MODEL FOR ASSIGNING PROJECT MANAGERS TO MINIMIZE LOSSES

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Abstract
The competence of an assigned project manager is the key to the success of a project. However, only a few studies address the issue of losses due to incorrect assignment of project managers. Assigning an incompetent project manager results in extra costs, because a project manager with poor technical capability may lead to making technical decisions of high defect rate, which is linked to later waste, scrap and rework costs. On the other hand, a project manager with poor management capability leads to a high frequency of project changes due to poor planning, monitoring and control, which also increases project costs. This study intends to develop a model incorporating both the costs of technical and managerial capability gaps to minimize the overall losses of inadequate project manager assignment. The problem is formulated as a non-linear programming model, and an algorithm is applied to solve the cost minimizing project manager assignment. Finally, a case with 8 projects and 16 project managers is used to demonstrate the applicability of the proposed model.

Keywords: Assignment, project manager, managerial capability, technical capability

I. Introduction

A project manager’s capability can generally be classified into technical capability and managerial capability. Technical capability is the ability of a project manager to provide the required performance in terms of project execution, while managerial capability is the ability to perform specific and general managerial functions in terms of project planning, monitoring and control. However, most researches on project managers focus on personal characteristics instead of technical or managerial capability, leading to project losses. Assigning an appropriate project manager is the key factor to the success of a project (Faulkner and Day 1986; Parker and Skitmore 2005)[1, 2]. In addition, the project manager’s capability is also an important factor affecting project performance, particularly the ability to work with people rather than technical skills (Sabaa 2001) [3]. When project managers’ technical capability is much better than managerial capability, the project will be vulnerable to lack of careful planning, potentially leading to future changes, scope creep, progress delay and budget overruns (Kromer 2009)[4]. On the contrary, if project managers’ managerial capability is much better than technical capability, then it will be highly likely the end product will be of poor quality and unable to meet the project requirements. Unfortunately, in the studies of assigning project manager, the determination of the relative weight between technical and management skills remains inconclusive. However, previous researches indicated the project capability required for project managers is quite situational and subjective, thereby affecting the performance of project implementation (Ogunlana et al. 2002)[5]. To optimize the project managers’ assignment to improve project performance, the characteristics of project managers should conform to the project needs (Patanakul and Milosevic 2006)[6].

II. Literature review

Assigning an optimal project manager has become an important issue for project management (Toney 1997; Rubin and Seeling 1967)[7, 8]. The ability of project managers and the success of the project have shown high correlation in many studies (Smith et al. 1984; Beer et al. 1990; Karpin 1995; Belassi 1996; Parker and Skitmore 2005)[9, 10, 11, 12, 2]. Questionnaires are generally utilized to study the attributes of project managers (Posner 1987; Pettersen 1991; Ogunlana et al. 2002) [13, 14, 5] and the research results suggest the managerial ability of project managers is a key factor in the success of a project (Belassi and Tuke 1996)[12]. However, there are also studies concluding the leadership of project managers is more important than general managerial capability (Sotiriou and Wittmer 2001, Parker and Skitmore 2005)[15, 2]. Koch (2012)[16] indicated that the output of an employee who is promoted into a job for which he is not well suited need not decline post promotion. Patanakul (2011) explored the impact of the methods used in project manager assignment on project management effectiveness [17]. Patanakul (2015) provided an overview of an optimization based method for project manager assignment [18].

Traditionally, the Hungarian algorithm is commonly used to deal with the linear assignment problem. Prasad (2009) utilized the Hungarian algorithm to solve the cost functions of assigning project managers [19]. The genetic algorithm, simulated annealing (Sahu and Tapadar 2007)[20] and the neural network (Azim 2006; Ramlogan et al. 1989; Büther 2010)[21, 22, 23] are often used to solve non-linear quadratic assignment problem.

III. Model Formulation

As stated previously, a project manager with poor technical capability leads to a high defect rate increasing the possibility of waste, scrap and rework costs. On the other hand, insufficient managerial capability results in future budget and progress correction which elevate crush costs. To help enterprises assign the most suitable project manager, this study proposes a linear and non-linear cost minimizing model which can simultaneously deal with costs due to gaps in technical capability and managerial capability. The model is described by the following algorithm.

Algorithm

Step 1: Identify the required capability of projects and the actual capability of project managers.

Table 1 lists the required managerial and technical capability for different projects, where P_i = the i^{th} project, M^R_i = the i^{th} project managerial capability requirement, and T^R_i = the i^{th} project technical capability requirement. Table 2 shows the actual managerial and technical capability of project managers, where PM_j = the j^{th} project manager, M_j = the j^{th} project manager's real managerial capability, and T_j = the j^{th} project manager's real technical capability.

Table 1. Capability Requirements for Projects

Projects (P_i)	P_1	P_2	P_3	P_4	….	P_k
Managerial capability requirement (M^R_i)	M^R_1	M^R_2	M^R_3	M^R_4	…	M^R_k
Technical capability requirement (T^R_i)	T^R_1	T^R_2	T^R_3	T^R_4	…	T^R_k

Table 2. Actual Capability of Project Managers

Project Manager (PM_j)	PM_1	PM_2	PM_3	PM_4	…	PM_{k+n}
Actual managerial capability (M_j)	M_1	M_2	M_3	M_4	…	M_{k+n}
Actual technical capability (T_j)	T_1	T_2	T_3	T_4	…	T_{k+n}

Step 2: Compute the gaps between the required and actual capabilities.

It is assumed k+n candidates are assigned to k projects and the gaps between the required and actual capabilities are termed as the project capability gap (PCG). The PCG can be classified into a technical capability gap and managerial capability gap. The technical capability gap ($\triangle T_{ij}$) is defined as the difference between actual technical capability (T_j) and the required technical capability (T^R_i), which can be described by Equation (1).

$$\triangle T_{ij} = T_j - T^R_i \text{, where } i = 1 \ldots k \text{ and } j = 1 \ldots k+n \qquad (1)$$

Managerial capability gap ($\triangle M_{ij}$) is defined as the difference between actual managerial capability (M_j) and the required managerial capability ($M^R{}_i$), which can be expressed as Equation (2).

$$\triangle M_{ij} = M_j - M^R{}_i \text{ , where } i = 1 \ldots k \text{ ; } j = 1 \ldots k+n \qquad (2)$$

According to Equations (1) and (2), there will be k*(k+n) possible combinations of technical capability and managerial capability. The details of these are shown in Table 3, where ΔM_{ij} represents the managerial capability gap between the i[th] project and the j[th] project manager, and ΔT_{ij} is the technical capability gap between the i[th] project and the j[th] project manager. Figure 1 depicts the capability required for each project and the actual capability of each project manager. Project i and project manager j are used for explanation in Figure 1, where ($M^R{}_i$, $T^R{}_i$) imply the required capability of project i and (M_j, T_j) indicate the actual capability of project manager j.

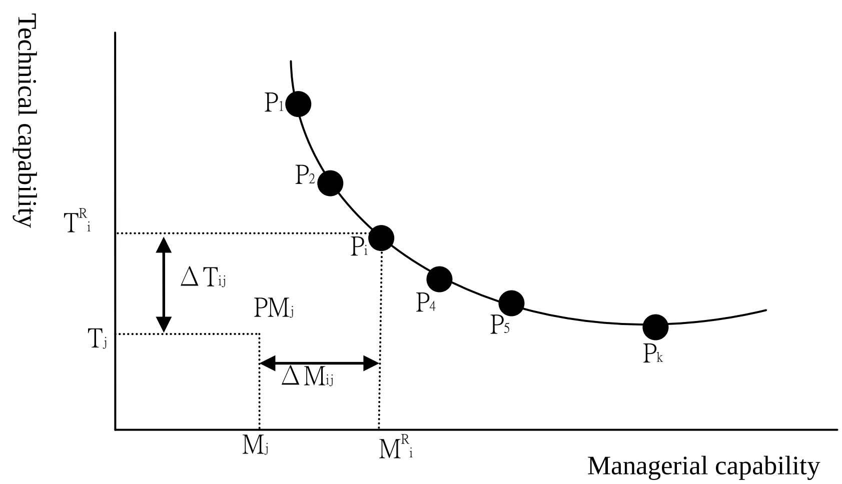

Figure 1 Required and Actual Capability

Step 3: Specify quality loss function

If the technical capability gap is positive ($\triangle T_{ij}$ >=0), it means the project manager meets the project technical requirement and thus can guarantee the quality of the project. Conversely, when the technical capability gap is negative ($\triangle T_{ij}$ <0), then the project managers may not be able to effectively detect and solve technical problems, leading to a high defect rate. The relationship between technical capability and the defect rate DR_{ij} can be described as Equation (3): \

Table 3 Managerial and Technical Capability Gaps

Capability Requirement / PCG / Actual Capability		P_1		P_2		P_3		P_4		…	P_k	
		M^R_1	T^R_1	M^R_2	T^R_2	M^R_3	T^R_3	M^R_4	T^R_4	…	M^R_k	T^R_k
PM_1	M_1	ΔM_{11}		ΔM_{21}		ΔM_{31}		ΔM_{41}		…	ΔM_{k1}	
	T_1		ΔT_{11}		ΔT_{21}		ΔT_{31}		ΔT_{41}	…		ΔT_{k1}
PM_2	M_2	ΔM_{12}		ΔM_{22}		ΔM_{32}		ΔM_{42}		…	ΔM_{k2}	
	T_2		ΔT_{12}		ΔT_{22}		ΔT_{32}		ΔT_{42}	…		ΔT_{k2}
PM_3	M_3	ΔM_{13}		ΔM_{23}		ΔM_{33}		ΔM_{43}		…	ΔM_{k3}	
	T_3		ΔT_{13}		ΔT_{23}		ΔT_{33}		ΔT_{43}	…		ΔT_{k3}
PM_4	M_4	ΔM_{14}		ΔM_{24}		ΔM_{34}		ΔM_{44}		…	ΔM_{k4}	
	T_4		ΔT_{14}		ΔT_{24}		ΔT_{34}		ΔT_{44}	…		ΔT_{k4}
PM_5	M_5	ΔM_{15}		ΔM_{25}		ΔM_{35}		ΔM_{45}		…	ΔM_{k5}	
	T_5		ΔT_{15}		ΔT_{25}		ΔT_{35}		ΔT_{45}	…		ΔT_{k5}
…	.	.	.	.	.	.	.	.	.	…	.	
PM_{k+n}	M_{k+n}	$\Delta M1_{k+n}$		ΔM_{2k+n}		ΔM_{3k+n}		ΔM_{4k+n}		…	ΔM_{kk+n}	
	T_{k+n}		ΔT_{1k+n}		ΔT_{2k+n}		ΔT_{3k+n}		ΔT_{4k+n}	…		ΔT_{kk+n}

$$DR_{ij} = \begin{cases} 0 & if \quad \Delta T_{ij} \geq 0 \\ a\Delta T_{ij}^2 - b\Delta T_{ij} + c & if \quad \Delta T_{ij} < 0 \end{cases} \tag{3}$$

The defect rate (DR_{ij}) is a quadratic function of the negative technical capability gap, and coefficients a, b and c are greater than zero, and can be specified according to the characteristics of the projects.

The costs C^T_{ij} associated with waste, scrap and reworking defective products can then be computed and described as Equation (4).

$$C_{ij}^T = \begin{cases} -\eta & if \quad \Delta T_{ij} \geq 0 \\ DR_{ij} * [\alpha(waste \,\&\, scrap \cos t) + \beta(rework \cos t)] & if \quad \Delta T_{ij} < 0 \end{cases} \tag{4}$$

Where, $\alpha + \beta = 1$.

As stated earlier, when $\triangle T_{ij}$ >=0, then there would be no costs due to quality losses, since the project manager is technically competent. However, if $\triangle T_{ij}$ is much greater than zero, implying the project manager is over qualified technically, and then the assignment of the project manager is actually a waste of resources. Therefore, this study suggests a project manager should be selected when his or her technical capability is as close to the requirement as possible. To distinguish the abovementioned two cases, Equation (4) introduces a coefficient η to distinguish project managers meeting the basic requirement and those that are over qualified. Nevertheless, η can be adjusted depending on the actual capability level. On the other hand, since the costs of quality losses are positively correlated to the defect rate, when $\triangle T_{ij} <0$, the costs due to quality losses can be easily determined by finding the multiplication of the defect rate and the corresponding scrap and rework costs. To be flexibly applicable, factors of α and β are used to adjust the actual weights between scrap and rework.

Step 4: Specify managerial loss function

If the managerial capability gap is positive ($\triangle M_{ij}>=0$), it means the project manager meets the project managerial requirement and can properly manage the project. Conversely, when the managerial capability gap is negative ($\triangle M_{ij}<0$), then the project manager may not be able to effectively exercise the managerial functions of planning, monitoring and controlling, leading to budget overrun and schedule delays. The earned value management system (EVMS) is normally utilized to simultaneously measure the performance of the schedule and cost by computing the schedule performance index (SPI) and cost performance index (CPI). Three values are needed for the calculation, i.e., the planned value (PV), earned value (EV) and actual cost (AC), and the details are as follows:

$$SPI_{ij} = \frac{EV}{PV}\begin{cases} >1, & \text{ahead} \\ =1, & \text{as scheduled} \\ <1, & \text{delay} \end{cases}$$

$$CPI_{ij} = \frac{EV}{AC}\begin{cases} >1, & \text{under spend} \\ =1, & \text{as budgeted} \\ <1, & \text{over spend} \end{cases}$$

It is assumed managerial deficiency will result in poor schedule performance index and cost performance index. Therefore, SPI and CPI can be expressed as a function of managerial capability gaps using Equation (5) and (6) respectively.

$$SPI_{ij} = \begin{cases} \mathrm{P}\Delta M_{ij} & \text{if } \Delta \mathrm{M}_{\mathrm{ij}} > 0, \\ 1 & \text{if } \Delta \mathrm{M}_{ij} = 0 \\ -K\Delta M_{ij} & \text{if } \Delta \mathrm{M}_{ij} < 0 \end{cases} \quad (5)$$

Where, P is a transformation coefficient if SPI>1, $P > \frac{1}{\Delta M_{ij}}$ and P > 0,

K is a transformation coefficient if SPI<1, $0 < K < -\frac{1}{\Delta M_{ij}}$.

$$CPI_{ij} = \begin{cases} \mathrm{R}\Delta M_{ij} & \text{if } \Delta \mathrm{M}_{\mathrm{ij}} > 0 \\ 1 & \text{if } \Delta \mathrm{M}_{ji} = 0 \\ -L\Delta M_{ij} & \text{if } \Delta \mathrm{M}_{ii} < 0 \end{cases} \quad (6)$$

Where R is a transformation coefficient if CPI>1, $R > \frac{1}{\Delta M_{ij}}$ and $R > 0$,

L is a transformation coefficient if CPI<1, $0 < L < -\frac{1}{\Delta M_{ij}}$.

The costs $C^{M}{}_{ij}$ associated with poor performance indices due to inadequate managerial capability can then be expressed as Equation (7). Where, m, n and ρ are the coefficients of the quadratic function, and γ, δ are the relative weights of CPI and SPI.

Step 5: Compute overall assignment cost losses

The overall assignment cost losses due to the technical capability gap and managerial capability gap can now be determined as the addition of quality loss and managerial loss.

$$C^{M}{}_{ij} = \begin{cases} -PR & SPI > 1,\ CPI > 1 \\ 0 & SPI = 1,\ CPI = 1 \\ m\left[\dfrac{1}{\gamma CPI_{ij} + \delta SPI_{ij}}\right]^2 + n\left[\dfrac{1}{\gamma CPI_{ij} + \delta SPI_{ij}}\right] + \rho & SPI < 1, CPI < 1 \ \text{where} \quad \gamma + \delta = 1 \end{cases} \qquad (7)$$

Where coefficients *m*, *n* and ρ are greater than zero. The possible combinations of the technical capability gap and managerial capability gap can be illustrated using Figure 2, where the horizontal axis represents zero technical capability gaps, and the areas above and below this line indicate positive and negative technical capability respectively. The vertical axis implies zero managerial capability gap, and the areas on the right and left sides of this line indicate positive and negative managerial capability respectively. There are four quadrants in Figure 2, and the overall assignment cost losses will be obtained for each quadrant.

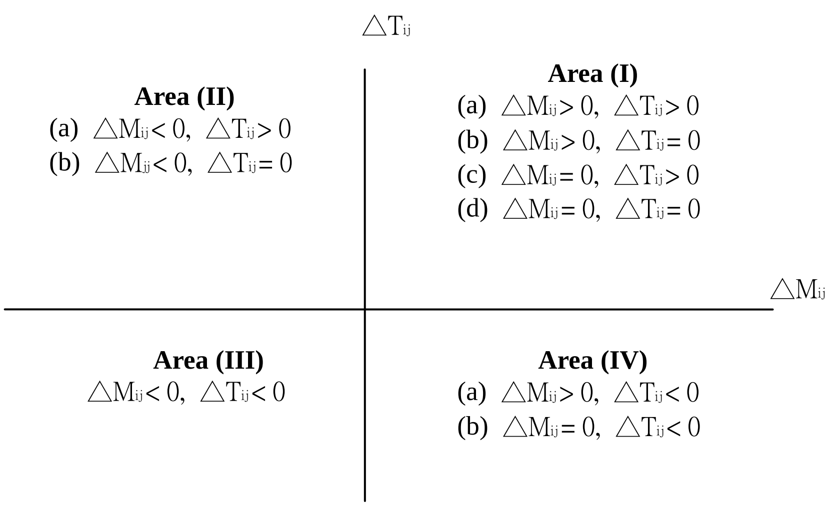

Figure 2 Combinations of Capability Gaps

(1) Overall assignment cost losses for Area (I)

Area (I) has four possible combinations of managerial and technical capability gaps, and the assignment cost for each of the four cases are obtained as follows.

(a) Assignment cost losses $AC^{I\text{-}a}{}_{ij}$

This is a case where $\triangle M_{ij} > 0$, $\triangle T_{ij} > 0$, i.e., both gaps are positive, meaning the project managers are over qualified managerially and technically. Clearly, the quality and managerial costs will not occur in this case, but a waste of resources may need to be avoided. The assignment cost loss $AC^{I\text{-}a}_{ij}$ can be expressed as equation (8).

$$AC^{I\text{-}a}_{ij} = -(PR)-\eta \qquad P, R, \eta > 0 \tag{8}$$

(b) Assignment cost losses $AC^{I\text{-}b}_{ij}$

This is a case where $\triangle M_{ij}>0$, $\triangle T_{ij}=0$, i.e., a positive managerial capability gap and zero technical capability gaps, meaning project managers are over qualified managerially and perfectly matched technically. The assignment cost loss $AC^{I\text{-}b}_{ij}$ can be expressed as Equation (9).

$$AC^{I\text{-}b}_{ij} = -(PR) \qquad P, R > 0 \tag{9}$$

(c) Assignment cost losses $AC^{I\text{-}c}_{ij}$

This is a case where $\triangle M_{ij}=0$, $\triangle T_{ij} >0$, i.e., zero managerial capability gap and positive technical capability gap, meaning project managers are perfectly matched managerially and over qualified technically. The assignment cost loss $AC^{I\text{-}c}_{ij}$ can be expressed as Equation (10).

$$AC^{I\text{-}c}_{ij} = \eta \qquad \eta > 0 \tag{10}$$

(d) Assignment cost losses $AC^{I\text{-}d}_{ij}$

This is a case where $\triangle M_{ij}=0$, $\triangle T_{ij}=0$, i.e., zero managerial capability gap and zero technical capability gap, meaning project managers are perfectly matched managerially and technically. This is the best possible assignment scenario that enterprises should strive to achieve, and the assignment cost loss $AC^{I\text{-}d}_{ij}$ can be expressed as Equation (11).

$$AC^{I\text{-}d}_{ij} = 0 \tag{11}$$

(2) Overall assignment cost losses for Area (II)

Area (II) has two possible combinations of managerial and technical capability gaps, and the assignment cost loss for each of the two cases is obtained as follows.

(a) Assignment cost losses $AC^{II-a}{}_{ij}$

This is a case where $\triangle M_{ij} < 0$, $\triangle T_{ij} > 0$, i.e., a negative managerial capability gap and positive technical capability gap, meaning the projects managers are under qualified managerially and over qualified technically. The assignment cost loss $AC^{II\text{-}a}{}_{ij}$ can be expressed as Equation (12).

$$AC^{II-a}{}_{ij} = m\left[\frac{1}{\gamma CPI_{ij} + \delta SPI_{ij}}\right]^2 + n\left[\frac{1}{\gamma CPI_{ij} + \delta SPI_{ij}}\right] + \rho - \eta \tag{12}$$

(b) Assignment cost losses $AC^{II-a}{}_{ij}$

This is a case where $\triangle M_{ij} < 0$, $\triangle T_{ij} = 0$, i.e., a negative managerial capability gap and zero technical capability gaps, meaning project managers are under qualified managerially, and perfectly matched technically. The assignment cost loss $AC^{II\text{-}b}{}_{ij}$ can be expressed as Equation (13).

$$AC^{II-b}{}_{ij} = m\left[\frac{1}{\gamma CPI_{ij} + \delta SPI_{ij}}\right]^2 + n\left[\frac{1}{\gamma CPI_{ij} + \delta SPI_{ij}}\right] + \rho \tag{13}$$

(3) Overall assignment cost losses for Area (III)

Area (III) has only one possible combination of managerial and technical capability gaps, and this is a case where $\triangle M_{ij} < 0$, $\triangle T_{ij} < 0$, i.e., both gaps are negative, meaning the project managers are under qualified managerially and technically. This is the worst case that will cause the greatest losses, and the assignment cost loss for this case is obtained as follows.

$$AC^{III}{}_{ij} = m\left[\frac{1}{\gamma CPI_{ij} + \delta SPI_{ij}}\right]^2 + n\left[\frac{1}{\gamma CPI_{ij} + \delta SPI_{ij}}\right] + \rho$$
$$+ DR_{ij} * \left[\alpha(waste \,\&\, scrap \ \text{costs}) + \beta(\text{rework cost})\right] \tag{14}$$

(4) Overall assignment cost losses for Area (IV)

Area (IV) has two possible combinations of managerial and technical capability gaps, and assignment cost loss for each of the two cases is obtained as follows.

(a) Assignment cost losses $AC^{IV-a}{}_{ij}$

This is a case where $\triangle M_{ij} > 0$, $\triangle T_{ij} < 0$, i.e., a positive managerial capability gap and negative technical capability gap, meaning project managers are over qualified managerially and under qualified technically. The assignment cost loss $AC^{IV-a}{}_{ij}$ can be expressed as Equation (15).

$$AC_{ij}^{IV-a} = -(PR) + DR_{ij} * [\alpha(waste \,\&\, scrap \cos t) + \beta(rework \cos t)] \quad \alpha + \beta = 1 \tag{15}$$

(b) Assignment cost losses $AC^{IV\text{-}b}{}_{ij}$

This is a case where $\triangle M_{ij} = 0$, $\triangle T_{ij} < 0$, i.e., zero managerial capability gap and negative technical capability gap, meaning project managers are perfectly matched managerially and under qualified technically. The assignment cost loss $AC^{IV\text{-}b}{}_{ij}$ can be expressed as Equation (16).

$$AC_{ij}^{IV-b} = DR_{ij} * [\alpha(waste \,\&\, scrap \cos t) + \beta(rework \cos t)] \tag{16}$$

IV. Case implementation

To demonstrate the applicability of the proposed model, an experimental case is tested in this section. 16 potential project managers are assigned to 8 projects based on managerial and technical capabilities in expectation of minimizing the overall assignment cost losses. The implementation processes are described step wisely as below.

Step 1: Identify the required capability of the projects and the actual capability of project managers.

For ease of computation, a scale from 1 to 10 is used to measure the level of required managerial capability ($M^R{}_i$), technical capability ($T^R{}_i$), actual managerial capability (M_j) and actual technical capability (T_j). Table 4 lists the level of required capability for the 8 projects. Table 5 shows the actual level of capability of the 16 project managers.

Table 4 Level of Required Capability for 8 Projects

Project (P_i)	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
Required Managerial Capability ($M^R{}_i$)	9	2	4	6	6	7	4	8
Required Technical Capability ($T^R{}_i$)	2	7	5	3	6	3	8	7

Table 5 Actual Level of Capability of 16 Project Managers

Project Manager (PM_j)	PM_1	PM_2	PM_3	PM_4	PM_5	PM_6	PM_7	PM_8	PM_9	PM_{10}	PM_{11}	PM_{12}	PM_{13}	PM_{14}	PM_{15}	PM_{16}
Actual managerial capability (M_j)	9	1	3	8	5	7	8	6	7	4	3	5	4	2	5	4
Actual Technical Capability(T_j)	1	5	7	4	5	7	8	4	3	4	3	2	8	9	8	1

Figure 3 depicts the relationship between the required capability of project 3 and the actual capability of project manager 4.

Step 2: Compute the gaps between required and actual capabilities.

Totally 128 possible combinations of 8 projects and 16 project managers can be obtained to form the entire set of assignment alternatives. Table 6 shows the details.

Step 3: Specify quality loss function

It is assumed coefficient *a*, *b*, and c in Equation (3) are set to be 0.01, 0.005, and 0.025 respectively, therefore, the defect rate represented by Equation (3) becomes:

$$DR_{ij} = \begin{cases} 0 & if \quad \Delta T_{ij} > 0 \\ 0.01\Delta T_{ij}^2 - 0.005\Delta T_{ij} + 0.025 & if \quad \Delta T_{ij} < 0 \end{cases}$$

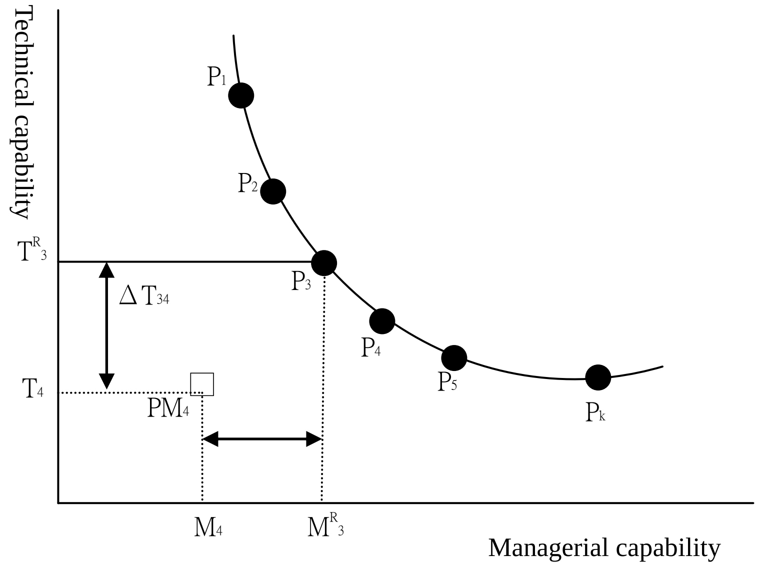

Figure 3 Required and Actual Capabilities of Project 3 and Manager 4

In addition, to distinguish perfectly matched project managers from those that are over qualified, η is set as 0.01 for $\Delta T_{ij} > 0$ and 0 for $\Delta T_{ij} = 0$, whereas waste and scrap costs and rework cost are assumed to be 500 and 750. Moreover, the weight of scrap cost and rework cost α 、β are specified as 0.1 and 0.9. All coefficients can be specified based on real situations.

Therefore, the costs due to defective quality represented by Equation (4) become:

$$C^{T}{}_{ij} = \begin{cases} -0.01 & if \quad \Delta T_{ij} > 0 \\ 0 & if \quad \Delta T_{ij} = 0 \\ DR_{ij} * \left[0.1(500) + 0.9(750) \right] & if \quad \Delta T_{ij} < 0 \end{cases}$$

Table 6 128 Combinations of Capability Gaps

Capability Re / Capabilit / Actual Capab		P_1		P_2		P_3		P_4		P_5		P_6		P_7		P_8	
		M^R_1	T^R_1	M^R_2	T^R_2	M^R_3	T^R_3	M^R_4	T^R_4	M^R_5	T^R_5	M^R_6	T^R_6	M^R_7	T^R_7	M^R_8	T^R_8
PM_1	M_1	0		7		5		3		3		2		5		1	
	T_1		-1		-6		-4		-2		-5		-2		-7		-6
PM_2	M_2	-8		-1		-3		-5		-5		-6		-3		-7	
	T_2		3		-2		0		2		-1		2		-3		-2
PM_3	M_3	-6		1		-1		-3		-3		-4		-1		-5	
	T_3		5		0		2		4		1		4		-1		0
PM_4	M_4	-1		6		4		2		2		1		4		0	
	T_4		2		-3		-1		1		-2		1		-4		-3
PM_5	M_5	-4		3		1		-1		-1		-2		1		0	
	T_5		3		-2		0		2		-1		2		-3		-2
PM_6	M_6	-2		5		3		1		1		0		3		-1	
	T_6		5		0		2		4		1		4		-1		0
PM_7	M_7	-1		6		4		2		2		1		4		0	
	T_7		6		1		3		5		2		5		0		1
PM_8	M_8	-3		4		2		0		0		-1		2		-2	
	T_8		2		-3		-1		1		-2		1		-4		-3
PM_9	M_9	-2		5		3		1		1		0		3		-1	
	T_9		1		-4		-2		0		-3		0		-5		-4
PM_{10}	M_{10}	-5		2		0		-2		-2		-3		0		-4	
	T_{10}		2		-3		-1		1		-2		1		-4		-3
PM_{11}	M_{11}	-6		1		-1		-3		-3		-4		-1		-5	
	T_{11}		1		-4		-2		0		-3		0		-5		-4
PM_{12}	M_{12}	-4		3		1		-1		-1		-2		1		-3	
	T_{12}		0		-5		-3		-1		-4		-1		-6		-5
PM_{13}	M_{13}	-5		2		0		-2		-2		-3		0		-4	
	T_{13}		6		1		3		5		2		5		0		1
PM_{14}	M_{14}	-7		0		-2		-4		-4		-5		-2		-6	
	T_{14}		7		2		4		6		3		6		1		2
PM_{15}	M_{15}	-4		3		1		-1		-1		-2		1		-3	
	T_{15}		6		1		3		5		2		5		0		1
PM_{16}	M_{16}	-5		2		0		-2		-2		-3		0		-4	
	T_{16}		-1		-6		-4		-2		-5		-2		-7		-6

Step 4: Specify managerial loss function

Schedule performance index SPI and cost performance index CPI can be obtained using Equations (5) and (6), and let P=1/6, K=1/8 and R=1/6, L=1/8, Equations (5) and (6) become:

$$SPI_{ij} = \begin{cases} \frac{1}{6}\Delta M_{ij} & \text{if } \Delta \mathrm{M}_{ij} > 0 \\ 1 & \text{if } \Delta \mathrm{M}_{ij} = 0 \\ -\frac{1}{8}\Delta M_{ij} & \text{if } \Delta \mathrm{M}_{ij} < 0 \end{cases}$$

$$CPI_{ij} = \begin{cases} \frac{1}{6}\Delta M_{ij} & \text{if } \Delta \mathrm{M}_{ij} > 0 \\ 1 & \text{if } \Delta \mathrm{M}_{ij} = 0 \\ -\frac{1}{8}\Delta M_{ij} & \text{if } \Delta \mathrm{M}_{ij} < 0 \end{cases}$$

Cost losses due to a negative managerial capability gap incurring budget overrun and progress delay can be obtained using Equation (7), and coefficients m, n, ρ are set to be 8, 5 and 1 respectively; the weight γ and δ for SPI and CPI is specified as 0.1 and 0.9. Therefore Equation (7) becomes the following:

$$C^{M}{}_{ij} = \begin{cases} -\frac{1}{36} & SPI > 1,\ CPI > 1 \\ 0 & SPI = 1,\ CPI = 1 \\ 8\left[\frac{1}{0.1CPI_{ij} + 0.9SPI_{ij}}\right]^2 + 5\left[\frac{1}{0.1CPI_{ij} + 0.9SPI_{ij}}\right] + 1 & SPI < 1, CPI < 1 \end{cases}$$

Step 5: Compute overall assignment cost losses

The overall assignment cost due to the technical capability gap and managerial capability gap can now be determined for each area in Figure 2.

(1) Overall assignment cost losses for Area (I)

(a) $AC^{\text{I-a}}{}_{ij} = -\frac{1}{36} - 0.01$

(b) $AC^{\text{I-b}}{}_{ij} = -\frac{1}{36}$

(c) $AC^{\text{I-c}}{}_{ij} = -0.01$

(d) $AC^{I\text{-}d}{}_{ij} = 0$

(2) Overall assignment cost losses for Area (II)

(a) $AC^{II-a}{}_{ij} = 8\left[\frac{1}{0.1CPI_{ij} + 0.9SPI_{ij}}\right]^2 + n\left[\frac{1}{0.1CPI_{ij} + 0.9SPI_{ij}}\right] + 1 - 0.01$

(b) $AC^{II-b}{}_{ij} = 8\left[\frac{1}{0.1CPI_{ij} + 0.9SPI_{ij}}\right]^2 + 5\left[\frac{1}{0.1CPI_{ij} + 0.9SPI_{ij}}\right] + 1$

(3) Overall assignment cost losses for Area (III)

(a) $AC^{III}{}_{ij} = 8\left[\frac{1}{0.1CPI_{ij} + 0.9SPI_{ij}}\right]^2 + 5\left[\frac{1}{0.1CPI_{ij} + 0.9SPI_{ij}}\right] + 1 + DR_{ij} * \left[0.5(500) + 0.5(750)\right]$

(4) Overall assignment cost losses for Area (VI)

(a) $AC^{IV-a}{}_{ij} = -(\frac{1}{36}) + DR_{ij} * \left[0.1(500) + 0.9(750)\right]$

(b) $AC^{\text{IV - b}}{}_{ij} = DR_{ij} * \left[0.1(500) + 0.9(750)\right]$

The combinations of the overall cost losses of the project manager assignment can be summarized in Table 7.

Table 7 Overall Cost losses of Project Manager Assignment

Assignment cost functions	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
PM_1	IV-b	IV-a	IV-a	IV-a	IV-a	IV-a	IV-a	IV-a
PM_2	II-a	III	II-b	II-a	III	II-a	III	III
PM_3	II-a	I-b	II-a	II-a	II-a	II-a	III	II-b
PM_4	II-a	IV-a	IV-a	I-a	IV-a	I-a	III	III
PM_5	II-a	IV-a	I-b	II-a	III	II-a	IV-a	IV-b
PM_6	II-a	I-b	I-a	I-a	I-a	I-c	IV-a	II-b
PM_7	II-a	I-a	I-a	I-a	I-a	I-a	I-b	I-c
PM_8	II-a	IV-a	IV-a	I-c	IV-b	II-a	IV-a	III
PM_9	II-a	IV-a	IV-a	I-b	IV-a	I-d	IV-a	III
PM_{10}	II-a	IV-a	IV-b	II-a	III	II-a	IV-b	III
PM_{11}	II-a	IV-a	III	II-b	III	II-b	III	III
PM_{12}	II-b	IV-a	IV-a	III	III	III	IV-a	III
PM_{13}	II-a	I-a	I-c	II-a	II-a	II-a	I-d	II-a
PM_{14}	II-a	I-c	II-a	II-a	II-a	II-a	II-a	II-a
PM_{15}	II-a	I-a	I-a	II-a	II-a	II-a	I-b	II-a
PM_{16}	III	IV-a	IV-b	III	III	III	IV-b	III

Each of the cases in Table 7 can be easily obtained using the relevant equations stated previously. Table 8 presents all possible combinations of overall assignment cost losses for the 16 candidates and 8 projects. A positive assignment cost loss indicates the project manager is either under qualified managerially or technically, and the larger the value the worst the qualification. On the other hand, a negative assignment cost loss implies the project manager is either over qualified managerially or technically, and the larger the value the more serious the situation. Therefore, the best project manager to be assigned would be the one with a positive value closest to zero. Therefore, starting from zero assignment cost loss, project managers 9 and 13 are assigned to projects 6 and 7 respectively. Project manager 4 is next assigned to project 3 since it is the second smallest positive assignment cost loss of 12.68. Project manager 2 is assigned to project 1 because it is 23.74 nearest to 12.68, and project manager 14 is assigned to project 8 with a loss value of 35.55. Finally, project managers 1 and 5 are assigned to projects 4 and 2 respectively with identical loss values of 45.19. The optimal assignment of project managers is presented in Table 9.

Table 8 Assignment Cost Losses of all Combinations

Project Managers	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
PM_1	29.00	250.89	123.12	**45.19**	208.32	50.29	373.25	299.85
PM_2	**23.74**	909.38	110.56	46.99	76.00	35.55	204.81	82.84
PM_3	35.55	-1.02	854.99	110.55	110.55	67.49	884.00	47.00
PM_4	854.99	57.53	**12.68**	-4.09	50.29	-1.03	155.35	112.25
PM_5	67.49	**45.19**	-1.02	854.99	884	229.99	93.23	54.38
PM_6	229.99	-25.51	-9.19	-1.03	-1.03	-0.01	19.82	855.00
PM_7	854.99	-36.73	-16.33	-4.09	-2.05	-1.03	-16.32	-0.01
PM_8	110.55	77.93	24.92	-0.01	**17.99**	854.99	144.54	324.25
PM_9	229.99	123.12	45.19	-1.02	93.23	**0.00**	208.32	1003.63
PM_{10}	46.99	90.17	29.00	229.99	284.38	110.55	148.63	161.75
PM_{11}	35.55	147.60	909.38	110.56	204.81	67.50	1072.50	195.63
PM_{12}	67.50	208.32	93.23	884.00	1003.63	259.00	299.85	328.06
PM_{13}	46.99	-4.09	-0.01	229.99	229.99	110.55	**0.00**	67.49
PM_{14}	28.46	-0.01	229.99	67.49	67.49	46.99	229.99	**35.55**
PM_{15}	67.49	-9.19	-1.03	854.99	854.99	229.99	-1.02	110.55
PM_{16}	76.00	298.83	148.63	284.38	447.50	164.93	398.75	368.38

Table 9 Optimal Project Managers Assignment

Project	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
Optimal Project Manager	PM_2	PM_5	PM_4	PM_1	PM_8	PM_9	PM_{13}	PM_{14}

V. Conclusion

One of the most important issues before initiating a project is the assignment of a project manager, who is commonly viewed as one of the most vital success factors of a project. Traditionally, the project manager is selected based on explicit criteria such as work experience, professional background, personal interests or even availability of personnel. However, work experience may simply mean experience in making mistakes; professional background may just signal possible future prejudice of expertise; and personal interest may obviously reveal a more technical mindset. Therefore, the existing approach of project manager assignment cannot guarantee the quality of project outcome, and unfortunately, a method that can quantify the appropriateness of assigning a project manager is nonexistent. This study proposes a model that can measure the losses from improper project manager assignment by mathematically quantifying the costs of insufficient management capability and incompetent technical capability. To optimize the assignment, factors distinguishing one that slightly exceeds or lacks from those significantly over qualified and under qualified are used to improve the accuracy of the assignment. The implementation case demonstrates the proposed model can be an effective method for assigning the most suitable project managers to the most appropriate projects. Consequently, future costs due to problems of incorrect assignment of project managers can be greatly avoided.

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