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Development of Poor Productivity Mitigation Model for a Viaduct Bridge Project

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Abstract: Poor productivity is a common phenomenon in the construction industry. Poor or lack of project knowledge management continues to plague the construction process especially in relation to project delays. At the same time, the human resource function has undergone dramatic change, owing, it would seem, to greater use of rapidly evolving information technology. The goal of this paper is to investigate how the choice of the human resource management strategy would positively impact both the organizational and project performance. The research methodology adopted for this study comprised three steps. First, the productivity problems encountered during the construction operations of a viaduct bridge are reviewed and reported using interviews on the potential factors contributing directly and indirectly to more effective project operations. Second, the least squares method is utilized to prioritize and rank the importance, impact, and effect of these factors. Third, a scalable and transferable poor productivity mitigation model is developed. The adopted model incorporates concepts from knowledge management, project learning and supervisory controls. Results of this research indicate that knowledge management and generally the human resource management strategy is a key factor for project success.
Keywords: Construction productivity; Viaduct bridge project; Poor productivity; Mitigation model.

1. Introduction

The issue of construction poor productivity has captured considerable attention from researchers. However, while numerous labor productivity studies have been undertaken to investigate the causes and effects, only a few have addressed the productivity issues from the labor management perspective. Bordoli and Baldwin [1] proposed an important systematic methodology for the evaluation of construction project poor productivity that causes delays. In particular, methodology focuses the project progress in six types of delays: date delay; total delay; extended delay; additional delay; sequence delay; and progress delay. A study in the construction industry in Singapore by Lim and Alum [2] indicated that the most important problems affecting productivity were: difficulty with recruitment of supervisors and workers; a high rate of labor turnover and absenteeism; and communication problems with foreign workers. A separate study by Olomolaiye et al. [3] indicated the factors affecting productivity. Five specific productivity problems identified were: lack of materials; rework; absenteeism; shortage of tools; and equipment. Rojas and Aramvareekul [4] reported the 10 most significant problems affecting construction productivity in Thailand, which were: lack of materials; incomplete drawings; incompetent supervisors; lack of tools and equipment; absenteeism; poor communication; short instruction time; poor site layout; inspection delay; and rework. Finally, Motwani et al. [5] reported five factors impeding productivity in the United Sates, namely, adverse site conditions; poor sequencing of works and conflicting drawings; lack of information; non-availability of tools and materials; and poor weather.

Many researchers support though that the poor productivity is owed mainly in endogenous and exogenous factors [6]. The exogenous factors include various reasons such as natural (earthquakes, floods etc.), political (irregular political situation), legislative (prohibitions, limitations, imposition of obligations, continuous changes of institutions law), economical (international and national economic crises, inflation, downturn, difficulty of capitals finding, high interest-rates of lending etc.), demographical (internal and external immigration, differentiations in the composition of population, input of foreign workers), technologically (depreciation of equipment and installations because of the rapid technical progress, design assumptions, site conditions, construction procedures, construction occupational safety), environmental (environment pollution) and public safety regulation (noise pollution). The endogenous factors on the other hand comprise other reasons such as bad operation of a sector (procurement of materials), staff (lacks, reactions, absences etc), organization (bad distribution of places and competences, conflicts etc.), lack of cash flow (possibility from the persons in charge of the project to correspond to their direct obligations) and communication (bad understanding between executives and workers).

The level of productivity on a construction site depends on a combination of integrated conditions throughout the project life cycle and the idea of productivity cannot be viewed in isolation. Improving site conditions; management and supervision; proper payment procedures on completed works; avoiding labor density; and improved scheduling are some of the important factors when attempting to limit productivity losses on site [4, 7]. An essential step towards improvement is a clear appreciation and understanding of the severity of each factor on site [8]. Consequently, considerable efforts to understand the concept of productivity have resulted in a wide variety of definitions in the field [9-11]. Productivity improvement can be viewed as a function of management as changes for improvement can only be implemented at management level [12]. The short-lived construction project life cycle and project-based management hinder progressive improvements in work conditions and management. However, a study that aims at establishing a best practice model for productivity improvement should be considered a significant contribution for the construction project [13]. Despite the considerable efforts on this front, researchers have not agreed on a universal set of factors with significant influence on productivity, nor has any agreement been reached on the classification of these factors [2, 4, 14, 15].

One of the earlier studies examining problems causing poor productivity on construction projects was conducted by Alaghbari et al. [16] who included and ranked 52 predefined factors affecting construction labour productivity in Yemen, categorizing them into four primary groups: human/labour, management, technical and technological, and external. The results showed that the group of technical and technological factors ranked first among the four groups whereas the top five factors identified were the most significant in their effect on construction labour productivity in Yemen: (1) labour's experience and skills, (2) availability of materials in site, (3) leadership and efficiency in site management, (4) availability of materials in the market, and (5) political and security situation. Hamza et al. [17] determined the impact of CLP (Construction Labour Productivity) through available scientific databases and a set of 88 articles by using Jenks classification method. The results of the study helped in understanding the directions required for better management of CLP in different geographical regions. On the other hand, Ahmad et al. [18] investigated macro-economic labour productivity and identified the methodological problems inhibiting the effective measurement of construction labour productivity. Their findings revealed that many productive construction activities related to construction products and services are excluded from the construction labour productivity statistics. Finally, Gurmu [19] identified and prioritized construction materials management practices that have the potential to enhance labour productivity in multi-storey building projects. According to his study, the long-lead materials identification, procurement plans for materials and materials delivery schedule were found to be the three most important construction materials management practices.

Based on the aforementioned thorough review, it can be noted that the poor productivity if it is not solved swiftly, can cause major problems such as cost overruns in projects; harm cooperative relationships; reduce efficiency; and lead to claims and disputes. Poor productivity results not only in financial setbacks but also in a bad reputation for the contractors. Therefore, time efficiency should be looked at as a long-term competitive advantage. All these research studies have developed the use of value engineering in order to overcome the problems of construction poor productivity. They also put a strong emphasis on thorough planning, realistic scheduling, and continuous monitoring to avoid construction delays. Hence, early prediction and a thorough diagnosis of the problems can help avoid construction delays and complete the projects within time, budget and expected quality.

The goal of this paper is to investigate how the choice of the human resource management strategy would positively impact both the organizational and project performance. To this end, the author would study and analyze the problems affecting construction productivity as well as the factors contributing towards improved productivity using the least squares method to develop a poor productivity mitigation model. This paper should not only provide a substantial evidence on the current understanding and perception of labor productivity in relation to construction projects but it also clear pathways for the project stakeholders to address the current productivity problems.

2. Research methodology

The research methodology adopted for this study comprises three steps. First, the author reviewed the productivity problems encountered during the construction operations of a viaduct bridge and reported using interviews on the potential factors contributing directly and indirectly to more effective project operations. Second, the author utilized the least squares method to prioritize and rank the importance, impact, and effect of these factors. Third, the author developed scalable and transferable poor productivity mitigation model.

The squares method approach fully embeds the fuzzy structure of the human resource management effectiveness as a target output into the optimization problem. This method examines the effect of certain variables (independent variables) on other variables (dependent variables). The determination of a model for the g(x) form should be portrayed as the graphic notation of the points $(x_1, y_1), (x_2, y_2),\dots, (x_n, y_n)$ in the level xy, where these points depict n pairs of measurements for the independent and depended variable. The above analysis will result in dispersion diagrams for the points (X_i,Y_i). We have to suppose a linear relation because the most points do not align exactly on a straight line. Consequently, we will suppose a simple linear model of the form [20]:

$$Y_i = \beta_O + \beta_1 x_i + e_i \quad (i = 1, 2, \dots, n) \tag{1}$$

where, Y_i is the accidental variable that depicts the observation i of the dependent variable and it corresponds in the rate x_i of the independent variable, β_0 and β_1 are the unknown parameters so as to be applied the relation: $E(Y_i) = \beta_O + \beta_1 x_i$ $(i = 1,2,\dots, n)$, and e_i is the accidental error that corresponds in Y_i and it has mean rate [20]:

$$E(e_i) = E(Y_i) - (\beta_O + \beta_1 x_i) = 0 \ (i = 1, 2, \dots, n) \tag{2}$$

Also, we will suppose that the dispersion of the accidental variable Y_i is represented by a constant (σ^2) for each $i = 1,2, \dots, n$, and the covariance of accidental variables Y_i and Y_j are zero $\forall \ i \neq j$. The last assumptions correspond in the following relations for the accidental errors e_i [20]:

$$\operatorname{var}(e_i) = \sigma^2 \neq i = 1,2,\dots,n \ , \tag{3}$$

$$\operatorname{cov}(e_i, e_j) = 0 \ \ \forall \ i \neq j \quad i,j = 1,2,\dots,n \tag{4}$$

Because the rate of the observation Y_i is $y_{i,}$ equation (1) can be written as [20]:

$$y_i = \beta_0 + \beta_1 x_i + e_i \quad (i = 1,2,\dots,n) \tag{5}$$

where, e_i is the corresponding rate that the accidental variable e_i takes. With the help of an approximate method, the parameters can be calculated with the rates b_O and b_1 as well as the real but unknown regression line $g(x) = \beta_0+\beta_1 x$ with the function $g(x) = b_0+b_1x$ with the help of data $(x_1,y_1),(x_2,y_2),\dots,(x_n,y_n)$. The calculation of the rates b_O and b_1 is realized through the regular conditions [20]

$$\begin{gathered} nb_0 + b_1 \sum_{i=1}^{n} x_i = \sum_{i=1}^{n} y_i \\ b_0 \sum_{i=1}^{n} x_i + b_1 \sum_{i=1}^{n} x_i^2 = \sum_{i=1}^{n} x_i y_i \end{gathered} \tag{6}$$

Based on Eq. (6), the calculation of the rates b_O and b_i arises the following relations [20]:

$$b_0 = \frac{\sum_{i=1}^{n} y_i - b_1 \sum_{i=1}^{n} x_i}{n} \Rightarrow b_0 = \bar{y} - b_1 \bar{x}. \tag{7}$$

$$b_i = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{8}$$

However, the adaptation will be as better as bigger the percentage is of the total fluctuation, which means to approach the unit, expressed by the following relation

$$r^2 = \frac{SSR}{SST} \tag{9}$$

where, the ratio r^2 is called determination factor and it is used as precision measure of the adaption. For the calculation of the quantities SST and SSR the following relations are used [20]:

$$SST = \sum_{i=1}^{n} y_i^2 - \frac{\left(\sum_{i=1}^{n} y_i\right)^2}{n} \tag{10}$$

$$SSR = b_1 \left\{ \sum_{i=1}^{n} x_i y_i - \frac{(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n} \right\} \quad (11)$$

where, the SSE rate arises as the difference of the SSR from the SST. SST has (n-1) freedom degrees because in its calculation are needed (n-1) independent elements of information which are (n-1) from the numbers $(y_1 - \bar{y}), (y_2 - \bar{y}), \dots, (y_n - \bar{y})$, while SSE = e_i^2 has (n-2) freedom degrees because from the relations (linear conditions) [20]. However, the freedom degrees have additive attribute, the following relation will be applied: freedom degree(s) (SSR) = freedom degree(s) (SST) – freedom degree(s) (SSE) = (n-1) – (n-2) = 1, which means that the sum SSR has 1 freedom degree. If the assumptions that have been realized for the regression model are correct, the mean square around from the regression s^2 (i.e. remainder dispersion) will be used in the estimate of the common dispersion σ^2 of the accidental errors e_i, having the form [20]

$$\hat{\sigma}^2 = s^2 = \frac{\sum_{i=1}^{n} e_i^2}{n-2} \quad (12)$$

3. Analysis and results

3.1 Survey description

The author closely observed the construction operations of a US$125 million viaduct bridge. To this end, the author reviewed all the project documents (i.e. design, procurement, contractual, construction, management, and personnel administration manuals). Then, the author visited the site 5 full days and observed around 200 workers on one section of the project. Based on the study of Toor and Ogunlana [21], 60 direct and indirect productivity problems were documented and categorized under 8 categories as shown in Table 1.

According to the literature review, the analysis was relied on standards of quantitative survey. Based on that, the author solicited feedback from 25 project stakeholders having different specialties, as shown in Table 2. Their experience ranging from 10 to 30 years and spanning over all levels about their perception rating of the aforementioned 60 problems. Hence, he personally interviewed the associated project managers regarding the productivity issues witnessed in relation to the various construction activities. Table 1 shows the specialties which were involved in the survey as well as the results of the problems which encounter in the project and, thus, affect negatively the construction productivity. The perception rating regarding factors/problems related to construction productivity were ranged from 1~5 (1: very little/minimal, 2: a little bit, 3: moderate, 4: enough, 5: very much).

On the other hand, a feedback received from the same respondents regarding potential factors for improved productivity. Table 3 shows the factors contributing towards Improved Construction Productivity [22]. More specifically, there are 3 categories/factors (i.e., planning and programming, job satisfaction and incentives) where each one involves 3 subcategories. Based on this observation, a statistical analysis using the least squares method is essential though to provide more in-depth understanding of the collected data.

Table 1. Direct and Indirect Problems Affecting Construction Productivity.

Problems of Management	Inadequate experience of staff
	Slow response
	Lack or responsibility
	Failure to utilize tools to manage the project symmetrically
	Poor leadership on part of the project manager
	Lack of timely decisions and corrective actions
	Large number of participants of project
	Involvement of several foreign designers and contractors
	Unrealistic project schedule
	Poor project planning and control
	Bureaucracy at the workplace
	Lack of top management commitment
	Lack of project manager’s experience
	Unreasonable risk allocation
Problems of Labor	Absenteeism problems
	Unavailability of local labor
	Non-cooperation between workforce and management
	Unskilled labor
	Severe overtime and shifts
	Poor labor productivity problems

(*Table 1 Cont.*)

Problems of Finance	Delay of workforce payment High interest rate Increased cost due to high inflation during the project Shortage of funding Unforeseeable financial and economic crises
Problems of Site & Environment	Unforeseen ground conditions Poor site access or availability Lack of temporary facilities on site (buildings, phones, electricity, etc.) Site pollution and noise Severe weather problems (hot, cold, rainy) Poor site layout Poor site storage capacity Difficult site terrain to work Poor site management and slow site clearance Poor safety conditions on site Inaccurate site investigation
Problems of Contractor	Lack of competent subcontractors/suppliers Lack of necessary machinery, tools and automation available for project Lack of contractor's experience and control over project Poor efficiency of supervisor or foreman Using obsolete technology Contractor's financial difficulties Inappropriate construction methods Lack of good relationship with workforce/contractor
Problems of Communication	Unclear lines of responsibility Lack of communicating the requirements Lack of effective communication Lack of coordination among project team members Multicultural and multilingual environment causing ineffective communication Lack of IT use for information, coordination and interface management
Problems Due to Other Factors	Lack of available resources Non-value added works Poor quality control over project
Problems of Contract	Poor contract management Lack of cooperation from local authorities Incomplete contract documents Inappropriate method of dispute resolution Improper project feasibility study Too many scope changes and constructive changed orders Wrong choice of contractor

Table 2. Perception Rating Regarding Factors Affecting Construction Productivity.

Description of Problems	Mean perception ratings (M) of problems by various groups of respondents							
	Site Supervisor	Consultants	Designers	Engineers	Technical Personnel	Accountants	Foremen	Project Manager
Poor leadership on part of the project manager	3.5	4.2	4	4	4.2	3.2	3.5	3.5
Lack of contractor's experience & control over project	4	4.7	4.5	4.5	4.5	3.5	3.3	3.3
Inadequate experience of staff	4.3	4.2	4.5	4.2	4.5	3.5	4	3.3
Lack of competent subcontractors/suppliers	4.5	4.2	4	4.5	4.5	3.5	3.7	4
Unrealistic project schedule	4	4.2	4.5	4.5	4.2	3.7	3.5	3.2
Lack of responsibility	4	4.5	4.5	5	4.3	4	4	3.5
Contractor's financial difficulties	3.7	4.7	4.3	4.2	4.5	3.7	3.5	3.2
Poor contract management	4	4	4.3	4.5	4.5	3.5	3.7	3.5
Poor site access or availability	4	4.3	4.5	5	4.5	3.7	3.7	4
Poor efficiency of supervisor or foreman	4.3	4.5	4.5	4	4.3	3.7	4	3.5

(*Table 2 Cont.)*

Delay of payment of workforce	4	4	4.2	4.2	5	4	4	3.7
Shortage of funding	3.6	4.5	4.2	4.5	4.5	3.5	3.7	3.7
Errors & omissions in design documents	4	4.3	4.2	4.2	4.5	3.5	4	4.2
Low constructability of design	4	4.3	4.2	4.5	4.7	3.7	3.5	3.7
Lack of timely decisions & corrective actions	4	4.2	4	4.5	5	3.7	4	3.7
Impractical design	3.4	4.2	4.3	4	4.5	4	3.5	4
Unclear lines of responsibility	4.3	4.3	4.2	4.2	4.5	4	4	4
Lack of necessary machinery, tools & automation available for project	4	4.5	4.3	4	4.5	4	4	4
Incomplete contract documents	3.4	4.5	4.3	4.2	4.3	4	3.5	3.5
Slow response	3.7	4	4.2	4.2	4.5	3.8	3.7	3.7
Poor project planning & control	4	4	4.5	4.5	4.3	3.8	3.7	4
Lack of effective communication	4	4	4	4.5	4	3.8	4	4
Poor leadership on part of project manager	4	4.2	4.2	4.2	4.3	4	3.7	4.2
Lack of project manager's experience	4	4	4.2	4.2	3.7	4	3.7	4.2
Too many scope changes and constructive changed orders	3.4	4.5	4.2	4	4	4	3.7	3.7
Lack of communicating the requirements	3.4	4.3	4.5	4.5	4.5	4	3.5	4
Lack of co-ordination among project team members	4	4	4.5	4.2	4.3	4	4	4.2
Inappropriate construction methods	3.2	4	4.2	3.5	4.3	4	3.5	4.2
Unforeseeable financial & economic crises	3.7	4.2	4.3	4.2	4.5	4	4	3.7
Unavailability of local labor	3.7	4	4.2	4.3	4.3	4	4.2	4.5
Lack of involvement during construction stage	3.7	4	4	4.5	4.2	4.2	3.7	4
Poor safety conditions on site	3.4	3.5	4.2	4	4.5	4.2	4	4.2
Inaccurate site investigation	4.3	4	4	4.5	4	4.5	4	4
Non-cooperation between workforce & management	4	4.3	4.2	4.5	3.5	4.5	3.5	4
Lack of good relationship with workforce-contractor	3.4	4	4	4.5	4	4.6	4.2	4.3
Lack of top management commitment	3.6	4	4	4	4.5	5	3.7	4.5
Absenteeism problems	3	4	4	4.5	4.3	5	3.7	4
Poor site management & slow site clearance	4	4.5	4	4.5	4	5	4	3.7
Lack of temporary facilities on site (buildings,phones. electricity etc)	3.4	3.5	4.5	3.5	4	4	4	4
Over-design increasing the overall cost	3.4	4	4	3.5	4.3	4	3.7	4
Unforeseen ground conditions	3.2	4	4	4.5	4	4	3.5	4
Increased cost due to high inflation during the project	3.7	4	4	4.5	4.5	4	3.5	4.3
Inappropriate method of dispute resolution	4	3.5	4	4	3.7	4	3.5	3.8
Unskilled labor	3.7	3.5	4	3.2	4	4	4	4.3
Unreasonable risk allocation	3.4	3	3.5	4.5	4.2	4.2	3.2	4.2
High interest rate	4	3.7	3.7	4	4	4.2	3.5	3.7
Poor site storage capacity	4	4	4	4	3.7	4.2	4.2	4.2
Using obsolete technology	3.7	3.7	3.7	4.2	4.2	4.2	3.5	4
Severe weather problems (hot, cold, rainy)	3.7	3.5	3.8	4	4	4.2	4	3.8
Poor site layout	3.7	4	4	4.2	4	4.2	4	4

(*Table 2 Cont.)*

Failure to utilize tools to manage the project symmetrically	3.7	4	3.7	3.5	4	4.2	3.7	3.8
Severe overtime & shifts	3	3.7	3.8	4	3.7	4	3.5	3.5
Bureaucracy at the workplace	3.7	3.7	3.5	4	3.5	4	3.3	3.5
Lack of information, co-ordination & interface management	3.4	3	3.5	4	4	4	3.2	3.5
Large number of participants of project	3.4	3.7	3.2	3.5	3.7	4	3.5	3.7
Site pollution & noise	3	3.5	4	3.5	3.7	3.5	3.3	4
Involvement of several foreign designers & contractors	3.2	3.5	3	4	3.7	3.5	3.7	3.5
Lack of timely decisions and corrective actions	3.9	3.6	3.8	3.6	3.8	4	4.2	3.5
Poor labor productivity problems	4	4.25	3.6	4	4.3	3.5	4.3	4.4
Non-value added works	3.7	3.5	3.5	3.5	3.7	3.5	3.5	3.3

Table 3. Factors Contributing towards Improved Construction Productivity.

First-Level Criteria	Second-Level Sub-Criteria
Planning & Programming (Criterion 1)	Increased Planning & Programming Productivity Measurement Subcontractors Participation & Co-operations
Job Satisfaction (Criterion 2)	Recognition & Feedback Site Improvement Management Team
Incentives (Criterion 3)	Financial Incentives Productivity Bonuses Non-Financial Incentives including Union Support

3.2 Survey analysis

The analysis procedure was also relied on the standards of quantitative survey, investigating two factors: i) coordination and cooperation and ii) experience. The project stakeholders were categorized in two groups: Engineers and Technical Personnel because they interact directly with the construction productivity. As shown in Figures 1-4, a total of four pairs of criteria were taken into account, which ranged from 1~5. The scale of the experience was structured as follows: 1: very experience, 2: enough experience, 3: experience, 4: little experience, 5: inexperience. On the other hand, the answers of the engineers and the technical personnel were ranged from very positive to very negative. In this case, the minimum and maximum values were 1.0 and 5.0, respectively. It is worth noting though that the development of this model was based on one single project and while inference can be hardly deducted from one project, the authors also note the difficulty of getting complete access to projects of this size (i.e. complete construction documents, on-site visits, and interviews with top officials), the author would hope that their model would be deemed acceptable on interim basis that will be subject to revisions in light of other large scale projects.

3.3 Least square method analysis

The objective of this step is to develop matrices to judge the relative importance of the different productivity related criteria. Accordingly, the mean value of relative importance was computed. Moreover, pairs of criteria were compared in order to systematically determine the relative influence of the criteria on the attributes in the hierarchy. As it is practically impossible to show the complete analysis for all the factors due to space limitations of this paper, the author decided just to show in Figures 1-4 the analysis for two sample factors namely coordination and cooperation as well as experience as related for improved productivity from the perspective of engineers and technical personnel as well as the analysis process for one case, i.e. Figure 2.

Example: The serial number of observations (n) is equal to 5.0. Therefore, based on Eq. (6) the regular equation will be written as

$$\sum_{i=1}^{n} x_i = 15\ ,\ \sum_{i=1}^{n} x_i^2 = 55 \qquad \Longrightarrow \qquad 5b_0+15b_1=15.42$$

$$\sum_{i=1}^{n} y_i = 15.42\ ,\ \sum_{i=1}^{n} x_i\, y_i = 55.96 \qquad\qquad 15b_0+55b_1=55.96$$

Thus, the rates b_0 and b_1 are calculated from the relations (7) and (8), respectively, as

$$b_1 = \frac{5(55.96) - 15 \cdot 15.42}{5(55) - 15^2} = \frac{48.50}{50} = 0.970$$

$$b_0 = \frac{15.42 - 0.97 \cdot 15}{5} = 0.174$$

Therefore, the straight line that gives the better adaption in the data (x_i, y_i) has the equation $\hat{y} = g'(x) = 0.174 + 0.97x$.

The calculation of the adaptation precision is the second one stage that should be taken into account. More specifically, according to Eqs (9)-(11) the parameters SSR, SST, SSE and r^2 can be calculated as follows:

$$SSR = b_1 \left\{\sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n}\right\} = 0.97\left\{55.96 - \frac{15 \cdot 15.42}{5}\right\} = 9.409$$

$$SST = \sum y_i^2 - \frac{(\sum y_i)^2}{n} = 57.04 - \frac{15.42^2}{5} = 9.484$$

SSE = SST–SSR = 9.484 – 9.409 = 0.075

(a)

Answers of the engineers		Experience scale	
very positive	1.33	very experience	1
positive	2.15	enough experience	2
stagnation	2.90	experience	3
negative	3.74	little experience	4
very negative	4.87	inexperience	5

Serial number of the observation	Observation	Adapted rate	Remainder
1	1.33	1.26	1.33
2	2.15	2.13	2.15
3	2.90	2.99	2.90
4	3.74	3.86	3.74
5	4.87	4.73	4.87

Origin	Freedom degree	Sum of square	Mean square	f
Regression	1	7.516	7.516	469.750
Remainders	3	0.049	0.016	
Total (around from the mean)	4	7.565	-	-

(b)

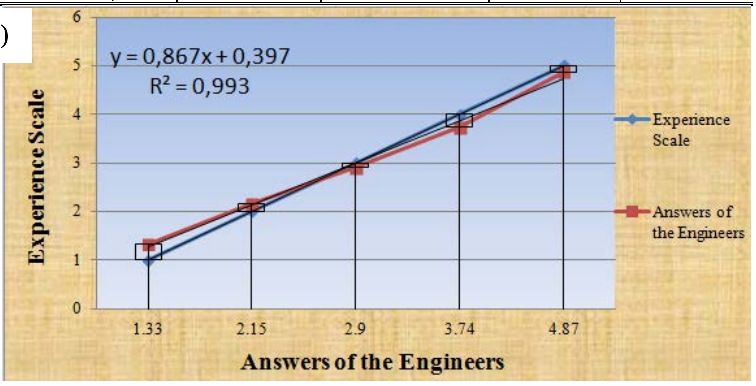


Figure 1. Least Squares Method Analysis for Engineers' Perception for Effect of Experience on Construction Productivity: (a) results and (b) response of the least square method analysis.

Therefore, the determination factor has the rate:

$$r^2 = \frac{SSR}{SST} = \frac{9.409}{9.484} = 0.992$$

That means, the closer the *determination factor* is to the unit, the answers will be reliable and accurate. Therefore, the answers that gave the engineers of the project in the above problems were more reliable in relation with the answers of the technical personnel. Finally, the dispersion analysis examines the relation between the dependent and independent variable, calculating in the substance whether the variability of the rates of the dependent variable Y is explained by the independent variable X. The Table shown in Figures 1-4 presents the dispersion analysis, including the rate of the statistician “f”. This rate is calculated from the ratio of the mean square that is owed in the regression to the rate of the s^2. On the basis of Fig. 2, it can be seen that the dispersion analysis, s^2, is directly related to R^2, leading to the result that the higher the dispersion analysis is the more accurate results will exported.

(a)

Answers of the engineers		Co-ordination & co-operation scale	
very positive	1.21	very good	1
positive	2.91	good	2
stagnation	3.22	moderately	3
negative	4.13	bad	4
very negative	4.95	very bad	5

Serial number of the observation	Observati on	Adapted rate	Remainder
1	1.21	1.14	0.07
2	1.91	2.11	-0.20
3	3.22	3.08	0.14
4	4.13	4.05	0.08
5	4.95	5.02	-0.07

Origin	Freedom degree	Sum of square	Mean square	f
Regression	1	9.409	9.409	376.360
Remainders	3	0.076	0.025	
Total (around from the mean)	4	9.485	-	-

(b)

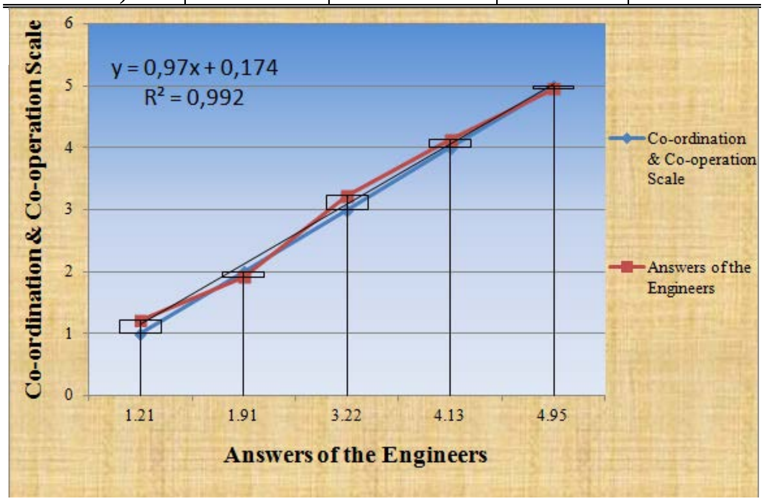


Figure 2. Least Squares Method Analysis for Engineers’ Perception for Effect of Coordination and Cooperation on Construction Productivity: (a) results and (b) response of the least square method analysis.

(a)

Answers of the technical personnel		Experience scale	
very positive	1.11	very experience	1
positive	1.76	enough experience	2
stagnation	2.17	experience	3
negative	4.23	little experience	4
very negative	5.00	inexperience	5

Serial number of the observation	Observati on	Adapted rate	Remainder
1	1.11	0.80	0.31
2	1.76	1.83	-0.07
3	2.17	2.85	-0.68
4	4.23	3.88	0.35
5	5.00	4.90	0.10

Origin	Freedom degree	Sum of square	Mean square	f
Regression	1	10.506	10.506	45.284
Remainders	3	0.698	0.232	
Total (around from the mean)	4	11.205	-	-

(b)

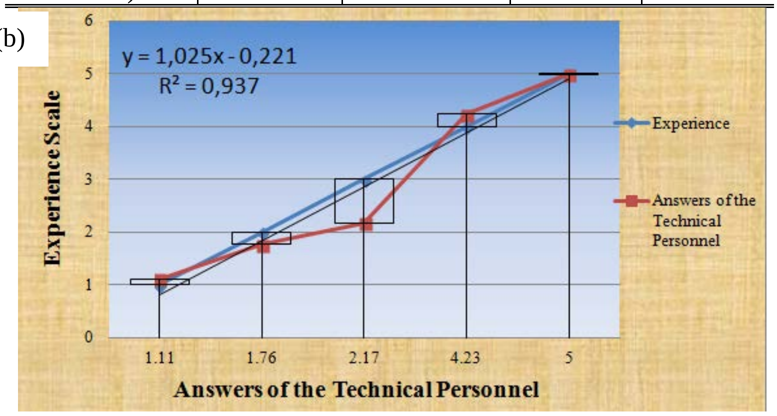


Figure 3. Least Squares Method Analysis for Technical Personnel Perception for Effect of Experience on Construction Productivity: (a) results and (b) response of the least square method analysis.

4. Poor productivity mitigation model

Analyzing of the entire factors affect negatively the construction productivity as described above, a poor productivity mitigation model is designed as shown in Figure 5. The conceptual delay mitigation model [23] has been used in construction projects and with an intention to deal with major factors of the poor productivity that is caused by lack of knowledge and poor management of lessons learned; this model has also been adopted in the current study. To ensure an effective project learning process throughout the project period, project experienced personnel should act as teaching supervisors to ensure all project activities are performed in knowledge-based manner.

1) Phase 1: Knowledge Identification

The quantification of project activities into several milestones is the focal point of knowledge. However, these activities related to size and complexity of the project leading to delay and other types of causes which has to do with poor productivity. Hence, five important components should be considered and described in-detail.

a) Knowledge content is essential to complete a particular milestone within specified time goal.

b) Differences between the knowledge content and the actual knowledge available.

c) Risk associated with accessing of knowledge content, knowledge gap and alternative knowledge.

d) Knowledge source where the people can be focused on targeted knowledge content.

(a)

Answers of the technical personnel		Co-ordination & co-operation scale	
very positive	1.32	very good	1
positive	1.62	good	2
stagnation	2.95	moderately	3
negative	4.11	bad	4
very negative	5.00	very bad	5

Serial number of the observation	Observati on	Adapted rate	Remainder
1	1.32	1.03	0.29
2	1.62	2.02	-0.39
3	2.95	3.00	-0.05
4	4.11	3.99	0.12
5	5.00	4.97	0.03

Origin	Freedom degree	Sum of square	Mean square	f
Regression	1	9.702	9.702	112.814
Remainders	3	0.259	0.086	
Total (around from the mean)	4	9.961	-	-

(b)

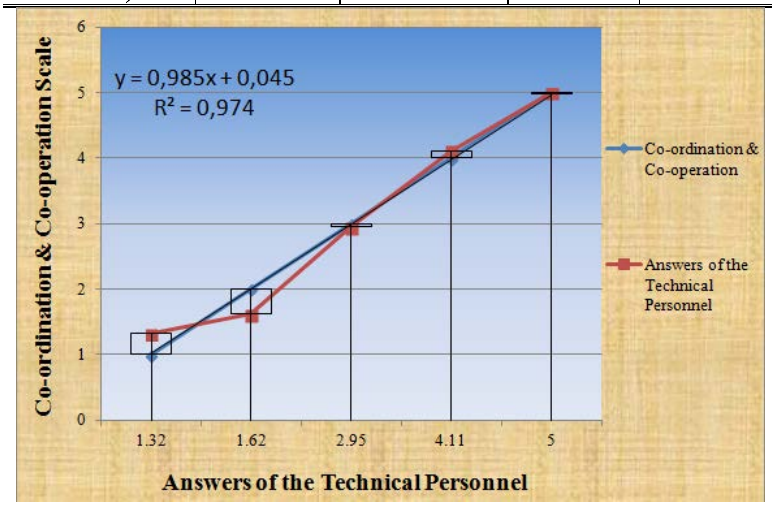


Figure 4. Least Squares Method Analysis for Technical Personnel Perception for Effect of Coordination and Cooperation on Construction Productivity: (a) results and (b) response of the least square method analysis.

2) Phase 2: Knowledge Sharing, Creation, and Integration

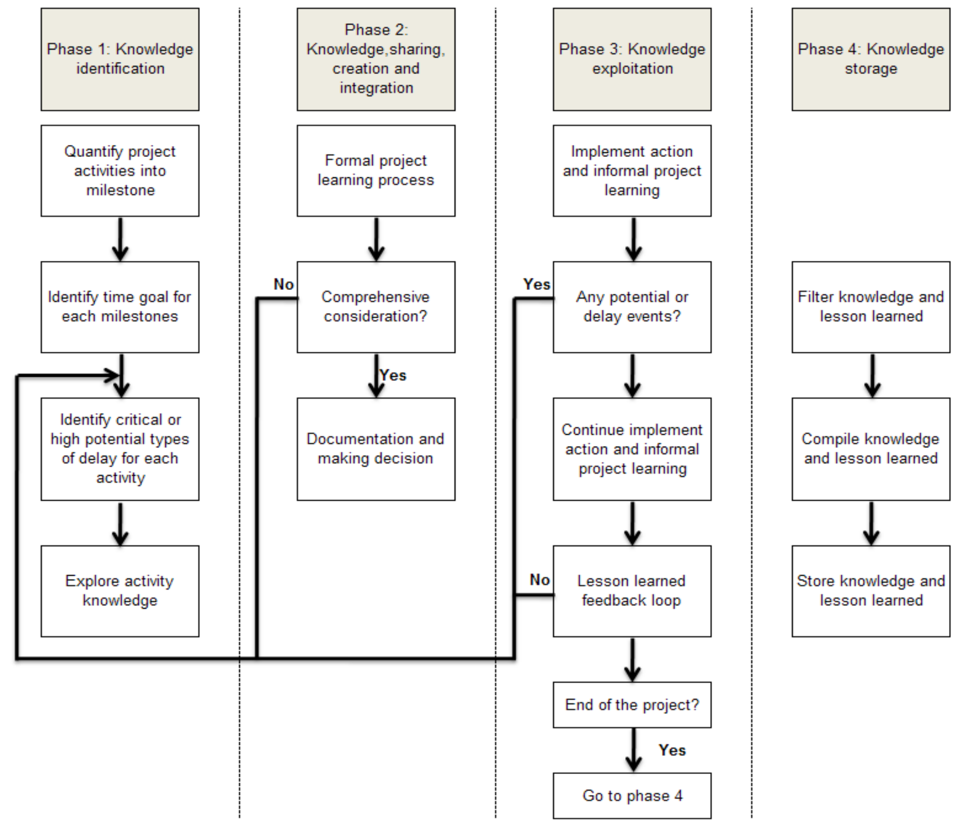
Regular meetings should be held from the experienced personnel, focusing mainly on the problems around the productivity. Hence, the experienced personnel will share and exchange opinions, new knowledge, searching for optimum solutions. During the meeting, feedback should also be performed to improve the quality of new knowledge and solutions. However, the more complex the project is the more problems will take place, leading to delay phenomena. Hence, the way to mitigate the delay is directly related to meeting frequency of the organizers. During the meeting, relevant and important information and knowledge should be properly documented for the purpose of retrieving and referring. Thus, negative impacts on project schedule performance will be faced prior to the finalization of the decision.

3)Phase 3: Knowledge Exploitation

When performing the project activity, the stakeholders should estimate the potential problems which may arise and will affect unfavorably the timetable of the project, offering potential solutions. In the feedback report, any learned mistakes, learned knowledge and problem solving should be added in order to avoid similar mistakes. Thus, a a real time feedback loop will be made where the stakeholders will take place optimum solutions ensuring that all stakeholders are well informed.

4) Phase 4: Knowledge Storage

At the end of the project, the "new" knowledge that may be gained throughout the project period should be evaluated, forming a standard template. Based on this standard template, actions which cause delay and bad practices, in general, will be avoid while useful knowledge will be collected as references for future projects.



Project Stages	Preconstruction and Construction Stages	Construction Stage	Near the Project Completion Stage
Enablers	Continuous individual commitment	Continuous individual commitment	Continuous individual commitment
	Continuous top management commitment	Continuous top management commitment	Continuous top management commitment
	Continuous inductive environment	Continuous inductive environment	Openness
	Continuous human network	Continuous human network	–
	Continuous open communication	Continuous open communication	–
	Teamwork	Active	–
	Equity	Opportune feedback	–
Barriers	Poor commitment	Poor commitment	Discontinuous commitment
	Adversarial relationship	Poor teamwork	Conceal
	Individualism	Lack of observance	–
	Discrimination	–	–

Figure 5. Poor Productivity Mitigation Model.

5. Conclusions

Poor management of project knowledge encourages difficulty of access to valuable and quality knowledge in performing project tasks. This in turn will lead to repeated mistakes; slow and wrong decision making; and as a consequence, it will lead to an increase in time and delay events. Thus, aim of this research was to determine the optimum solution to achieving increased labor productivity. To this end, the author used a combination of project observation and application of least squares method to develop a poor productivity mitigation model.

The author believes that the application of project learning should be managed with due care and due diligence to grasp the maximum value. This study will accent the importance of project learning and will improve the level of competency of contractors for future projects. For academic researchers, there is a need to highlight and draw the practitioners' attention to the significance of project learning in the development of project performance competency. In addition, there is a need for researchers to look beyond the construction project delay factors and employ a more comprehensive and practical approach to deal with such factors. Also, this research suggests increased pre-planning and programming as the most critical factor to improving labor productivity on construction projects. Construction pre-planning and programming encapsulates the elements of planning human and capital resources for a project through the construction phase; work scheduling; activity programming; site coordination planning; and financial cash flow planning. All these elements must be the initial focus of construction organizations if they are to improve current levels of labor productivity.

Furthermore, provision for incentives had been suggested as the second most critical factor for improving labor productivity. Among the incentives investigated, the leading factor was productivity bonuses, with financial incentives being also an important incentive to increase productivity. Productivity bonuses are financial bonuses provided to onsite labor and contracting labor if they are able to achieve project targets ahead of construction program dates. The bonuses would be attached to the quantity of output achieved to a specified quality above the required contractual performance. The difference between the two most critical factors was reasonable in magnitude and indicated that a greater emphasis will need to be placed on addressing these issues before using organizational resources to focus on further factors. The alternative that was least preferred to the two alternatives above was the provision of improved site conditions in improving labor productivity. While the search results indicate that conditions of site including the occupational health and safety standards and provisions; site location; a stable workforce; skills of the site management team; and establishment of collective project team sentiments are important, they were only important to a certain degree. Also, while they were considered important, the same were not believed to be the most critical factors that could affect and improve labor productivity on site. Finally, the author believes that as human elements play a critical role in the areas of knowledge and learning, leadership and professional ethics should serve as springboard for future studies on mitigating construction project delay using the project learning approach.

6. References

[1] Bordoli D.W., Baldwin A.N. A methodology for assessing construction project delays. Construction Management and Economics. 1998; 16(3): 327-337.
[2] Lim E.C. , Alum J. Construction productivity: issues encountered by contractors in Singapore. International Journal of Project Management. 1995; 13(1): 51-58.
[3] Olomolaiye P., Kaming P., Holt G., Harris F. Factors influencing craftsmen's productivity in Indonesia. International Journal of Project Management. 1996; 15(1): 21-30.
[4] Rojas E.M., Aramvareekul P. Labor productivity drivers and opportunities in the construction industry. Journal of Management in Engineering. 2003; 19(2): 78-82.
[5] Motwani J., Kumar A., Novakoski M. Measuring construction productivity-a practical approach. Work Study. 1995; 44(8): 18-20.
[6] Lock D. Project Management, 6th Edition. Gower, Aldershot, 1996.
[7] Odeh A.M., Battaineh H.T. Causes of construction delay: traditional contracts. International Journal of Project Management. 2002; 20: 67-73.
[8] Allmon E., Hass C., Borcherding J., Goodram P. US construction labor productivity trends, 1970-1998. Journal of Construction Engineering and Management. 2000; 126(2): 97-104.
[9] Pilcher R. Principles of Construction Management. McGraw-Hill, London. 1997.
[10] Oglesby C.H., Parker H.W., Howell G.A. Productivity Improvement in Construction. McGraw-Hill, New York. 1989.
[11] Klanac G.P., Nelson E.L. Trends in construction lost productivity claims. Journal of Professional Issues in Engineering Education and Practice. 2004; 130(3): 226-236.
[12] Parham D., Zheng S. Aggregate and industry productivity estimates for Australia. Australian Economic Review. 2006; 39(2): 216-226.
[13] Cox R.F., Issa R.R.A., Ahrens D. Management's perception of key performance indicators for construction. Journal of Construction Engineering and Management. 2003; 129(2): 142-151.
[14] Olomolaiye P., Jayawardane A., Harris F. Construction Productivity Management. Chartered Institute of Building, Englemere, Ascot, UK, 1998.

[15] Teicholz P. US construction labor productivity trends, 1970-1998. Journal of Construction Management and Engineering. 2001; 127(5): 427-429.
[16] Alaghbari W., Al-Sakkaf A.A., Sultan B. Factors affecting construction labour productivity in Yemen. International Journal of Construction Management. 2019; 19(1): 79-91.
[17] Hamza M., Shahid S., Bin Hainin M.R., Nashwan M.S. Construction labour productivity: review of factors identified. International Journal of Construction Management. 2019; 1-13. doi: 10.1080/15623599.2019.1627503
[18] Ahmad S.B.S., Mazhar M.U., Bruland A., Andersen B.S., Langlo J.A., Torp O. Labour productivity statistics: a reality check for the Norwegian construction industry. International Journal of Construction Management. 2020; 20(1): 39-52. doi:10.1080/15623599.2018.1462443
[19] Gurmu A.T. Construction materials management practices enhancing labour productivity in multi-storey building projects. International Journal of Construction Management. 2020; 20(1): 77-86. doi:10.1080/15623599.2018.1462447
[20] Koutrouvelis I. A. Statistical methods, Issue 1, Symmetry Editions. University of Patras, Greece. 1994.
[21] Toor S.U.R., Ogunlana S.O. Problems causing delays in major construction projects in Thailand. Construction Management and Economics. 2008; 26: 395-408
[22] Doloi H. Application of AHP in improving construction productivity from a management perspective. Construction Management and Economics. 2008; 26: 839-852.
[23] Hamzah A.R., Yahya I.A., Berawi M.A., Wah L.W. Conceptual delay mitigation model using a project learning approach in practice. Construction Management and Economics. 2008; 26: 15-27.