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ORIGINAL ARTICLE

Implementation of lean construction techniques for minimizing the risks effect on project construction time

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Time quantification

Abstract The construction projects involve various risk factors which have various impacts on time objective that may lead to time-overrun. This study suggests and applies a new technique for minimizing risk factors effect on time using lean construction principles. The lean construction is implemented in this study using the last planner system through execution of an industrial project in Egypt. Evaluating the effect of using the new tool is described in terms of two measurements: Percent Expected Time-overrun (PET) and Percent Plan Completed (PPC). The most important risk factors are identified and assessed, while PET is quantified at the project start and during the project execution using a model for time-overrun quantification. The results showed that total project time is reduced by 15.57% due to decreasing PET values, while PPC values improved. This is due to minimizing and mitigating the effect of most of the risk factors in this project due to implementing lean construction techniques. The results proved that the quantification model is suitable for evaluating the effect of using lean construction techniques. In addition, the results showed that average value of PET due to factors affected by lean techniques represents 67% from PET values due to all minimized risk factors.

Abbreviations: PET, Percent Expected Time-overrun; PPC, Percent Plan Completed; TPS, Toyota Production System; LPS, Last Planner System; WWP, Weekly Work Plan; PI, Probability Index; IIT, Impact Index for Time; VL, Very Low; L, Low; M, Medium; H, High; VH, Very High

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1. Introduction

Egypt as a developing country faces many problems in construction industry such as lack of detailed and documented previous data concern risks and lack of adapting modern techniques for minimizing the effect of risk factors on construction projects objectives. Lean construction is a new philosophy oriented toward construction production administration. It sets productive flows in motion in order to develop control systems with the aim of reducing losses throughout the process. It was taken from lean production that can be traced to Toyota Production System (TPS), with its focus on the reduction and elimination of waste [1]. The types of wastes that are addressed

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in TPS are wastes of production, time, transportation, processing itself, stock at hand, movement, and making defective products. The Lean construction is also defined as a production management strategy for achieving significant continuous improvement, in the performance of the total business process of a contractor through elimination of all wastes of time and other resources that do not add value to the product or delivered service to the customer [2]. Lean construction consists of a series of flow conversion activities [3]. It visualizes the project as a flow of activities that must generate value to the customer [4]. According to Koskela [3] and Thomas et al. [5], lean construction includes practice of just-in-time, use of pull-driven scheduling, reduction of variability in labor productivity, improvement of flow reliability, elimination of waste, simplification of the operation, and implementation of benchmarking.

The last planner concept proposed by Ballard [6] is based on principles of lean production to minimize the waste in a system through assignment-level planning or detailed look-ahead scheduling. The studies of Ballard and Howell [7] about the last planner technique showed that the use of formal and flexible production planning procedures is the first step to keep the production environment stable. It emphasizes in this case on the use of the daily production plans, constraint analysis, look-ahead, and PPC as tools for immediate implementation on any jobsite. The Last Planner System (LPS) was completed as a useful tool to be introduced broadly in the construction process [8]. Ballard and Howell [9] designed the LPS as one of the methods for applying lean techniques to construction. In the LPS, the sequences of implementation setup an efficient schedule planning framework through a pull technique, which shapes work flow, sequence, and rate; matches work flow and capacity; develops methods for executing work; and improves communications between trades. It usually forms only a small fraction of high-level programming, with great attention being given to details, while it does not contain quality control assignments [10].

Look-ahead in the LPS is to reach a set of objectives described below [11]:

- Shape work flow sequence and rate.
- Match work flow and capacity.
- Distribute master schedule activities into work packages and operations.
- Develop detailed work completion methods.
- Maintain a backlog of ready work.

LPS focuses on increasing the quality of the Weekly Work Plan (WWP) assignments when combined with the look-ahead process, originate, and control work flow. WWP controls the flow and helps make sure assignments are ready by proactively acquiring materials, designing information to be used, and monitoring previous work or prerequisites [10,12].

This study aims to investigate and evaluate the effects of implementing the lean construction techniques using LPS as a new tool for minimizing the risk effects on time of construction projects. The aims extend to introduce and discuss the results obtained from the application of using lean construction techniques in an Egyptian construction project to reduce the effects of many risk factors on the project time and quantify their effects. The strategy used is based on evaluation the effect of using lean construction techniques in terms of two measurements: PET and PPC.

2. Lean techniques applications in construction projects

Recent researches and discussions have been carried out using lean construction applications and LPS in many countries all over the world such as Nigeria by Adamu and Hamid [13], Ecuador by Fiallo and Revelo [14], Chile by Alarcón et al. [15] and Malaysia by Marhani et al. [16]. In addition, attempts have been made to apply lean principles and techniques to all project management processes, including the project delivery system, production control, work structuring, design, supply chain, project controls, and overall construction project management. Abdel-Razek et al. [17] focused on improving construction labor productivity in Egypt by applying two lean construction principles (benchmarking and reducing variability of labor productivity). The benchmarks include disruption index, performance ratio, and project management index. Ballard et al. [18] presented an overview of the entire intervention, which confirms the applicability of lean concepts and techniques to the management of fabrication processes. Also, they illustrated the benefits achievable in improved management of demand, reduced cycle time, greater productivity, heightened work force involvement, and increased revenue and profitability. The results achieved illustrate the power of lean concepts and techniques and their applicability to the operations of fabricators supplying engineered-to-order products to construction projects. Tsao et al. [19] illustrated how lean thinking and work structuring helped to improve the design and installation of metal door frames for a prison construction project. Koskela et al. [20] examined a fast-track office building project and showed how the building process could be made leaner and speedier.

In the field of simulation and software, Marzouk et al. [21] used computer simulation as a tool for assessing the impact of applying lean principles to design processes in construction consultancy firms to aid in decision-making at early stages of construction projects. Sacks et al. [22] have been specified a pull flow construction management software system based on the LPS, and a set of functional mock-ups of a proposed system that has been implemented and evaluated. Alinaitwe [23] provided a graphical aid to enable decision-makers to concentrate their efforts to overcome barriers by investigating the influence of many barriers on the success of lean construction initiatives.

3. Risk management and risk response planning

Risk management can be defined as the process of taking calculated risks, reduces the likelihood that a loss will occur and minimizes the scale of the loss should it occur [24]. The main objective of risk management process is to reduce the risk effect on the project objectives and thus improve decision-making. It includes both the prevention of potential problems and the early detection of actual problems when they occur [24]. The Project Management Body of Knowledge defined the risk management planning as the process of deciding how to approach and plan the risk management activities for a project [25]. It is important to plan for the risk management processes that follow to ensure that the level, type, and visibility of risk management are commensurate with both the risk and importance of the project to the organization. The magnitude of the risk management task varies with the size of the project, and its importance. Schwalbe [26] suggested that risk management is a set of principles, whereby the project manager continually assesses risks and their consequences, and takes appropriate preventive strategies.

Risk management is nowadays a critical factor for successful project management, as projects tend to be more complex and competition increasingly tougher. There is a direct relationship between effective risk management and project success since risks are assessed by their potential effect on the objectives of the project. Contractors have traditionally used high markups to cover risk, but as their margins have become smaller, this approach is no longer effective. In addition, the construction industry has witnessed significant changes particularly in procurement methods with clients allocating greater risks to contractors.

The risk response planning phase exists to develop responses to identified risks that are appropriate, achievable, and affordable. Owners are also allocated to each risk response, to be responsible for its implementation and for monitoring its effectiveness. Risk responses are usually grouped according to their intended effect on the risk being treated. It is common to use four such groupings, or risk strategies [27]:

- Avoid: seeking to eliminate the uncertainty by making it impossible for the risk to occur (i.e., reduce probability to zero) or by executing the project in a different way which will achieve the same objectives but which insulates the project from the effect of the risk (i.e., reduce impact to zero).
- Transfer: identifying another stakeholder better able to manage the risk, to whom the liability and responsibility for action can be passed.
- Mitigate: reducing the size of the risk in order to make it more acceptable to the project or organization, by reducing the probability and/or the impact.
- Accept: recognizing that residual risks must be taken and responding either actively by allocating appropriate contingency or passively doing nothing except monitoring the status of the risk.

4. Research methodology and case study

Fig. 1 shows the proposed research methodology for this study that used during the execution of a case study project through the following steps:

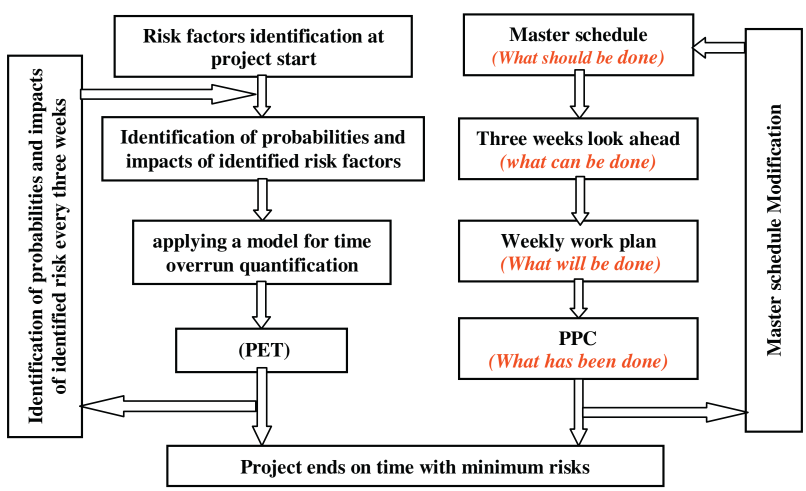

Figure 1 Steps of the proposed research methodology.

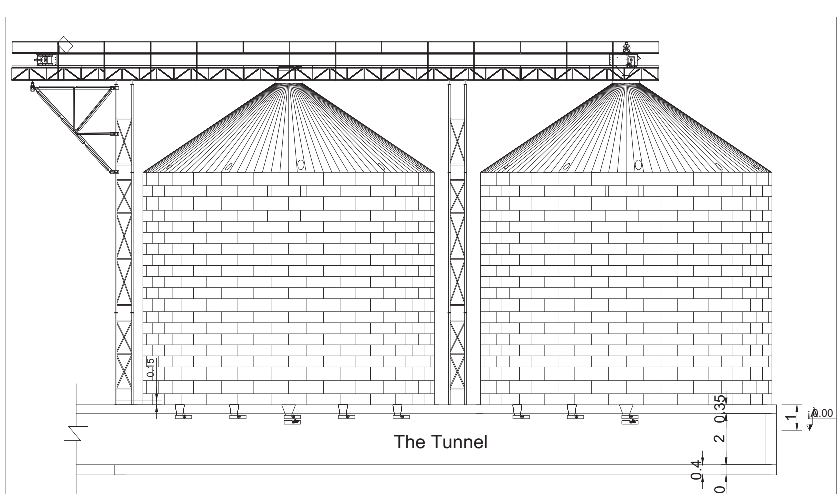

Figure 2 A sectional elevation for tunnel and silos used in the case study.

1. Identifying risk factors associated with the case study and calculating their probabilities of occurrences and their impacts on time at the project start, in addition, performing the master schedule of the project including all activities to show (what should be done).
2. Quantifying PET due to the effect of risk factors on time at the project start using a model for time-overrun quantification which will be explained later.
3. Performing three weeks look-ahead to show (what can be done) and Weekly Work Plan (WWP) to show (what will be done).
4. Quantifying the expected time-overrun due to the effect of risk factors on time during execution of the project (every three weeks) using the same model used in step 2.
5. Evaluating the completed works due to three weeks look-ahead and weekly work plan by calculating PPC to show (what has been done).
6. Modifying the master schedule and the three weeks look-ahead based on observations and introduced solutions for the reasons and risks.

The last planner system was applied during the execution of (a flour storage construction stage) in a flour milling factory in Minia industrial zone, El-Minia city, Egypt. The required work consists of construction of an intake tunnel for the flour, foundations of steel silos, and installing and fixing the steel silos. The structural design was completed by an international company from Turky and modified by an Egyptian consulting company for the purpose of adjusting design to meet the Egyptian standards. The main problem was that most of the tunnel length is located under silos, so it should be constructed before construction of the silos foundations. In addition, there is a fixed date for installing and fixing the steel silos. So, finishing the tunnel and silos foundations should be before this fixed date. Fig. 2 shows a sectional elevation for both tunnel and silos.

A master schedule is designed based on the project activities and their durations. Due to the fact that the case study had a short term and a fixed finish date, the master schedule for this project is calculated for 12 weeks. The total duration was measured based on six working days per week. So, the total duration of the project is 72 days. As mentioned before, there is no allowance to extend the time because the steel silos should be installed on a fixed date. The overall construction process consisted of many different activities such as surveying works, excavation, plain and reinforced concrete works, insulating works, back filling, compaction for fill, and silos installation.

5. Determination of PET

The expected time-overrun due to the effect of the probabilities of occurrences and impacts of the identified risk factors can be calculated using a fuzzy model for time-overrun quantification developed in previous study [28]. This model was developed for the purpose of time-overrun determination in construction projects. The model is mainly based on many relationships among the impacts of risk factors on time and the time-overrun through several logical rules taking into considerations the probabilities of the risk factors. Issa [28] applied, validated the model, and showed that it can be used successfully to calculate the expected time-overrun, as a percent of the original time of the project.

In the case study, the most critical risk factors which affect the project time were identified and developed by the consultant group, with the help of both owner representative and contractor. Data are introduced as probability of occurrence and impact on time for each risk factor in the form of two indices, namely Probability Index (PI) that represents probability of occurrences for a certain risk factor and Impact Index for Time (IIT) that represents impact of a certain risk factor on time. The form of these indices can be introduced as linguistic

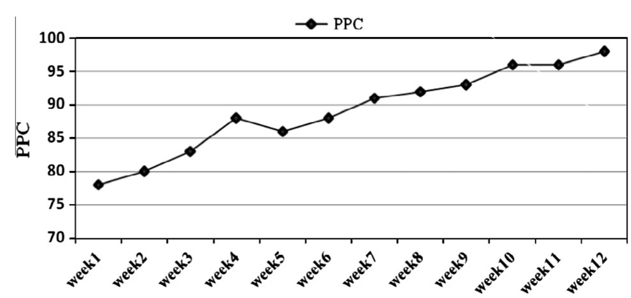

Figure 3 PPC values during weeks.

Table 1 Risk factors affecting time, their indices, and PET values.

Factors affecting time	At project start		At week 4		At week 7		At week 10	
	PI	*IIT*	*PI*	*IIT*	*PI*	*IIT*	*PI*	*IIT*
1. Contractor problems and inadequate experience	H	VH	VL	VL	VL	VL	0	0
2. Change in material prices or price escalation	M	M	VL	VL	VL	VL	0	0
3. Unskilled workers and poor labor productivity	H	VH	M	VH	M	H	M	L
4. Inefficient use of equipments	L	L	L	L	VL	VL	0	0
5. Delay in running bill payments to the contractor	L	M	L	M	L	VL	VL	VL
6. Delay in material procurement	L	VH	L	H	L	M	VL	L
7. Design errors and suitability to the nature	L	M	M	M	L	M	VL	VL
8. Client's problems such as bureaucracy in client's organization	M	M	M	M	M	M	L	M
9. Inadequate and slow decision-making mechanism	H	VH	H	VH	H	M	M	L
10. Poor quality of local materials	H	VH	H	VH	H	H	M	L
11. Poor coordination among parties	H	H	L	L	L	L	0	0
12. Rework due to error in execution	H	VH	H	VH	H	H	H	M
13. Improper accommodations for workers	M	H	L	L	0	0	0	0
PET using time-overrun quantification model	22.5		15.1		12.35		4.7	

variables. The states of linguistic variables are defined as follows: Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH) [28]. These data are used as input for the model and the output will be PET which estimates the expected time-overrun of the project at any stage. Due the expected risk factors at the project start, PET was determined and equal to 22.50% of the total time of the project. It is expected that, due to effect of risk factors, the project needs 16 additional days plus the original time to complete the work. Based on the results and evaluation of the works during execution, the probability and impacts of the factors are also identified every three weeks and the PET is calculated to manage the effect of the incomplete plan items. Table 1 shows the identification of critical risk factors and their indices for the investigated case study at the project start and every three weeks. The outputs of applying the model during the project were tabulated also in Table 1.

6. Observations during project execution

Look-ahead planning is the process undertaken to achieve possible constraints, free assignment, and cut down uncertainty [29]. In the case study, look-ahead schedules were prepared for the upcoming three weeks in a bar chart format. WWP is produced based on three weeks look-ahead, the master schedule, and field conditions using notes and memos. Look-ahead schedules were updated on a weekly basis during a weekly project meeting. Ballard and Howell [30] indicated that WWP should emphasize the learning process more by investigating the causes of delays on WWP instead of assigning blames and only focusing on PPC values. On the other hand, PPC is also calculated every week during the project execution. The PPC is the measurement metric of the last planner system. It is calculated as the number of activities that are completed, as planned, divided by the total number of the planned activities [11]. Fig. 3 shows the weekly values for PPC. The upward slope between two PPC values indicates that production planning was reliable and vice versa. It is clear from this figure that there is a significant improvement for the values of PPC, with as increase in time, as the PPC values increase.

In this project, a systematic approach of risk identification and quantification for the risk effect on time is used. In addition, work procedure redesign and decisions are taken to

Table 2 Activities and observations during project execution.

Activities	Negative observations	Positive observations
Weeks 1, 2, and 3		
Surveying works, excavation for the tunnel, supporting excavated soil sides by retaining walls, pouring works for PC tunnel foundation, manufacturing and installing for tunnel foundation rebar, pouring works for RC tunnel foundation, carpentry works for tunnel walls, and manufacturing and installing for tunnel walls rebar	– Rejection for the excavation and the gravel from the consultant – The client was hesitating in taking many decisions and there were problems from his representatives – Observations for some design errors – Delay in materials supply – There were many workers mistakes specially carpentry works	– Fewer problems come from the contractor not as expected in the project start – No increase in materials prices – No problems due to workers accommodations
Weeks 4, 5, and 6		
Installing for tunnel walls rebar, pouring works for tunnel walls, carpentry works for tunnel slabs, manufacturing and installing for tunnel slabs rebar, pouring works for RC tunnel slabs, and insulating works for tunnel elements	– No improving in materials quality (gravel) – There were some workers mistakes – Observations for small design errors – The client was hesitating in taking many decisions and there were problems from his representatives	– Redesign for the work plan and specifications, for examples, using the retaining walls for tunnel instead of side carpentry works, using concrete additives to decrease curing time and modifying the work package to combine the work of tunnel walls and slabs in one work. – Slight improvement in material supply – The accommodation problem for workers completely disappeared – Improving in decision-making from the client
Weeks 7, 8 and 9		
Back filling around the tunnel, compaction around the tunnel, excavation for silos foundations, adjusting land levels, carpentry works for PC silos foundations, Pouring works for PC silos foundations, carpentry works for RC silos foundations	– Material quality is still not good – There were some workers' mistakes – Rejection for some works such as back filling around the tunnel – The client was hesitating in taking many decisions and there were problems from his representatives	– Problems from contractor was disappeared – Procuring required materials immediately – Increasing of Number of crews for silos foundations works
Weeks 10, 11, and 12		
Carpentry works for RC silos foundations, manufacturing and installing for silos foundations rebar, pouring works for RC silos foundations, insulating works for silos foundations, installing and fixing the steel silos	– Material quality is still not good – There were little workers mistakes – The client was hesitating in taking some decisions	– Increasing working hours – Using blocks bricks instead of carpentry works in one of the silos foundations – Delaying the foundation insulation after installing the steel silos

overcome the effects of risks and the major obstacles in the works. Effective look-ahead scheduling and management of handoff points between different disciplines are used to eliminate the effects of risks. Many observations are monitored during the execution of the work. Table 2 summarizes the most important activities and both positive and negative observations during project execution. The solutions for any problem are suggested and introduced. The master schedule is modified every three weeks based on the available suggestions, results, and evaluation. The project is completed on time, and so, there was no evaluation considered for risks in the end of this project. Table 3 summarizes the main reasons for non-completing works every three weeks.

Fig. 4 shows a comparison between the measurements of PET and the percent of non-completed works every three weeks. It can be noticed that there is a significant decrease in both PET and the percent of non-completed works as time increases. Also, it is observed from this figure that both investigated parameters decrease together and the rate of decreasing is gradual with time. There is close values for the two parameters in each observation which validate that using the time-overrun quantification model is suitable for evaluating the effect of using lean construction techniques.

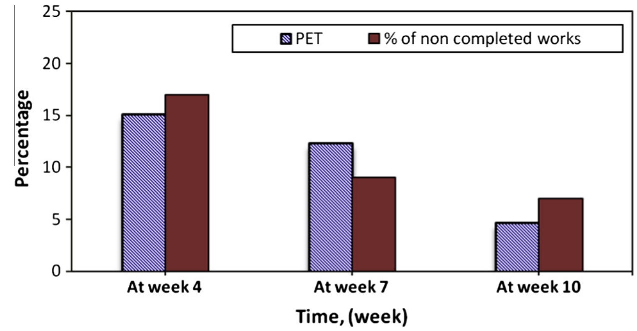

Figure 4 PET and the percent of non-completed works every three weeks.

Table 4 The values of PET due to factors affected by lean construction techniques.				
Week	At project start	At week 4	At week 7	At week 10
PET	15.57	10.34	8.75	2.9

7. Factors affected by lean construction techniques

Although project time has been reduced as a result of using lean construction techniques, not all factors are affected by these techniques. From the observations, it is noticed that there are four risk factors not affected by using lean. They are (1) Change in material prices or price escalation, (2) Delay in running bill payments to the contractor, (3) Design errors and suitability to the nature, and (4) Poor quality of local materials. The remaining nine factors are affected by lean construction techniques. Using the time-overrun quantification model, the PET due to the nine factors affected by lean construction techniques is calculated and shown in Table 4. PET average value due to factors affected by lean construction techniques represents about 67% from PET values for all the minimized risks.

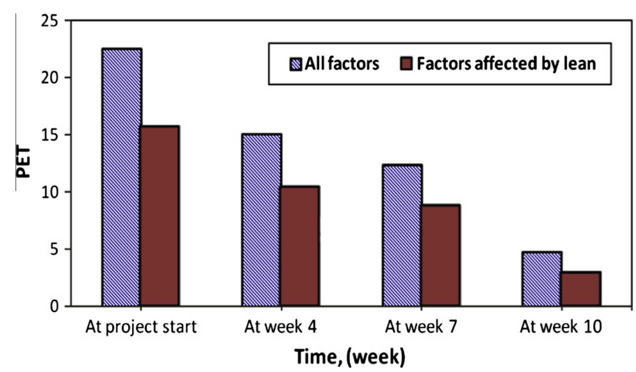

Figure 5 PET due to all factors and due to factors affected by lean construction techniques.

Fig. 5 shows a comparison between PET values due to all factors and due to factors affected by lean construction techniques. It is clear that the effect of all factors on PET is higher than the effect of factors affected by lean in all observations of the project different times. The difference between PET values ranges between 7 in the project start and decreases to 1.8 in the week 10.

Tukey [31] invented box plots as a powerful way for summarizing distributions of data to allow visual comparisons of centers. It spreads through the five-number summary (minimum, lower quartile, median, upper quartile, and maximum), which divides the data into four equally sized sections. Also, it graphically provides the location and the spread of the data set, which gives an idea about the skewness of the data set, and it can provide a comparison between variables by constructing a side-by-side box plots. In this research, the boxplot was used to summarize and compare the distribution of the

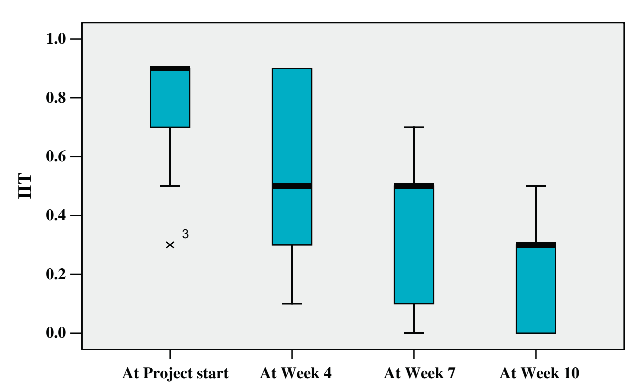

Figure 6 Impact distribution for factors affected by lean construction techniques on time objective.

Table 3 Main reasons for non-completing works.		
Week	PPC	Main reasons
4	83	Factors 3, 6, 7, 8, 9, 10, and 12
7	88	Factors 3,9, and 12
10	93	Factors 10 and 12

impact of factors affected by lean construction techniques represented by IIT at the start and during the project execution. The boxplots are constructed side-by-side for the IIT values as shown in Fig. 6. For the impacts measured at the project start, there is one factor located out of lier (factor No. 3). The IIT values for the remaining factors range from 0.5 to 0.9, which reflects the high impacts of most risk factors on time at the project start. It can be noted that the longest calculated range for IIT is at week 4 (about 0.8), and most of the factors lie in the box range. This wide range is due to reducing the effects of some of risk factors while other factors are still with high impacts. It is shown also that the measured impacts' ranges and magnitudes at weeks 7 and 10 are less than the previous weeks, and all IIT values at week 10 are less than 0.5. Generally, it can be noted that from Fig. 6, the IIT values in first week range from 0.3 to 0.9, while these values decrease in week 10 and range from 0 to 0.5. This concludes that the impacts of risk factors decrease as time increases due to using lean construction techniques.

8. Conclusions

This paper presents and discusses the results of applying the lean construction principles and thinking as a new tool to reduce the effect of risk factors on time objective for an industrial project in Egypt. The risk factors associated with the case study project were identified. The time-overrun was quantified based on the probabilities of occurrences and the impacts of many risk factors on the project time using a time-overrun quantification model. The PET was determined at the start of the project, and LPS was implemented during execution. Three weeks look-ahead, and WWP was provided to manage and monitor the progress of work for the project activities. PPC was evaluated weekly and based on the shortage of works, a modification for the three weeks look-ahead, and master schedule was completed. Identifications for the risk factors every three weeks were introduced based on the observations and the suggested solutions for the reasons of delayed works. Based on the observations, model outputs, and results analysis, the conclusions can be drawn as follows:

1. Lean construction techniques and principles have a potential to be used in reducing the effects of risk factors on time objective for construction projects in developing countries.
2. The use of lean construction techniques in construction projects has significant effects on the decrease in PET values and the increase in PPC values.
3. The effect of most investigated risk factors is minimized using lean construction techniques. In this study, the effects of nine factors are minimized among the total (13) investigated factors.
4. The average of PET due to factors affected by lean construction techniques represents about 67% of PET due to all risk factors.
5. The impacts of factors affected by lean construction techniques decreased with the increase in time as supported by boxplot analysis.
6. The results proved the success and suitability of using the time-overrun quantification model for evaluating lean construction techniques implementation.
7. Based on observations and results analysis, it is recommended to apply lean techniques in construction projects in developing countries due to its simplicity and high efficiency.

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