the one with a higher priority value. The large constant Y makes $x_{ia} = 0$ if M_a has a lower priority value (i.e. $a > b$). If M_a has a higher priority value (i.e. $a < b$), $x_{ia} = 1$. As tie breakers, constraints (6) also meet the general assignment conditions. The use of $Y(1 - x_{ia})$ in Eq. (6) allows $x_{ia} = 0$ as initial values for every P_i and M_j. It also allows $x_{ia} = 0$ (i.e. not force $x_{ia} = 1$), when s_{ia} is not the highest but is same as others (i.e. $s_{ia} = s_{ib}$). The use of $Y\,|s_{ia} - s_{ib}|$ in Eq. (6) allows M_a to be assigned ($x_{ia} = 1$) when s_{ia} is higher than others (i.e. $s_{ia} - s_{ib} > 0$).

5.2. Empirical illustration

Given the data in Tables 1 and 2, the company can use the optimal project assignment model to support the project assignment decisions when new projects are available. To reflect the assignment limitations as stated in Constraints (5), the company and the project managers specify the projects that cannot be assigned together, as shown in Table 3. For example, the company specifies that projects P_1, P_3, P_4, P_5 and P_{10} must be assigned to different project managers. The project managers specify their own assignment limitations by considering their own capacity and preference in addition to the company's specified limitations. For example, project manager M_1 prefers not to take both projects P_2 and P_6 together.

Table 4 shows the project assignment outcome by solving the optimal project assignment model using the data given in Tables 1 to 3. It is noteworthy that tie-breakers constraints (6) have been applied for a few assignments. For example, project managers M_8, M_9, M_{10}, and M_{11} all have the same highest expected performance score on project P_3. Project P_3 is assigned to manager M_8 who has a relative higher priority value than others.

Table 3
Project assignment limitations specified by the company and project managers.

	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
Co.	P_3 P_4 P_5 P_{10}			P_1 P_3 P_5 P_{10}	P_1 P_3 P_4 P_{10}					P_1 P_3 P_4 P_5
M_1		P_6				P_2				
M_8		P_6 P_7				P_2 P_7	P_2 P_6			
M_{10}		P_7					P_2			
M_{11}	P_9								P_1	
M_{12}		P_8				P_7	P_6	P_2		

Table 4
Optimal project assignment outcome.

Project P_i	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
Project manager M_j	M_6	M_{10}	M_8	M_9	M_7	M_{11}	M_6	M_8	M_{10}	M_1
Expected performance score s_{ij}	87	90	85	86	85	86	87	85	89	85

6. The efficiency-based evaluation process

6.1. Variables for performance efficiency evaluation and DEA model selection

Two DEA models are developed for evaluating the relative performance efficiency of the completed projects and of their project managers respectively. The DEA model for the performance evaluation of the completed projects is used to identify efficient projects and to investigate the performance inefficiencies of the projects in achieving their expected contribution objectives. The output variables of the DEA model are thus the achievement rates of a project, which are measured, for each project contribution objective individually, by the ratio between the actual contribution objective value achieved and the expected contribution objective value.

The DEA model for the performance evaluation of the project managers responsible for the completed projects is used to identify efficient project managers and to investigate the causes of inefficient project managers. The performance efficiency of the project managers is evaluated in terms of the relative degree to which the project managers perform their job and help their responsible project achieve its expected overall contribution value to the organizational objectives as a whole. As such, the output variables of the DEA model are the overall contribution rates of the completed projects and the achievement rates of the project managers. The overall contribution rate of a project is measured by the ratio of the actual overall contribution value to the expected overall contribution value. The achievement rate of a project manager is measured by the ratio of the actual performance score to the expected performance score.

The total effort consumed by a project for achieving the project contribution objectives has been used as an input variable in many DEA applications of project performance evaluation (e.g. Banker et al., 1991; Cao and Hoffman, 2011; Coelli et al., 2005; Farris et al., 2006; Mahmood et al., 1996; Stensrud and Myrtveit, 2003). To be in line with the output variables used, the input variable for the two DEA models described above is the effort consumption rate of a completed project, measured by the ratio between the actual effort and the planned effort of the project. The planned effort, measured as work-months, is given during the project assignment phase. The actual effort is the total amount of work-months spent by a completed project. The consumption rate of a completed project represents the relative degree to which the project consumes the planned work-months.

In evaluating the performance efficiency of projects as DMUs, two types of DEA models are commonly used (Amores and Contreras, 2009; Chen and Zhu, 2011; Farris et al., 2006; Mahmood et al., 1996; Revilla et al., 2003; Stensrud and

Myrtveit, 2003; Ulucan and Baris Atici, 2010; Verma and Sinha, 2002). One assumes constant returns to scale, known as the CRS model, i.e. an increase in input will result in a proportionate increase in output (Charnes et al., 1978). The other assumes variable returns to scale, known as the VRS model, i.e. an increase in input will result in a greater or less than proportionate increase in output (Banker et al., 1984). The CRS model compares all DMUs against an efficiency frontier formed by the DMUs operating under the most productive scale size. The VRS model, on the other hand, allows the DMUs operating under diseconomies of scale to form a part of the efficiency frontier. Apart from the model type, the DEA model can be set up as input-oriented, which attempts to minimize input with the current level of output, or output-oriented, which attempts to maximize output with the current level of input.

The selection of the DEA model type depends on the application problems and the characteristics of the output and input variables (Farris et al., 2006). For the performance evaluation problem formulated in this paper, we use the output-oriented CRS model. The CRS model ensures that the relative performance efficiencies of all completed projects are measured against the best performed projects. The output-oriented model enables the performance efficiency of the projects to be improved by producing more outputs (i.e. higher project contribution objective values) with the same amount of input (i.e. effort).

6.2. Actual performance assessment of the completed projects and project managers

6.2.1. Actual overall contribution value of the completed projects

Given the actual contribution objective value achieved by a completed project, its actual contribution rating to each organizational objective can be calculated by Eq. (1). The actual overall contribution value of each project can then be obtained by Eq. (2).

6.2.2. Actual performance score of project managers

A set of performance evaluation criteria E_k ($k = 1, 2, \ldots, K$) are used by the company to assess the project managers' actual performance in managing projects. The weights u_k of evaluation criteria (E_k) are given to indicate their relative importance. Each project manager M_j will be given a score v_{ik} with respect to each criterion E_k. The actual performance score s^*_{ij} of project manager M_j on project P_i is obtained by multiplying the score v_{ik} by the criteria weights u_k as

$$S^*ij = \sum_{k=1}^{K} u_k v_{ik}; \sum_{k=1}^{K} u_k = 1; \quad i = 1, 2, \ldots, I. \tag{7}$$

6.3. Empirical illustration of performance efficiency evaluation

6.3.1. The DEA model for the performance efficiency evaluation of the completed projects

The company conducts the performance evaluation process using the output-oriented CRS model for 20 completed projects and their responsible 15 project managers in the current planning year. For easy illustration, the completed projects P_y and project managers M_z to be evaluated are numbered consecutively and are independent of those used in the project assignment process. Columns 2–5 of Table 5 show the output variables (achievement rate of project contribution objectives) and the input variable (consumption rate of effort). The last two columns of Table 5 show the efficiency score and performance efficiency ranking of the 20 projects. Projects P_1 and P_{10} with an efficiency score of 1 are considered efficient, while other projects with an efficiency score of less than 1 are rated inefficient. For the inefficient projects to reach efficiency, Table 6 shows the DEA targets and the improvement percentages of the projects in terms of the three project contribution objective outputs. For example, no improvements are needed for efficient projects P_1 and P_{10}. To achieve efficiency, project P_2 should increase its profit (output 1) by 7.41%, employee development level (output 2) by 7.42%, and client satisfaction level (output 3) by 15.6%.

6.3.2. The DEA model for the performance efficiency evaluation of project managers

The company evaluates the relative performance efficiency of the 15 project managers by using the output-oriented CRS model. Columns 2–5 of Table 7 show the output variables (overall contribution rate of projects and achievement rates of project managers) and the input variable (consumption rate of effort) of the model. The actual performance score of the 15 project managers is assessed by the company using five performance evaluation criteria: team management and leadership, commitment, communication with stakeholders, initiatives for improvement, and technical competence. The company regards these criteria as having equal weights in reflecting how the project management job is performed. To facilitate the subjective

Table 5
The performance efficiency evaluation result for the completed projects.

Project	Achievement rate of project			Input		
	Output 1	Output 2	Output 3	Consumption rate of effort	Efficiency score	Ranking
P_y	CO_1	CO_2	CO_3			
P_1	1.010	1.025	1.113	1.000	1.000	1
P_2	0.985	1.038	1.000	1.060	0.930	5
P_3	0.785	0.988	0.913	1.273	0.705	20
P_4	0.923	1.038	0.900	1.136	0.830	12
P_5	0.982	1.013	1.075	1.000	0.977	3
P_6	0.900	0.950	0.913	1.111	0.812	15
P_7	0.850	0.963	1.025	1.200	0.774	17
P_8	0.985	0.875	1.025	1.025	0.952	4
P_9	0.950	0.988	0.950	1.250	0.758	19
P_{10}	0.988	1.113	1.063	1.011	1.000	1
P_{11}	0.961	1.038	1.025	1.117	0.869	10
P_{12}	0.905	1.063	1.025	1.067	0.910	8
P_{13}	0.850	1.013	0.900	1.200	0.767	18
P_{14}	0.870	0.888	0.975	1.100	0.797	16
P_{15}	0.955	1.038	0.975	1.120	0.862	11
P_{16}	0.962	0.963	0.975	1.025	0.929	6
P_{17}	0.987	1.000	1.063	1.057	0.924	7
P_{18}	0.942	1.063	1.025	1.067	0.910	8
P_{19}	0.949	1.013	0.963	1.158	0.824	14
P_{20}	0.858	1.025	0.950	1.129	0.825	13

Table 6
Target improvements in project contribution objectives for inefficient projects.

Project	DEA target of achievement rate			Improvement %		
P_y	Output 1	Output 2	Output 3	Output 1	Output 2	Output 3
	CO_1	CO_2	CO_3	CO_1	CO_2	CO_3
P_1	1.010	1.025	1.113	0	0	0
P_2	1.058	1.115	1.156	7.41	7.42	15.60
P_3	1.244	1.400	1.337	58.47	41.70	46.44
P_4	1.111	1.250	1.195	20.37	20.42	32.78
P_5	1.005	1.036	1.103	2.34	2.27	2.60
P_6	1.109	1.170	1.210	23.22	23.16	32.53
P_7	1.206	1.243	1.324	41.88	29.08	29.17
P_8	1.035	1.051	1.140	5.08	20.11	11.22
P_9	1.253	1.303	1.373	31.89	31.88	44.53
P_{10}	0.988	1.113	1.063	0	0	0
P_{11}	1.106	1.194	1.202	15.09	15.03	17.27
P_{12}	1.045	1.167	1.126	15.47	9.78	9.85
P_{13}	1.173	1.320	1.261	38.0	30.31	40.11
P_{14}	1.111	1.128	1.224	27.70	27.03	25.54
P_{15}	1.107	1.203	1.201	15.92	15.90	23.18
P_{16}	1.035	1.051	1.140	7.59	9.14	16.92
P_{17}	1.068	1.084	1.176	8.21	8.40	10.63
P_{18}	1.045	1.167	1.126	10.93	9.78	9.85
P_{19}	1.151	1.229	1.254	21.29	21.32	30.22
P_{20}	1.104	1.243	1.187	28.67	21.27	24.95

assessment for giving a score to the project managers' actual performance on each evaluation criterion, the company uses a set of linguistic terms associated with specified score bands as a guide. These terms are outstanding (91–100), excellent (86–90), very good (81–85), good (76–80), fair (70–75), and unsatisfactory (0–69). With a score assessed for each criterion, the actual performance score of a project manager can be obtained by Eq. (7).

Columns 6 and 7 of Table 7 show the efficiency score and the performance efficiency ranking of the project managers. With an efficiency score of 1, project managers M_6 and M_{10} (responsible for P_1 and P_{10} respectively) are rated efficient, while others with an efficiency score of less than 1 are rated inefficient. The last four columns of Table 7 show the DEA targets and target improvement percentages, which indicate how inefficient project managers should improve to become efficient. For example, project manager M_{10} would be rated as efficient in performing project P_2 if P_2's overall contribution and her actual performance score are both increased by 11.1%.

It is noteworthy that the relative performance efficiency ranking of a project may not be consistent with that of its project manager, as shown in Tables 5 and 7. This inconsistency is mainly due to the difference between the expected and actual performance scores of the project managers. For example, project P_2 ranks 5th in terms of its relative efficiency in achieving its contribution objectives, but its manager M_{10} ranks 9th in helping the project achieve the overall contribution value and in performing her job. This is because M_{10}'s actual performance score of 82 is much lower than the expected performance score of 88. It is to be noted that the actual performance score of a project manager is assessed based on the actual performance on the job, and this assessment is independent of the expected performance score specified by the project manager. The expected performance score is used in the project assignment phase to indicate a project manager's preference on a project and the company's performance expectation if the project is assigned to the project manager. In the performance evaluation phase, it is used to examine whether a project manager's actual performance has met the performance expectation of the company. The outcome of this performance evaluation phase can be used as a guideline for the company to give an assignment priority value for the project

Table 7
The efficiency evaluation result and target improvements in outputs for project managers.

	Output 1		Output 2	Input			DEA target		Improvement %	
P_y	Overall contribution rate of project	M_z	Achievement rate of project manager (actual/expected)	Consumption rate of effort	Efficiency score	Ranking	Output 1	Output 2	Output 1	Output 2
P_1	1.066	M_6	1.065 (90.5/85)	1.000	1.000	1	1.066	1.065	0	0
P_2	1.018	M_{10}	0.935 (82.3/88)	1.060	0.900	9	1.132	1.039	11.10	11.10
P_3	0.945	M_8	0.885 (75.2/85)	1.273	0.696	20	1.358	1.271	43.70	43.66
P_4	0.964	M_9	0.948 (80.6/85)	1.136	0.795	16	1.212	1.192	25.73	25.71
P_5	1.041	M_7	1.038 (89.3/86)	1.000	0.977	3	1.066	1.063	2.40	2.37
P_6	0.931	M_{11}	0.900 (81.0/90)	1.111	0.785	18	1.185	1.146	27.28	27.33
P_7	0.992	M_6	1.045 (78.4/75)	1.200	0.818	13	1.280	1.278	29.03	22.26
P_8	0.953	M_8	1.060 (84.8/80)	1.025	0.971	4	1.093	1.091	14.69	2.92
P_9	0.969	M_4	0.917 (82.5/90)	1.250	0.726	19	1.334	1.262	37.67	37.67
P_{10}	1.079	M_{10}	0.986 (88.7/90)	1.011	1.000	1	1.079	0.986	0	0
P_{11}	1.028	M_5	1.018 (86.5/85)	1.117	0.864	10	1.191	1.178	15.86	15.76
P_{12}	1.040	M_{14}	1.029 (82.3/80)	1.067	0.915	6	1.137	1.125	9.33	9.36
P_{13}	0.955	M_{13}	1.027 (80.1/78)	1.200	0.804	15	1.280	1.278	34.03	24.45
P_{14}	0.927	M_{12}	0.901 (76.6/85)	1.100	0.790	17	1.173	1.141	26.54	26.61
P_{15}	1.001	M_{11}	0.958 (81.4/85)	1.120	0.838	11	1.195	1.143	19.38	19.36
P_{16}	0.968	M_2	0.987 (85.9/87)	1.025	0.905	8	1.093	1.091	12.91	10.50
P_{17}	1.030	M_5	1.055 (84.4/85)	1.057	0.937	5	1.127	1.126	9.42	6.73
P_{18}	1.038	M_3	0.985 (83.7/83)	1.067	0.912	7	1.138	1.079	9.63	9.58
P_{19}	0.984	M_1	1.014 (79.1/78)	1.158	0.823	12	1.235	1.233	25.51	21.59
P_{20}	0.979	M_{15}	0.909 (78.2/86)	1.129	0.812	14	1.205	1.120	23.08	23.17

manager and set a maximum expected performance score that can be specified by the project manager for new projects, which are to be used in the project assignment phase.

To examine the influence of the expected performance score on the relative performance efficiency ranking of the project managers, we develop an additional DEA model using the project managers' actual performance score as the output, instead of their achievement rate. Table 8 shows the result. Comparing this result with Table 7 indicates that the relative performance efficiency ranking of a project manager is influenced by the inclusion of the expected performance score. The ranking would decrease or increase, if the actual performance score is lower or higher than the expected performance score. This suggests that the expected performance score may play a significant role in determining the relative performance efficiency ranking of the project managers.

To examine how the relative performance efficiency ranking of a project manager would improve if a lower expected performance score has been specified, a sensitivity analysis is conducted. Fig. 2 shows the sensitivity analysis result for the project managers who have a relatively lower ranking due to a relatively higher expected performance score. For each project manager, the expected performance score is decreased by one point at a time from the specified one until the project manager is ranked first. The circled dots indicate the project manager's actual performance score and the corresponding performance efficiency ranking if the expected performance score is reduced to the actual performance score. For example, with an actual performance score of 81 and a specified expected performance score of 90, the ranking of the project manager M_{11} (responsible for project P_6) is 18th. If M_{11} lowers her specified performance score to 81, her ranking would increase to 11th. By lowering her specified performance score to 68, M_{11} would get the first ranking, but with the risk of not getting the project P_6 in the assignment process. As shown in Fig. 2, regardless of the actual performance score, the lower the expected performance score specified by a project manager, the higher the ranking of the project manager.

The result of this study suggests that the expected performance score specified by the project managers will determine whether they will get their preferred projects, and subsequently affect their relative performance efficiency ranking. Given the actual performance score, the performance efficiency ranking of a project manager will be adversely impacted by the expected performance score specified higher than the actual one. This suggests that in the preference-based scoring process for project assignment, project managers should specify an expected performance score that truly reflects their ability for performing the project, not just for winning the project.

Table 8
The efficiency evaluation result without using project managers' expected performance score.

P_y	M_z	Output 1: Overall contribution rate of project	Output 2: Actual performance score	Input: Consumption rate of effort	Efficiency score	Ranking
P_1	M_6	1.066	90.5	1.000	1.000	1
P_2	M_{10}	1.018	82.3	1.060	0.881	8
P_3	M_8	0.945	75.2	1.273	0.707	20
P_4	M_9	0.964	80.6	1.136	0.843	14
P_5	M_7	1.041	89.3	1.000	0.987	3
P_6	M_{11}	0.931	81.0	1.111	0.812	15
P_7	M_6	0.992	78.4	1.200	0.722	19
P_8	M_8	0.953	84.8	1.025	0.921	6
P_9	M_4	0.969	82.5	1.250	0.765	17
P_{10}	M_{10}	1.079	88.7	1.011	1.000	1
P_{11}	M_5	1.028	86.5	1.117	0.872	11
P_{12}	M_{14}	1.040	82.3	1.067	0.878	10
P_{13}	M_{13}	0.955	80.1	1.200	0.760	18
P_{14}	M_{12}	0.927	76.6	1.100	0.851	13
P_{15}	M_{11}	1.001	81.4	1.120	0.881	9
P_{16}	M_2	0.968	85.9	1.025	0.935	5
P_{17}	M_5	1.030	84.4	1.057	0.940	4
P_{18}	M_3	1.038	83.7	1.067	0.888	7
P_{19}	M_1	0.984	79.1	1.158	0.803	16
P_{20}	M_{15}	0.979	78.2	1.129	0.862	12

7. Discussion and limitations

The performance-based approach presented can be easily implemented in a project-based company. To facilitate its implementation, the company requires creating a transparent and proactive organizational culture where the project managers will have the opportunity of undertaking their preferred projects with motivation and responsibility. To help the project managers, especially new project managers with no past experience and performance, specify a reasonable performance score, the company should establish a benchmark performance score (e.g. the average actual performance score on the completed projects) for a given project type. In particular, the company should be aware of the possible opportunistic behavior of some project managers, because the project assignment decision is based on the performance score specified by the project managers.

To reduce the possibility of the project assignment procedure being abused, the performance-based approach integrates the project assignment phase with the performance evaluation phase. The performance score specified by a project manager in the project assignment phase will be used as a baseline for the performance evaluation of the project manager. In addition, the company may set a maximum performance score that the project managers can specify based on their past performance. In some specific management settings, the company can consider taking other effective measures to handle the possible opportunistic behavior of the project managers.

The project assignment phase can be applied whenever one or more new projects are available. To take advantage of the optimal project assignment model which is designed for a complex multi-project environment rather than a single project, this phase should ideally be carried out at a time when new projects must be assigned to get started for practical or management purposes. This will maximize the possibility of the best-performing managers being available and being assigned to the most important projects, thus maximizing the expected contribution values of the new projects. If the company wants to assign a given project to a specific project manager for certain management purposes, this project will not be available for assignment using

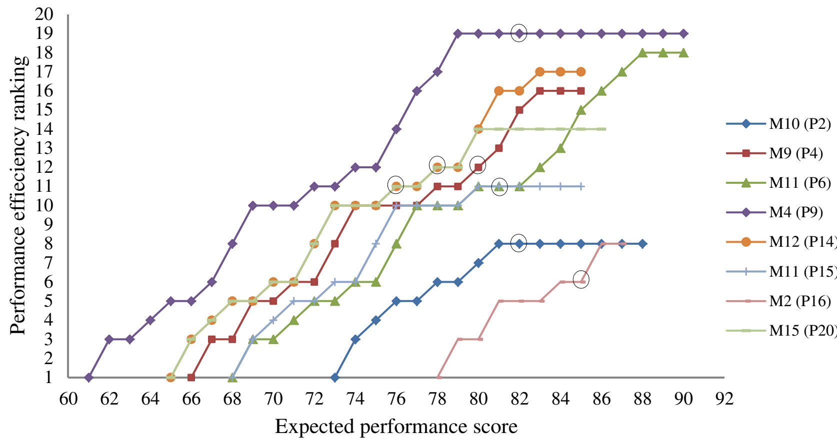

Fig. 2. Performance efficiency rankings of project managers under various expected performance scores.

the model. In some management settings, the company may consider assigning a certain project to a new project manager or assigning a project with no preference from the available project managers to a specific project manager.

With special constraints for accommodating some actual settings, the optimal project assignment model is developed for assigning a new project to one project manager only, although a project manager can be assigned more than one project. In some practical settings where a project can be assigned to more than one project manager, Constraints (4) of the model can be modified to accommodate this setting. In some practical settings where the change of the project manager for a given project is a common practice, the model can be extended to include this setting as a special constraint.

The performance evaluation phase presented focuses on measuring the relative performance efficiency of the projects and of the project managers, although some effectiveness-based performance evaluation criteria are used for assessing the actual performance score of the project managers. In some project-based company settings, the performance evaluation criteria used should ideally cover all relevant human aspects of project management and/or accommodate specific project climates such as unusually difficult project climate. Future research can thus be conducted to examine what performance evaluation criteria can be used to best assess the actual performance score of the project managers in specific settings. Future research can also be conducted to examine what input and output variables can be used to best measure the relative performance efficiency of the projects and of the project managers in specific settings.

8. Conclusions

Project assignment and project performance evaluation have traditionally been addressed as two separate research issues. In this paper, we have presented a new performance-based approach for integrating these two important issues by using the expected contribution value of the projects and the expected performance score specified by the project managers. This approach provides project-based organizations with a proactive and transparent mechanism for managing the assignment of new projects to project managers and for evaluating the performance efficiency of the completed projects and their responsible project managers. The use of the expected contribution values of the projects to the organizational objectives in both the project assignment process and the project performance evaluation process would facilitate objective-focused management of the projects. With the opportunity of specifying a performance score for getting a project, the project managers are encouraged to take proactive attitudes towards their preferred projects in the project assignment process and subsequently take responsibility for their preferred projects in the performance evaluation process.

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