OPEN ACCESS

International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-11 Issue-6, March 2023

Maximization of Contractor Business Competencies Resulting from Project Team Competencies

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Abstract: *Under the current circumstances of highly competitive business operations, contractors should allocate their resources to develop the project team competencies, which will lead to the improvement of the contractors' business competencies. A key question is how the contractors' limited resources should be allocated to develop the project team's competencies and thus maximise the contractor's business competencies. A literature review reveals that few research studies have addressed this question, indicating a knowledge gap that needs to be filled. Therefore, this research aimed to answer this question by developing a linear programming model that suggests optimal resource allocation to improve the project team's competencies. A survey case study in the Thai construction industry was used to illustrate the application of the model. The results of the model application show that the optimal proportion of resource allocation to develop the project team competencies should be as follows: physical health (32.80%), communication (16.30%), knowledge (15.60%), decision-making (10.60%), relationship management (9.80%), systematic construction work (9.80%), and systematic management (5.20%). These results can serve as a suggestion for contractors to optimise their resource allocation and develop their project team competencies, thereby maximising contractor business competencies.*

Keywords: *Contractor, Business Competency, Project Team Competency, Linear Programming*

I. INTRODUCTION

The competition for project work is very intense in today's construction industry. This has forced contractors to develop themselves in various areas to enhance their organizations' competencies, which leads to a competitive advantage over rivals. Developing project team competencies is one area that can improve contractor business competencies. [1] in 2015 also mentioned that competency is one of the key areas to developing business productiveness. Construction is a project-based business comprising many functions working under limited time and resources [2]. In old-fashioned construction, a project may depend on individual effort; however, to respond to a highly competitive environment, participants need to engage in work through multidisciplinary teams [3]. As such, many researchers were studying competency. Based on the construction project organization structure, [4] in 2011 stated that the key member competencies consist of project manager, engineering, and technician competencies. The key members work under a hierarchical structure in which project tasks are distributed from project managers to different divisions controlled by engineers. Then, each division utilises resources to implement project work under the supervision of the technicians. [2,3,5,6,7]

Individual competencies for project implementation must be consistent and mutually supportive of one another. [8] in 2000 mentioned that project managers are responsible for the overall success of delivering the owner's physical development within the constraints of cost, time, quality, and safety requirements. Sometimes, project managers need to decide on project direction, strategic implementation, organizing well-fare, construction management, training subordinate, negotiation with other parties, and project risk management. [7,9,10]. Engineering professional requires knowledge of mathematics and physical sciences and are expected to develop ways to economically utilize resources through design, planning, material selection, and workforce management [4,11]. Many researchers discussed engineer competencies such as knowledge, technical, behaviour, communication, problem-solving, systematic management, and resource control [4,6,12]

Construction technicians oversee labour production, construction, and maintenance of construction facilities (e.g., tools and equipment) under guidelines from engineers or project managers. Factors describing technician competencies are learning attitudes, health, social skills, construction skills, systematic working, and self-management [4,6,11,13,14,]. Business competency can be a significant determinant of contractor efficiency. One hundred eighty-five construction companies in Turkey were surveyed to study business competency in the view of construction project management [2]. Business competencies were discussed, aiming to select and predict their businesses. Factors indicating business competencies were suggested: information management, strategic management, financial management, resource allocation, relationship management, project management, and continuous development. [1, 6, 7, 8, 15]

Manuscript received on 08 February 2023 | Revised Manuscript received on 12 February 2023 | Manuscript Accepted on 15 March 2023 | Manuscript published on 30 March 2023.
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Although many researchers have studied project team competencies and contractor business competencies, the question is whom (i.e., project managers, engineers, or technicians) contractors should invest their limited resources to develop their competencies, resulting in the maximization of contractor business competencies. Few studies have answered this question of resource allocation. Thus, the objective of this study is to answer this question by using optimization techniques. Various optimization techniques exist for solving the resource allocation problem. In this study, linear programming (LP) has been employed because it is a simple and widely used approach. The results of this study will help contractors allocate their limited resources in the optimal proportion to develop the competencies of project managers, engineers, and technicians, thereby maximising the contractor's business competency. This, in turn, leads to a competitive advantage over competitors.

II. LITERATURE REVIEW

Many researchers have conducted studies on competency. [16] in 1991 studied resource-based view (RBV) to create a business advantage, which could be recognized early in the discussion. Competency in this period was primarily focused on performance against the output-based measure. Since the 20th century, the selection of personnel in construction companies has been a topic of widespread discussion in human resource management (HRM). Later, behavioural competency was discussed in terms of psychological understanding and predicting human performance based on competency [7]. [12] in 2012 also mentioned that the judgment of the selection of project team members with interview processes was uncertain. Their behavioural competencies cannot be accurately evaluated because they are still difficult to assess, particularly within a short period, such as during interviews. In 2016, [17] recommended that project leaders should have the ability to work under pressure and balance the strategic vision while dealing with strict monitoring progress. [7] have found that the project team (i.e., project managers, engineers, and technicians) competencies influence contractor business competencies. In their study, the relationship among various competencies is as follows:

- technician competencies (TC) explained by learning (LT), physical health (HT), social (ST), systematic construction work (SYT), and self-control (ScT)
- engineer competencies (EC) explained by knowledge (KE), technical skill (TE), communication (CE), problem-solving (PE), systematic management (SE), and resource management (RE)
- project manager competencies (PMC) explained by relationship management (RP), decision-making (DP), risk management (RiP), knowledge management (KP), strategic implementation (SP), construction management (CP), and organization management (OP)
- business competencies (BC) explained by information management (IB), strategic management (SB), financial management (FB), resource management (RB), relationship management (ReB), project management (PB), and continuous development (CB).

The effects observed across various competencies are as follows.

- TC has a direct effect on EC with a regression weight of 0.87.
  - o LT explains TC with a regression weight of 0.54.
  - o HT explains TC with a regression weight of 0.77.
  - o ST explains TC with a regression weight of 0.51.
  - o SyT explains TC with a regression weight of 0.51.
  - o ScT explains TC with a regression weight of 0.75.
- EC has a direct effect on both PMC and BC, with regression weights of 0.55 and 0.49, respectively.
  - o KE explains EC with a regression weight of 0.42.
  - o TE explains EC with a regression weight of 0.63.
  - o CE explains EC with a regression weight of 0.44.
  - o PE explains EC with a regression weight of 0.64.
  - o SE explains EC with a regression weight of 0.49.
  - o RE explains EC with a regression weight of 0.55.
- PMC has a direct effect on BC with a regression weight of 0.50.
  - o RP explains PMC with a regression weight of 0.48.
  - o DP explains PMC with a regression weight of 0.58.
  - o RiP explains PMC with a regression weight of 0.53.
  - o KP explains PMC with a regression weight of 0.66.
  - o SP explains PMC with a regression weight of 0.61.
  - o CP explains PMC with a regression weight of 0.53.
  - o OP explains PMC with a regression weight of 0.46.

However, the study on allocating resources to develop the competencies for each key project team member that maximizes contractor business competencies still has not been well expanded, showing a gap of knowledge that should be addressed. The study addresses this gap using an LP model to solve this allocation problem.

III. MODELING OF CONTRACTOR BUSINESS COMPETENCIES

Two models will be created to solve the allocation problem. First, a relationship model was made between project manager competencies, engineer competencies, technician competencies, and business competencies using structural equation modelling (SEM). This has already been done in the study of [7], and the results are shown in the previous section. Second, the result from SEM was used as a framework to develop the second model in this study, optimally allocating resources to enhance the competencies of project team members, resulting in maximizing business competencies. The schematic modelling of the research is shown in Figure I.

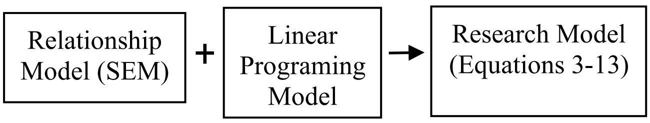

Figure- I: Schematic Modelling of the Research

A. Relationship Model

SEM was used to investigate the influence of technician, engineer, and project manager competencies on contractor business competencies.

The SEM model comprises two essential components: the measurement model and the structural model. Both are described with observed and latent variables, as shown in Equations (1) and (2), respectively [18].

$$\begin{cases} x = \lambda_x \xi + \delta \\ y = \lambda_y \eta + \varepsilon \end{cases} \tag{1}$$

where ξ is the vector of the exogenous latent variables; λ_x is the coefficient matrix that links the observed variables and latent variables; x is the vector of the observed variables; δ is the vector of the measurement errors in the exogenous latent variables; y is the vector of the endogenous variables; λ_y is a coefficient matrix that links the observed variables and latent endogenous variables; η is the vector of the endogenous latent variables; and ε is the vector of the measurement errors in the endogenous variables.

$$\eta = B\eta + \tau\xi + \zeta \tag{2}$$

where B is an influence coefficient matrix that links the η variable and other η variables; τ is an influence coefficient matrix that links the endogenous latent variables (η) and exogenous latent variables (ξ); and ζ is the vector of the errors in the equation.

B. Optimization Model Based on the Relationship Model

Concerning the measurement model, the regression weight (refer to λ_x or λ_y in Equation (1)) between the observed variable (refer to x or y in Equation (1)) and the corresponding latent variable (refer to ξ or η in Equation (1)) indicates the relationship ratio of these two variables. This relationship ratio determines the increase in the observed variable to increase the unit of the corresponding latent variable, which can be interpreted as the relationship coefficient (a_{ij}) of the j^{th} decision variable showing the increasing resources spent on the decision subvariable (competency of each project team member) of the growing unit of resources invested in the decision variable (project manager, engineer, technician competencies), comprising the constraints in the optimization problem. With respect to the structural model, either the influence (refer to τ in Equation (2)) between the exogenous and endogenous latent variables or the influence (refer to B in Equation (2)) between the endogenous and endogenous latent variables reveals the influence ratios of pairs of these variables. Similar to the relationship ratio of the measurement model, this influence ratio determines the change in one latent variable with respect to the other latent variables. This ratio can be expressed as the influence coefficient (aj), which constrains the proportion of resources invested in one team member's competencies (one latent variable) relative to the proportion of resources invested in the other team member's competencies (the other latent variable), thereby affecting contractor business competencies. Both the relationship and influence coefficients can be used to formulate the optimization problem.

In modelling the optimisation problem, the constraint functions are established between pairs of variables with their corresponding coefficients. The establishment of the constraint functions using the relationship coefficients and the influence coefficients is presented in Equations (3) and (4), respectively.

$$\begin{cases} \sum_{i=1}^{q_j} \left(x_{ij} - a_{ij}\,\xi_j\right) \le 0 \\ \sum_{i=1}^{q_j} \left(y_{ij} - a_{ij}\eta_j\right) \le 0 \end{cases} \tag{3}$$

where x_{ij} and y_{ij} are the decision subvariables for i = 1, 2, …, qj; qj is the number of decision subvariables describing the jth decision variable (ξ and η) for j = 1, 2, …, r; and r is the number of decision variables. Equation (3) is formulated by applying Equation (1) to constrain the proportion of resources distributed to all decision subvariables (each competency) and their corresponding decision variables (overall competency for each team member). This equation states that the value of each decision subvariable must be equal to or less than the value of its decision variable multiplied by the corresponding relationship coefficient, which is efficient.

$$\text{If} \begin{cases} \text{Each number of } \xi \text{ and } \eta > 1: \eta_j - (a_{jk}\xi_k \text{ or } a_j\eta_k) > 0 \\ \text{Each number of } \xi \text{ and } \eta = 1: \eta_j - (a_{jk}\xi_k \text{ or } a_j\eta_k) = 0 \end{cases} \tag{4}$$

where ξ and η are the other decision variables that influence the decision variables (η_j); a_{jk} is the influence coefficient corresponding to the j^{th} decision variable that influence to kth decision variable (ξ or η) for j = 1, 2, …r; and k = 1, 2, …r; and r is the number of decision variables (ξ and η). Equation (4) is established by applying Equation (2) to limit the proportion of resources allocated between pairs of decision variables (each competency). In this application, the error term (ξ) is assumed to be zero. Additionally, only two decision variables (η_j and ξ or η) are paired one by one to form a constraint function. Thus, Equation (4) expresses that if each number of the decision variable (ξ or η) influencing η_j is more than one, the value of η_j will always be higher than that of the other decision variable (ξ or η) multiplied by its influence coefficient (a_j). On the other hand, the value of the decision variable (η_j) equals that of the multiplication of the decision variable and its influence coefficient if each number of the decision variable influencing η_j equals one. Both Equations (3) and (5) present the typical arrangement to determine the constraint functions based on the relationship (SEM) model.

In the application of LP to find the optimal combination of project team competencies that maximizes business competencies, it is here assumed that the sum of proportional resources spent on developing competencies of project managers, engineers, and technicians is less than or equal to 1 (or 100%). Then, these fixed resources will determine the maximum proportional value of resources distributed to all corresponding subcompetencies (refer to x_{ij} or y_{ij} in Equation (3)) within each project team member (refer to ξ or η in

Equation (3)).

Thus, the constraint functions can be obtained as follows:

$$\sum_{i=1}^{q_j}(SubPMC_{ij} - a_{ij}PMC) \leq 0 \text{ for } j = 3 \quad (5)$$

$$\sum_{i=1}^{q_j}(SubEC_{ij} - a_{ij}EC) \leq 0 \text{ for } j = 2 \quad (6)$$

$$\sum_{i=1}^{q_j}(SubTC_{ij} - a_{ij}TC) \leq 0 \text{ for } j = 1 \quad (7)$$

$$\begin{cases} PMC + EC + TC \leq 1 \\ \sum_{i=1}^{q_j}(SubPMC_{ij}) = PMC \text{ for } j = 3 \\ \sum_{i=1}^{q_j}(SubEC_{ij}) = EC \text{ for } j = 2 \\ \sum_{i=1}^{q_j}(SubTC_{ij}) = TC \text{ for } j = 1 \\ \text{and } SubPMC_{ij}, SubEC_{ij}, SubTC_{ij}, PMC, EC, TC \geq 0 \end{cases} \quad (8)$$

where a_{ij} refers in Equation (3); $SubPMC_{ij}$, $SubEC_{ij}$, and $SubTC_{ij}$ are the i^{th} competencies describing project manager competencies (PMC), engineer competencies (EC), and technician competencies (TC), respectively, for i = 1, 2, …qj; q_j is the number of staff describing the j^{th} staff or business competencies (refer to Equation (3)). Equations (5 - 7) are extended from Equation (3), while Equation (8) defines the limitations of resource distribution from competencies and their corresponding staff and the nonnegative conditions. By expanding Equation (4), the additional constraint functions are:

$$EC - a_{jk}TC = 0 \quad \text{for } j = 2; k = 1 \quad (9)$$

$$PMC - a_{jk}EC = 0 \quad \text{for } j = 3; k = 2 \quad (10)$$

$$BC - a_{jk}EC > 0 \text{ for } j = 4; k = 2 \quad (11)$$

$$BC - a_{jk}PMC > 0 \text{ for } j = 4; k = 3 \quad (12)$$

where a j refers to Equation (4). To improve competitive advantage and remain long-term in business, contractors should invest their limited resources most efficiently in developing the competencies of their project teams. The resource investment should enhance business competencies, leading to a competitive advantage over rivals. Hence, the objective of the optimization problem is to maximize business competencies and is formulated as follows:

$$\begin{cases} \text{Max } S = BC \\ \quad = (a_{4,3}a_{3,2} + a_{4,2})a_{2,1}TC \end{cases} \quad (13)$$

Equation (13) expresses that the objective function comprises business competencies (BC), where BC can be obtained from Equations (11) and (12), respectively. As seen in the equation, the maximisation of business competencies depends on technician competencies.

IV. MODEL APPLICATION AND RESULTS

The SEM results of [7] in 2019 (refer to Section II) were used as a basis for solving the allocation problem to demonstrate the application of the optimization model. General Algebraic Modelling System (GAMS) version 40.4.0 software was used GAMS, 2020 to obtain an optimal solution. The optimal solution here is the proportions of resources that were invested in each competency of the project team to achieve the objective of maximizing business competencies. The results of the optimal resource proportions are shown in Table I. To further explain the results, the resource proportion spent on each competency was normalised (the last column of Table I). In the table, the descending resource-spent proportions on all competencies are physical health (32.80%), communication (16.30%), knowledge (15.60%), decision making (10.60%), relationship management (9.80%), systematic construction work (9.80%) and systematic management (5.20%). This result indicates that contractors should allocate 32.80% of resources to developing the physical health of technicians, 16.30% to improving the communication of engineers, 15.60% to enhancing the knowledge of engineers, and so on. Notably, to improve business competencies in limited-resource situations, resources should be allocated to develop risk management, knowledge management, strategic implementation, construction management, and organisational management for project managers. For engineers, the resource should not be spent on developing technical skills, problem-solving, and resource management. Lastly, for technicians, the resource should not be spent on developing learning, social, and self-control skills. The proportions of resource allocation to develop these competencies are expected to maximise contractor business capabilities.

Table- I: Results of Optimally Allocating Resources to Develop Project Team Competencies.

Project Team Competencies	Optimal Resource Proportion	Normalization weight, %
Project manager	**0.204**	**20.40**
• Relationship management	0.098	9.80
• Decision making	0.106	10.60
• Risk management	-	-
• Knowledge management	-	-
• Strategic implementation	-	-
• Construction management	-	-
• Organization management	-	-
Engineer	**0.370**	**37.00**
• Knowledge	0.156	15.60
• Technical skill	-	-
• Communication	0.163	16.30
• Problem-solving	-	-
• Systematic management	0.052	5.20
• Resource management	-	-
Technician	**0.426**	**42.60**

Retrieval Number: 100.1/ijrte.F74690311623
DOI: 10.35940/ijrte.F7469.0311623
Journal Website: www.ijrte.org

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Project Team Competencies	Optimal Resource Proportion	Normalization weight, %
• Learning	-	-
• Physical health	0.328	32.80
• Social	-	-
• Systematic construction work	0.098	9.80
• Self-control	-	-

Note: Project team members and their optimal resource proportions are shown in bold letters.

V. DISCUSSION

The optimization (LP) model was established based on the relationship model between project manager competencies, engineer competencies, technician competencies, and business competencies, which SEM analyzed. The optimization results in Table I suggest that contractors should spend 42.60%, 37.00%, and 20.40% of resources to develop technician, engineer, and project manager competencies, respectively. Interestingly, there are various competencies that contractors should refrain from investing resources in developing. A likely reason is that when contractor resources are limited, contractors should select to invest their resources in building only critical competencies based on their priorities that will maximise their business competencies. The optimization results also suggest that the contractors should allocate nearly half of their resources to developing technician competencies. The discussion of each project team's competency is as follows.

• Technician competencies: Labour activities and production were supervised by technicians. Technicians also play a role in maintaining construction tools and equipment. To keep the project's acceptable production rate, technicians must utilise the resources allocated by engineers to plan operations that labourers can follow systematically. Regarding technician competencies, the optimization solutions suggest that two competencies should be resourced with their resource-allocated proportions in parentheses: physical health (32.80%) and systematic construction work (9.80%). Physical health has the highest proportion of resources allocated to it. Technicians must work alongside labourers in harsh environments. Often, when labourers require support, such as with issues related to construction techniques or working procedures, immediate action from technicians is needed to prevent project delays. This means technicians must accompany labourers for almost the entire working day. Thus, physical health is unavoidable for this technical position. As [4] in 2011 mentioned that technicians have the role of supervising laborers who perform tasks involving physical construction activities, so technicians need to have skills over all the laborers. For systematic construction work competencies, technicians play a crucial role in teaching labourers how to perform their work systematically. When labourers work systematically, it improves the outcome of their work. Also, [14] in 2015 suggested that the construction skills of site supervisors or technicians are vital to project success.

• Engineer competencies: Engineers have an essential role in controlling project resource utilization, affecting project budget and profit. Within engineer competencies, the optimization solutions suggest that three competencies were resourced with their resource-allocated proportions in parentheses: communication (16.30%), knowledge (15.60%), and systematic management (5.20%). Among these competencies, communication has the highest proportion of resource spending. Engineers work between project managers and technicians, so they need to utilise their communication skills to receive project managers' project policies and then translate them into work procedures or regulations. Engineers need to understand both management-level policies and the feedback from the workforce. Compared to communication competency, knowledge competency has a slightly lower proportion of allocated resources. In construction, engineers establish design, safety plans, and material selection to ensure the highest production rate while operating in compliance with safety standards. As well, [4] in 2011 mentioned that engineers have a role in utilizing resources through design, planning, material selection, and workforce management. To perform these tasks, engineers need knowledge of mathematics and physical sciences that will enable them to develop economical methods of using resources.

• Project manager competencies: Construction projects consist of many sections working together under the guidance of project managers through project organization charts, personnel welfare, job prescription, and career path development. Project manager competencies affect the creation of project competitive advantages. Regarding project manager competencies, the optimization solutions suggest that two competencies should be resourced with their resource-allocated proportions in parentheses: decision-making (10.60%) and relationship management (9.80%). Decision-making accounts for the highest proportion of resource allocation. Project managers have the highest authority to decide which activities should be undertaken, resulting in changes to the project's budget, safety, and duration. Thus, the project managers' decisions should be accurate in terms of timing and information. [9] in 2008, project managers contributed directly or indirectly to any job and career in the organization, such as role prescriptions, rewards, and psychological environments. In addition, project managers should develop relationship competency to harmonise overall work processes, thereby increasing the chances of project success. Construction projects comprise numerous interrelated sections. For example, the financial section should prepare a budget for the procurement section, and then the procurement section can provide the necessary materials to the construction section. This suggests that the relationships among different sections in the project should be managed systematically by the project managers. [10] in 2013 also pointed out that construction project managers should be able to understand the relationship issues and politics at the organizational level as one of the critical project success factors.

Retrieval Number: 100.1/ijrte.F74690311623
DOI: 10.35940/ijrte.F7469.0311623
Journal Website: www.ijrte.org

Published By:
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VI. CONCLUSIONS

For contractor organizations to survive and thrive in an increasingly competitive environment, contractors may use their resources to develop project team competencies. The question is how much the contractors should allocate to the limited resources to build the project team's competencies. However, few research works have been found to suggest an answer to this question, showing a knowledge gap. Accordingly, this research aims to answer this question by developing an optimal (LP) model that suggests the distribution of resources to improve the project team competencies and then maximize business competencies.

The LP model was established based on the relationship between project manager competencies, engineer competencies, technician competencies, or contractor business competencies. A survey case study in the previous study of [7] in 2019 was used to demonstrate that the proposed LP model is applicable. In the application, the optimization (LP) results show that contractors should invest their limited resources in developing competencies of the project team members in the following descending order: physical health, communication, knowledge, decision-making, relationship management, systematic construction work, and systematic management. Comparisons among individual members of the project team reveal that (1) for technicians, most resources should be used to develop physical health competency; (2) for engineers, most resources should be used to develop communication competency; (3) for project managers, most resources should be used to develop decision-making competency. The results of this research will help contractors determine the optimal proportion of resources to develop the project team's competencies to maximize the contractor organizations' competencies.

DECLARATION

Funding/ Grants/ Financial Support	The authors had not received any funding.
Conflicts of Interest/ Competing Interests	There is no conflict of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	The article does not require ethical approval or consent to participate in evidence.
Availability of Data and Material/ Data Access Statement	Data sharing is not relevant in this article because no datasets were analysed during the study.
Authors Contributions	All authors have equal participation in this article.

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Retrieval Number: 100.1/ijrte.F74690311623
DOI: 10.35940/ijrte.F7469.0311623
Journal Website: www.ijrte.org

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