Application of Lean Manufacturing Principle to Construction Industry

Pedro E. Márquez Pagán
Master in Manufacturing Competitiveness
Carlos González, PhD.
Industrial Engineering Department
Polytechnic University of Puerto Rico

Abstract — *Waste in the construction industry has been the subject of several research projects around the world in recent years because of inefficiency. Researchers and professionals implement different methods to reduce the amount of waste in the construction industry. One of the efficient methods for reducing waste is the application of lean approaches. Lean construction is a result of the introduction of a new form of production management on the field. Although lean construction is still evolving, its generic principles, techniques and tools can already be applied. The construction projects include 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 wastes and 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 Puerto Rico. This is due to minimizing and mitigating the effect of most of the risk and debris factors in this project due to the implementation of lean manufacturing techniques.*

Key Terms — *Lean Construction, Process Flow, Risk Management, Waste.*

INTRODUCTION

In the past two decades, the manufacturing industry has remarkably improved its performance measures such as productivity, efficiency, etc. This is not true for the construction industry in which the measures have been improved slowly. There are a lot of problems related to the construction industry such as decreased productivity, schedule overrun, etc., which lead to customer delivered value to be decreased dramatically. One of the most common, unsolved and tough challenges related to the construction industry is the high rate of waste generation. Puerto Rico and the United States as developing countries face many problems in the construction industry such as lack of detailed and documented previous data concern risk and lack of adapting modern techniques for minimizing waste. Thus the effect of risk factors on construction projects' objectives. Lean construction is a philosophy oriented toward construction production administration to avoid wastes. It sets productive flows in motion in order to develop control systems with the aim of reducing losses throughout the process. Lean production it originates with the theory of the Toyota Production System (TPS), with its focus on the reduction and elimination of waste [1]. The types of wastes that are addressed in Toyota Production System are the followings factors: wastes of production, transportation, time, stock at hand, movement, processing itself and making defective products.

Research Description

This research is designed to analyze the current construction process and risk in order to identify opportunities to improve the time in completing the process. Today, even this industry is affected by bad decisions and coordination in the process, making those mistakes in losses standards, materials, budgets, customers and other factors. Studying this situation helps various entities as investors, contractors, architectural and engineering offices, government and federal development offices among others.

Research Objectives

This research is designed to analyze the current construction process in order to identify opportunities to improve the capacity of the flow line to produce more efficiency and to avoid losses in the product result. Design and implementation of a strategy to reduce the time in order to delivery the product with the original budget without compromising the quality of the construction. It will analyze data from a specific segment of the construction industry in Puerto Rico. Determining the profile of the sample of the construction projects, along with the perceptions of the owners on issues such as the time, cost and value of the construction processes. This contribute to identify the critical points in the construction process and the life cycle of a construction process.

Research Contributions

The research discussed in this article will contribute in the field to help understand, characterize and relieve the current practice in construction in the state of Florida, with the purpose to increase its construction capacity. By identifying and implementing tools and methods of quality improvement, having resulted in improvements in the process of construction, delivery and budget. The results of this research will contribute to practice in different sectors running a similar practice.

LITERATURE REVIEW

To properly explore the different forms of performance to minimize waste in the construction process will be exposing several points of discussion. Waste exists in different ways, including re-work, waiting, over –production, unnecessary movement, all these characteristic make a process non-environmental project. Managing the environmental parameters in constructions has been, in the past few years and the present one of the main concerns. The studies and different process analysis techniques have been applied to approach systematically quantify and identify wastes during the construction process [2]. Peculiarly, delay and other types of wastes due to poor coordination among various project participants have been well documented in various previous studies. The highly fragmented nature of the construction industry has caused considerable low productivity, and conflicts and disputes, cost and time overruns, all potentially resulting in claims and time-consuming litigations. The main factor is the necessity of a value stream schedule attach with the coordination to make the process. There is seldom a full awareness of all the process necessary to realize an optimum overall environmental project outcome without loss of materials, time and that the means of ensuring coordination of field operations are often not clear.

In order to be more competitive in the industry, the construction companies need to resort to the Lean Manufacturing methodology as a technique to improve the management costs by eliminating the process muda. Muda is a Japanese word that means waste. Lean Manufacturing methodology is utilized by many industries as a systematic approach to eliminate process muda with the objective of reducing the cost, processing time and excess of inventory [2].

Lean Principles

Fujimoto (1999), Womack and Jones (1996), MacInnes (2002) and others have codified sets of lean principles for manufacturing, some of which are briefly listed below. The core principles of the concept emanate directly from the Toyota Production System. However, as application of lean ideas became more prevalent, the fundamental principles of the Toyota Production System were expanded to incorporate a broader array of processes, tools and techniques.

Takahiro Fujimoto (1999) summarizes the essence of the Toyota Production System into the following three principles:

- Routinized manufacturing Capability-Standard ways of production.
- Routinized learning capability--Standard ways of problem solving and solution retention.
- Evolutionary learning capability--Learning for system change and improvement.

Womack defines the following five principles:

- Specify value from the standpoint of the customer. Identify the value stream. Make the product flow. Ensure that this happens at the pull of the customer.

Both of these characterizations of lean are too abstract for the purposes of this report. MacInnes provides a more comprehensive set of principles for manufacturing:

- Reduce Waste:
  - Produce only to order
  - Minimize product inventory
  - Minimize the seven wastes:

1. Overproduction, 2. Waiting, 3. Transport, 4. Extra processing, 5. Inventory, 6. Motion, 7. Defects

- Ensure Quality/Continuous Improvement:
  - Focus on the customer.
  - Apply error-proofing techniques.
  - Apply visual management and the 5S's.
- Reduce Lead Time:
  - Through product design
  - Through supply chains
  - In production:

One-piece flow, Reduce WIP, Pull scheduling, Quick changeover, Standardization, Total Productive Maintenance

- Reduce Total Costs:
  - Target pricing
  - Value engineering
- Use Metrics to Ensure Improvement:
  - Financial
  - Behavioral
  - Core process

Lean Manufacturing / Lean Construction

Koskela (1992), Ballard, Koskela et al. (2001), Picchi (2001) and others have proposed lean principles for construction. In addition, many other authors have interpreted individual lean principles for construction. For example, Lane and Woodman (2000) investigated the value of flexibility in construction processes, dos Santos, Powell et al. (2000) investigated WIP and Lantelme and Formoso (2000) and dos Santos (1998) studied the value of process transparency. Pull scheduling was studied by dos Santos (1999) and Tommelein (1998). The application of the flow concept has been investigated by Ballard (1999) and Alves and Formosa (2000). The application of metrics and benchmarking has been considered by Alarcon (1996) and Lantelme (2000). The effects of work flow variability have been examined by Tommelein, Riley et al. (1998) and Alarcon (1996). Finally, Ballard (1999) studied the value of reliable production planning.

The research team compiled the following comparison list using existing literature and information obtained from questionnaires:

- Customer Focus:
  - Constructors do not control the entire supply chain.
  - The largest constructors control only 1 percent of the market, whereas in manufacturing the largest manufacturers may control 20 percent or more.
  - Owners are much more involved in product features/ configuration, cost, schedule and process.
  - In construction, the responsibility for success is shared between producer and consumer construction.
- Culture/People:
  - In construction, high turnover results in less opportunity for training.
  - Construction workers are craft skilled; in manufacturing, they are process specialized.
  - There are alternate ways of doing each task; production methods are in the hands of the workers not the manufacturing engineers.
  - Production requirements, access and schedules are governed by multiple contracts.
- Workplace Organization and Standardization:
  - Construction has a fluid organization at the project level.

- The configuration of the production environment changes constantly; it is more difficult to maintain visual management systems.
  - Production people move through product, rather than the product moving through production people.
  - Construction has a more difficult supply change relationship, including different suppliers/subcontractors in different geographic regions.
  - There are alternate ways of doing each task; production methods are in the hands of the workers not the manufacturing engineers.
  - The typical construction project is what manufacturers would consider a prototype; it produces a unique product.
- Waste:
  - The production sequence is discretionary to a very large extent.
  - Material flow is not steady state; supply lines are different at different project locations.
  - Construction material storage locations and amounts vary at different points in the project.
  - Construction can change the execution time by adding or subtracting resources.
  - Construction is resource paced, and manufacturing is typically machine paced.
  - Construction is affected by weather.
- Continuous Improvement/Built-In Quality:
  - There is high turnover/less opportunity for training.
  - The ability to develop a quality tracking program is limited.
  - Production time is measured in hours in contrast to manufacturing where it is measured in minutes or seconds.

The primary issues common to this list are the greater degree of discretionary behavior and increased uncertainty evident in construction. In manufacturing, production systems are defined by and controlled by the configuration of the production line. In contrast, with construction, the production system is defined by project managers and the individual workers.

The Last Planner System

The last planner concept proposed by Ballard [3] is based on principles of lean production to minimize the waste in a system through planning at the allocation level or detailed advance programming. The studies of Ballard and Howell [4] on the latest planning technique showed that the use of formal and flexible production planning procedures is the first step in keeping the production environment stable. In this research, emphasis is placed on the use of daily production plans, restrictions analysis, prospecting and PPC as tools for immediate implementation in any workplace. The Last Planner System (LPS) was completed as a useful tool to be widely introduced in the construction process [4]. Ballard and Howell [5] designed LPS as one of the methods for applying lean techniques to construction. In LPS, the implementation sequences establish an efficient planning planning framework using an extraction technique, which configures workflow, sequence and speed; It matches workflow and capacity; Develop methods to execute the work; And it improves communication between trades. It usually only forms a small fraction of high-level programming, with great attention to detail, while not containing quality control tasks [6].

LSP is to reach a set of objectives described below [7].

1. Shape work flow sequence and rate. 2. Match work flow and capacity. 3. Distribute master schedule activities into work packages and operations. 4. Develop detailed work completion methods. 5. Maintain a backlog of ready work.

LPS focuses on increasing the quality of the Weekly Work Plan (WWP) assignments when combined with the anticipation process, originating and controlling the workflow. WWP controls the flow and helps ensure that assignments are ready by proactively procuring materials, designing the information to be used, and monitoring prior work or prerequisites [6][8].

This research aims to investigate and evaluate the effects of the application of lean construction techniques using LPS as a new tool to minimize the effects of risk on the time of construction projects. The objectives are extended to introduce and discuss the results obtained from the application of lean construction techniques in a Puerto Rico construction project to reduce the effects of many risk factors in the project time and quantify their effects. The strategy used is based on the evaluation of the effect of using lean construction techniques in terms of two measurements: PET and PPC.

Lean as Risk Planning

Risk management can be described 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 as a characterization of lean principles. The objective of risk management process is to minimize the risk effect on the project objectives and as a result improve decision-making. It incorporates both the prevention of potential problems and the early detection of existing problems when they occur [9]. It is important to plan the following risk management processes to ensure that the level, type and visibility of risk management are commensurate with the risk and importance of the project for organization and planning. The magnitude of the risk management task varies with the size of the project and its importance. Schwalbe [10] suggested that risk management is a set of principles by which the project manager continually assesses risks and their consequences and adopts appropriate preventive strategies.

METHODOLOGY

A model plan was developed to fulfill a endeavor undertaken to create a unique result through progressive elaboration in all its nature. To complete the project a step-by-step methodology approach is been selected, a Lean Flowchart Methodology, encompasses a roadmap and a logistic to identify and eliminate waste in the construction and improve the time to complete the construction.

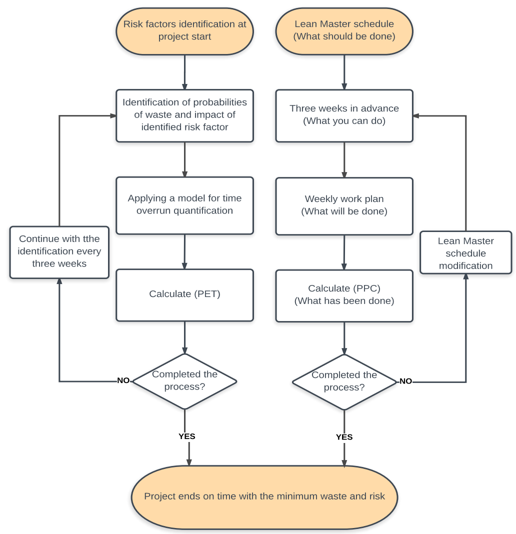

Figure 1
Flowchart of the Proposed Research Methodology

This approach will be documented as followed: Figure 1 shows the proposed research methodology for this study that used during the execution of a case study project through the following steps:

1. Identifying the risk factors associated with the occurrences and their impacts on time at the project start, in addition, performing the lean master schedule of the project including all activities to show (what you should be done).
2. The quantification of the PET due to the effect of the risk factors in the time at the beginning of the project is based on a model of quantification of the time of overload that will be explained in the next steps.
3. Perform three weeks in advance to show (what can be done) and the 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.

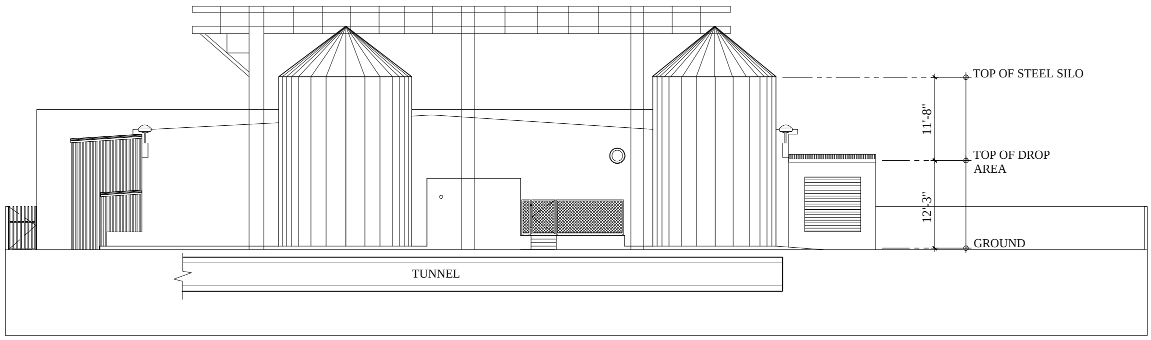

Figure 2
Sectional Elevation of Tunnel and Steel Silos used in the Case Study

5. Evaluation of completed work due to three weeks in advance and weekly work plan by calculating PPC to show (what has been done).
6. The modification of the lean master schedule and the three weeks of anticipation are based on previous observations and introduced solutions for wastes, reasons and risks.

The last scheduling system was applied during the execution of a stage of water construction in a factory in an industrial zone Carolina, Puerto Rico. The work required consists of the construction of an intake tunnel for the foundations of steel silos and the installation and fixing of steel silos. The structural design was completed by a company in Ponce, Puerto Rico and evaluated with specificities to meet the standards. The main problem was that most of the length of the tunnel is in silos, so it must be built before the construction of the silos foundations. In addition, there is a fixed date for the installation and fixing of steel silos. Therefore, finishing the tunnel and foundations of silos should be before this fixed date. Figure 2 shows a schematic section for tunnels and silos.

A lean master schedule was designed based on the project activities and their durations. Due to the fact that the case study had a fixed and short-term completion date, the master schedule for this project is calculated for 12 weeks. The total duration was measured on the basis of six work days per week. Therefore, the total duration of the project is 72 days. As mentioned above, there is no time limit to extend the time because steel silos should be installed on a fixed date to avoid any kind of losses. The general construction process consisted of many different activities such as excavation work, concrete and reinforced works, insulation work, topography, filling, compaction of filling and installation of the two silos.

RESULTS AND DISCUSSION

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 was 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.

Determination of PET

The expected lag time due to the effect of probabilities of occurrences and impacts of identified risk factors can be calculated using a diffuse model for the quantification of overrun time developed in the previous study [11]. This model was developed with the purpose of determining the overload time in the construction projects. The model is based mainly on many relationships between the impacts of risk factors in time and time elapsed through several logical rules taking into account the probabilities of risk factors. Issa applied, validated the model and demonstrated that it can be successfully used to calculate the expected saturation time, as a percentage of the original project time in particular [11].

In the case study, the most critical risk factors affecting project time were identified and developed by the consultant group, with the help of both the owner's representative and the contractor. The data was introduced as probability of occurrence and impact on time for each risk factor in the form of two indices, namely the Probability Index (PI) representing the probability of occurrences for a certain risk factor and the Impact Index for Time (IIT) that represents impact of a certain risk factor on time.

Table 2
Risk Factors

Risk factors affecting time, their indices, and PET values.								
Factors affecting time	Project start		Week 4		Week 7		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	M	M	VL	VL	VL	VL	0	0
3. Unskilled workers and poor quality productivity	H	VH	M	VH	M	H	M	L
4. Inefficient use of equipment	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	VL
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 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	H	VH	H	VH	H	H	H	M
3. 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	

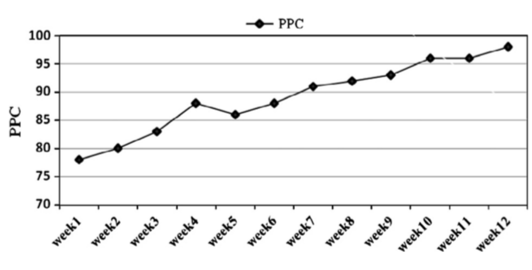

Figure 3
Activities and Observations

The states of the abbreviations are defined as follows: Very Low (VL), Low (L), Medium (M), High (H), and Very High (VH) [11]. These data are used as input for the model and the output will be PET that estimates the expected waiting time 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 project time. It is expected that, due to the effect of the risk factors, the project needs 16 additional days plus the original time to complete the work.

On the basis of the results and the evaluation of the work during the execution, the probability and the impacts of factor losses every three weeks are also identified and the PET is calculated to handle the effect of the incomplete elements of the plan. Table 2 shows the identification of critical risk factors and their indices for the case study investigated at the start of the project and every three weeks. The results of the application of the model during the project were also tabulated in Table 2.

Observations during Project Execution

Advance planning is the process undertaken to achieve possible constraints, free allocation and reduce the uncertainty of any project [12]. In the case study, prospective programs were prepared for the next three weeks in a bar chart format. WWP is produced based on three weeks in advance, the lean master calendar, and field conditions using memos and notes. The prospective schedules were updated weekly during a weekly project meeting with the architect and contractor. Ballard and Howell stated that WWP should emphasize the learning process more by investigating the causes of delays in WWP instead of assigning blame and focusing solely on PPC values. However, PPC is also calculated each week during project execution. PPC is the measurement metric of the last planner system. It is calculated as the number of activities completed, as planned, divided by the total number of activities envisaged [7].

Figure. 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 PPC values, with increasing time, as PPC values increase.

This project uses a systematic approach to the identification and quantification of risk for the risk effect over time. As part of the process, the redesign of working procedures and decisions are taken to overcome the effects of hazards and major obstacles in the works. To eliminate the effects of the risks, an effective programming and management of transfer points between different disciplines is used.

Table 3

Activities and Observations

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

Many observations are monitored during the execution of the work to identify points of wastes. Table 3 summarizes the most important activities and the positive and negative observations during project execution. Solutions for any problem are suggested and introduced. The lean master schedule is modified every three weeks based on the suggestions, results and evaluation available. The construction project was completed on time, so the risk assessment was not considered at the end of this project. Table 4 summarizes the main reasons for inconclusive works every three weeks.

Figure 4 shows a comparison between the PET measurements and the percentage of unfinished jobs at each three-week interval. It can be observed that there is a significant decrease in both PET and in the percentage of unfinished jobs as time increases. However, it is identified from this figure that both investigated parameters decrease together and the rate of decrease is gradual over time. There are close values for the two parameters in each observation that validate that the use of the overload time quantification model is adequate to evaluate the effect of the use of lean construction techniques.

Factors Affected by Lean Construction Techniques

However, the project time has been reduced as a result of the use of lean construction techniques, not all factors are affected by these techniques. From the observations, it is observed that there are four risk factors not affected by the use of lean.

- Change in the prices of materials and products or price escalation.
- Delays in the payment of current invoices to the contractor by the owner.
- Design errors or stipulations and suitability to nature
- Poor quality of local materials.

The other nine factors are affected by lean construction techniques. Using the time overload quantification model, PET is calculated because of the nine factors affected by lean construction techniques and is shown in Table 5. The mean value of PET due to factors affected by lean construction techniques represents approximately 67% from PET values for all minimized risks.

Figure 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 the PET is greater than the effect of the factors affected by lean in all observations of the project at different times. The difference between PET values ranges from 7 at the start of the project and decreases to 1.8 at week 10.

The researcher Tukey [12] invented box diagrams as a powerful way of summarizing data distributions to allow visual comparisons of centers. It extends through the five-number summary (minimum, lower quartile, median, upper quartile and maximum), which divides the data into four equally sized sections. In addition, it graphically provides the location and propagation of the total data, which gives an idea of the asymmetry of the total data, and can provide a comparison between the variables by building a side-by-side box box. In this case study, the boxplot was used to summarize and compare the distribution of the impact of the factors affected by the lean construction techniques represented by the IIT at the beginning and during the execution of the project. The box diagrams are constructed side by side for the IIT values as shown in Figure 6. For the measured impacts at the start of the project, there is a factor located outside the lier (factor No. 3).

Table 4
Main Reason

Main reasons for non-completing works in the field.		
Week	*PPC*	*Main reasons*
4	83	Factors 3, 6, 7, 8, 9,10 & 12
7	88	Factors 3, 9 & 12
10	93	Factors 10 & 12

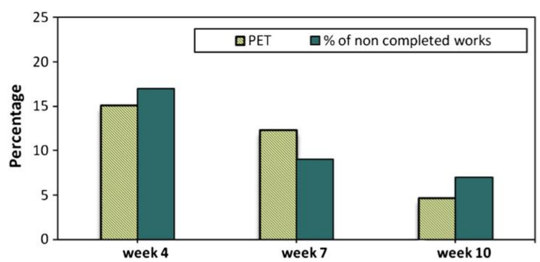

Figure 4
PET and % of Non-Completed Works on Field very Three Weeks

Table 5
The Value of PET – Lean Construction

The values of PET due to factors affected by Lean Construction techniques.				
Week	*Project start*	*Week 4*	*Week 7*	*Week 10*
PET	15.57	10.34	8.75	2.9

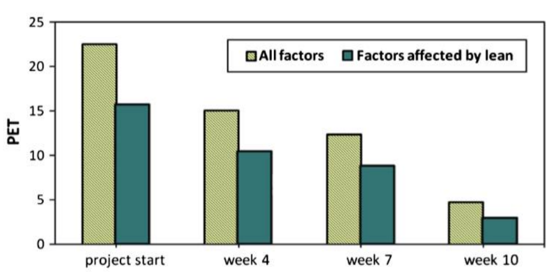

Figure 5
PET Due to all Factors and Due to Factors Affected by Lean Construction Techniques

The IIT values for the remaining factors range from 0.5 to 0.9, reflecting the high impacts of most risk factors at the time of the start of the construction project. It can be seen that the longest calculated interval for IIT is at week 4 (about 0.8), and most factors are in the range of the box. This wide range is due to the reduced effects of some of the risk factors, while other factors remain high impact.

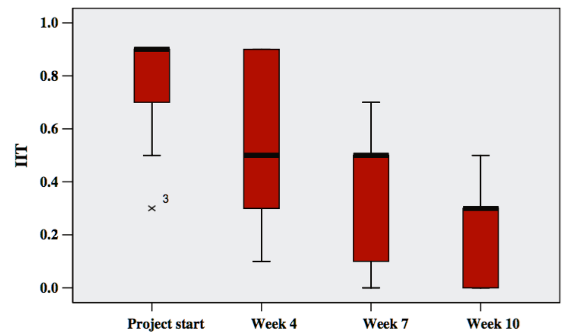

Figure 6
Impact Distribution for Factors Affected by Lean Construction Techniques on Time Objective

It is also shown that the ranges and magnitudes of the impacts measured at weeks 7 and 10 are lower than the previous weeks, and all IIT values at week 10 are less than 0.5. Usually, it can be seen that from Figure 6, IIT values in the first week range from 0.3 to 0.9, while these values decrease at week 10 and range from 0 to 0.5. This concludes that the impacts of risk factors decrease as time increases due to the use of lean construction techniques.

CONCLUSION

This research presents and raises the results of the application of the principles of lean construction and thought as a new tool to reduce the effect of risk factors in the target time of an industrial project in Puerto Rico, as well as in United States by the similarity before the specifications of construction of this nature. Risk factors associated with the case study project were identified. The overshoot time was quantified based on the probabilities of occurrences and the impacts of many risk factors at project time using an overshoot time quantification model. The PET was determined at the beginning of the project and the LPS was implemented during execution. Three weeks in advance, and WWP was provided to manage and monitor the progress of work for project activities. The PPC was evaluated weekly and was based on the shortage of papers. A modification for the three weeks of anticipation and the lean master program was completed. Identifications of risk factors every three weeks were introduced on the basis of observations and solutions suggested by the reasons for delayed work. On the basis of the observations, the results of the model and the analysis of the results, the conclusions can be drawn as follows:

1. Lean construction techniques and principles can be used to reduce the effects of risk factors on the target time of construction projects in developing countries.
2. The use of lean construction techniques in construction projects has a significant effect on the decrease of PET values and the increase in PPC values.
3. The effect of most of the risk factors investigated is minimized using lean construction techniques. In this case study, the effects of nine factors were minimized among the total (13) factors investigated.
4. The average PET by factors affected by lean construction techniques represents approximately 67% of PET due to all risk factors.
5. The impacts of the factors affected by the lean construction techniques decreased with the increase in time, as supported by the analysis of the boxplot.
6. The results demonstrated the success and suitability of using the elapsed time quantification model to evaluate the implementation of lean construction techniques.
7. On the basis of observations and analysis of results, it is recommended to apply lean techniques of manufacturing in construction projects in developing countries because of their simplicity and high efficiency.

References

[1] T. Ohno, The Toyota Production System: Beyond Large Scale Production, Productivity Press, Cambridge, 1998.

[2] H. Randolph Thomas; M. J. Horman, M.ASCE; R. Edward Minchin Jr., M.ASCE; and Dong Chen, M.ASCE, Improving Labor Flow Reliability for Better Productivity as Lean Construction Principle, June, 2003.

[3] M. Subburajan, *et al.* (May 2011). “Enhancing the Production Capacity of 300 Ton Press by Applying Lean Principles”, SasTech Journal, Volume 10, Issue 1, pp. 76-82.

[4] G. Ballard & G. Howell, Stabilizing work flow, in Proceedings of the 2nd Annual Conference of the International Group for Lean Construction, IGLC-2, Santiago, Chile, 1994.

[5] S. Bertelsen & J. Nielsen, Just-in-time logistics in the supply of building materials, in 1st International Conference on Construction Industry Development, Singapore, 1997.

[6] G. Ballard & G. Howell, Shielding production: an essential step in production control, J. Constr. Eng. Manage., ASCE 124 (1998) 11–17.

[7] G. Ballard, Look ahead planning, in Proceedings of the 5th Annual Conference of the International Group for Lean Construction, IGLC-5, Griffith University, Gold Coast, Australia, 1997.

[8] G. Ballard, The Last Planner System of Production Control, Ph.D. Thesis, Univ. Birmingham, Birmingham, United Kingdom, 2000.

[9] G. Ballard, Improving work flow reliability, in Proceedings of the 7th Annual Conference of the International Group for Lean Construction, IGLC-7, University of Berkeley, CA, 1999.

[10] C. Churchill & D. Coster, Microfinance Risk Management Handbook, Emily Pickrell and Calvin Miller, 2001.

[11] U. H. Issa & A. Ahmed, A model for time overrun quantification in construction of industrial projects based on risk evaluation, J. Am. Sci., vol. 8 no. 8, 2012, pp. 523–529.

[12] L. Koskela, An Exploration towards a Production Theory and its Application to Construction, VVT Technical Research Centre of Finland, 2000.