Flow Production of Construction Processes through Implementing Lean Construction Principles and Simulation

S. A. Abbasian Hosseini, A. Nikakhtar, and P. Ghoddousi

***Abstract*—The construction industry is one with a large number of specialized areas and disciplines, many based on cyclic processes at construction phase. With the advent of the lean construction concept, a few researchers have begun to apply lean principles to construction processes at construction phase. This paper seeks to test the applicability of lean principles to one of construction operations using discrete-event simulation. One of the general simulation tools with a powerful 3D animation in this regard is ARENA, which is used in this paper. Data required to simulation model development were gathered from the construction site. It concluded that the concepts of lean construction can be applied properly using simulation as means of testing lean concepts prior to actual field implementation. Results of the simulation models showed that lean principles enhanced the performance of the selected processes by reducing the total time of the project and increasing the process efficiency.**

***Index Terms*—Lean construction, construction process simulation, lean principles.**

I. Introduction

H After the study conducted by the International Motor Vehicle Program (IMPV), the Japanese techniques introduced firstly by John krafick as part of a new production system, known as lean production [1], [2]. Lean production is defined as an approach to manufacture the right product with the right quantity through instant material supply while minimizing wastes and maintaining flexibility to adapt to varying production requirements [3]. Lean thinking has proven very useful for improving production processes and product quality in the last few decades, and lean production techniques have been widely applied in the manufacturing industry [3]-[5].

Construction industry, according to researchers, is a slow progressing industry with frequent problems such as low productivity, insufficient quality, time over-runs, and poor safety which hinder customer delivered value [6], [7]. Koskela [8] believes that Construction is predominantly managed according to the transformation concept transformation of inputs to outputs and principles related to the flow and value generation concepts are largely neglected. Consequently it cause to considerable waste and value loss. Construction peculiarities (such as uniqueness, site production, complexity, quickness, etc.) are another issue increase uncertainty and variability which result in aforementioned construction problems.

Due to the success of lean principles in manufacturing industry and potential of construction projects for optimization, applying lean production principles in construction processes is seemed to be effective. In fact, lean construction attempts to move beyond the traditional view of project as transformation, to include flow and value generation.

Needless to say, in real life, testing a construction method is very expensive and time consuming. Hence, in order to reveal an understanding of lean applicability to a construction process, computer simulation was utilized. Processes can be efficiently modeled and analyzed from a practical perspective using simulation. Therefore, the concepts of lean construction can be validated using simulation as means of testing lean concepts prior to actual field implementation [3], [5], [9], [10].

II. Research Methodology

For simulating the construction process selected in this paper (brick work operations), first, the process flow, detailed tasks, sequences and linkages were identified to generate the process map. Process mapping is one useful tool to study and understand flow of construction materials through visualization of activities and their linkages. In the second step, data were collected during construction, and were then used to determined equate probabilistic density functions for the activity's duration. Third, the model was constructed using computer simulation according to process mapping and distributions of activity duration. One of the general simulation tools in this regard is ARENA which is used in this paper. Fourth, to test the accuracy of the simulated model, developed model was validated through comparison between model and actual outputs (such as cycle time). Fifth, after model validation, selected lean principles applied to the model. And in the final step, the comparison between the outputs of the base-line and lean process was done to evaluate the results of applicability of lean thinking into the construction process.

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III. Lean Thinking: Design the Construction Process for Flow and Value

Considerable waste and value loss due to neglect flow and value issues in a construction process constitutes the basis of lean theory concept. Actually, the main argument of the lean construction thinking is that processes need to be analyzed not only as transformations but also as flows and as value generation.

Construction methods consist of several on site activities carried out sequentially or in parallel where materials, equipment and workers are interacting in a complex way [11]. Flow view, describes processes as being composed by transformations, but also by inspection, waiting, and moving of information, materials, and equipment. Paying special attention to value transfer to the final product, is another basic aspect of lean thinking. Ballard [12] has seen the construction process as a flow of work delivering value to the client. In fact, Flow and value concept complement each other when apply to construction operations.

From lean thinking perspective, the activities in the physics of work flow can be classified as value adding and non-value adding activities. Value-adding activities are those that contribute value to the final product, and the remaining activities are non-value-adding activities. In this context, Koskela [6] divided various construction activities into two categories: conversion and flow activities. Conversion activities are defined those that transform raw materials or information into a final product and flow activities also defined those that link conversion activities together (inspection, waiting, moving, etc.), and do not themselves contribute value to the final product (Fig. 1). Koskela [6] believe that while all activities expend cost and consume time, only conversion activities add value to the material or piece of information being transformed into a product. Therefore, conversion and flow activities are value-adding and non value-adding activities respectively.

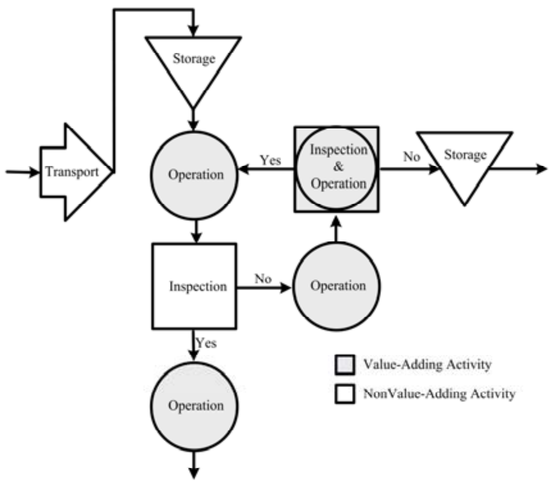


Fig. 1. Flow and conversion activities through an operation process chart symbols

Research show that the non-value adding activities hold a noticeable share in most of construction processes [9], [11], [13]. Therefore, Lean thinking attempts to improve construction processes via making value adding activities more efficient and eliminating or at least reducing the labor time spend on non value-adding activities in a construction process.

IV. Lean Construction Principles

To achieve lean goals, lean construction concept can be followed through five principles: 1. precisely specify value by specific product; 2. identify the value stream for each product; 3. make value flow without interruptions; 4. let the customer pull value from the producer; and 5. pursue perfection [14].

Interactions between resources, activities, and the flow of information in any construction process can be represented by process mapping [9]. It can clarify the flow of value to the final product in a process and identify the value stream. Therefore, managers can (1) identify activities, decisions, queues and resources required; (2) clarify process sequence and logic; and (3) seek opportunities for improvements. Furthermore, process map can be effective in well development of simulation model and how implementing lean principles. Fig. 2 depicts the process map of brick work operations of the buliding which examined in this research. Process mapping is done based on field observations, discussions with practitioners, and using operation process chart symbols.

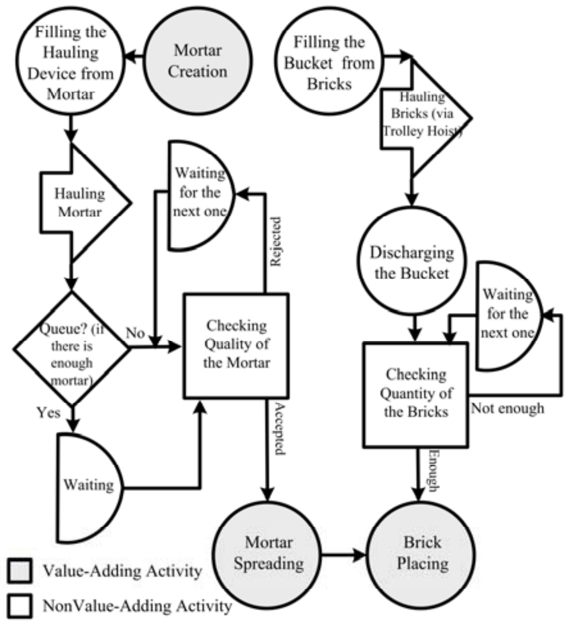


Fig. 2. General process mapping of brick work operations by operation process chart

Although some non-value adding activities are required and sometimes essential in carrying out an operation [3], [9], high percentage of their share in brick work operations (as can be seen in Fig. 2) bring about the high potential of optimization. After clarification of a construction process via process mapping, non value-adding flow activities should primarily be focused to reduce or eliminating, whereas conversion activities should be made more efficient. Simplification, just-in-time delivery of materials and optimized utilization of labors and crews, are the primary techniques using in this paper to make the lean process.

V. Simulation to Apply Lean Construction Principles

To test and evaluate the application of lean principles in the chosen construction process (brick work operations), simulation model developed according to actual behavior observed. The modeler through the process map, which is defined in previous section, can easily define the activities and their linkages for the model. Data on construction operations was collected from the construction site. Work study techniques were used for collecting data.

One of the general simulation tools in this regard is ARENA which is a generic discrete event simulation language with a powerful 3D animation interface [15], and therefore is used for the simulation of brick work operations in this paper. Various kinds of modules in ARENA (Process, Decide, Batch, Separate, Assign, Hold, etc.) were implemented to close the model to what happened in actual. It should be noted that some extra modules or linkages also were used to meet the logical aspects of the way that process done. Explanation of how simulated model works are not in the scope of this paper and therefore not included in detail Fig. 3 depicts the established simulation model.

A simulation model uses a random duration for each activity which should be chosen from a specific data set. Modeling a random process is usually performed by selecting and fitting a probability distribution to that process based on sample data. There are many computer packages used for fitting a statistical distribution to a sample data. The availability of such packages makes the process of fitting distributions to a sample of observed data quick, easy and accurate [9]. EasyFit is one commercial package that fits a wide variety of distributions to sample observations, which was used in this study.

A. Model Validation

Successful modeling is wholly dependent on the development of a base-line model that accurately depicts the present work flow process and the interrelationships among various tasks [9]. Therefore, before experimenting with simulation to evaluate the effect of lean principles, it is necessary to validate these models. Validation means that the model is almost behaving like the actual system.

To validate a computer model, first, model is run with distributions of activities duration as inputs. Second, comparison between the base-line model outputs (cycle time) with real one was done. After each validation, modification had been done to solve the probable problems. This cycle repeated for several times until the variations between the modified model outputs and actual outputs minimized. After each validation, modification had been done to solve the probable problems. This cycle repeated for several times until the variations between the modified model outputs and actual outputs minimized. In general, a single run of the model is not sufficient to produce adequate outputs [16]. For a terminating simulation, the number of simulation runs to produce the desired level of accuracy, were estimated according to Law and Kelton [17] which is obtained 13 replications or more (15 simulation runs were used in each validation). The results of final validation are shown in Fig. 4.

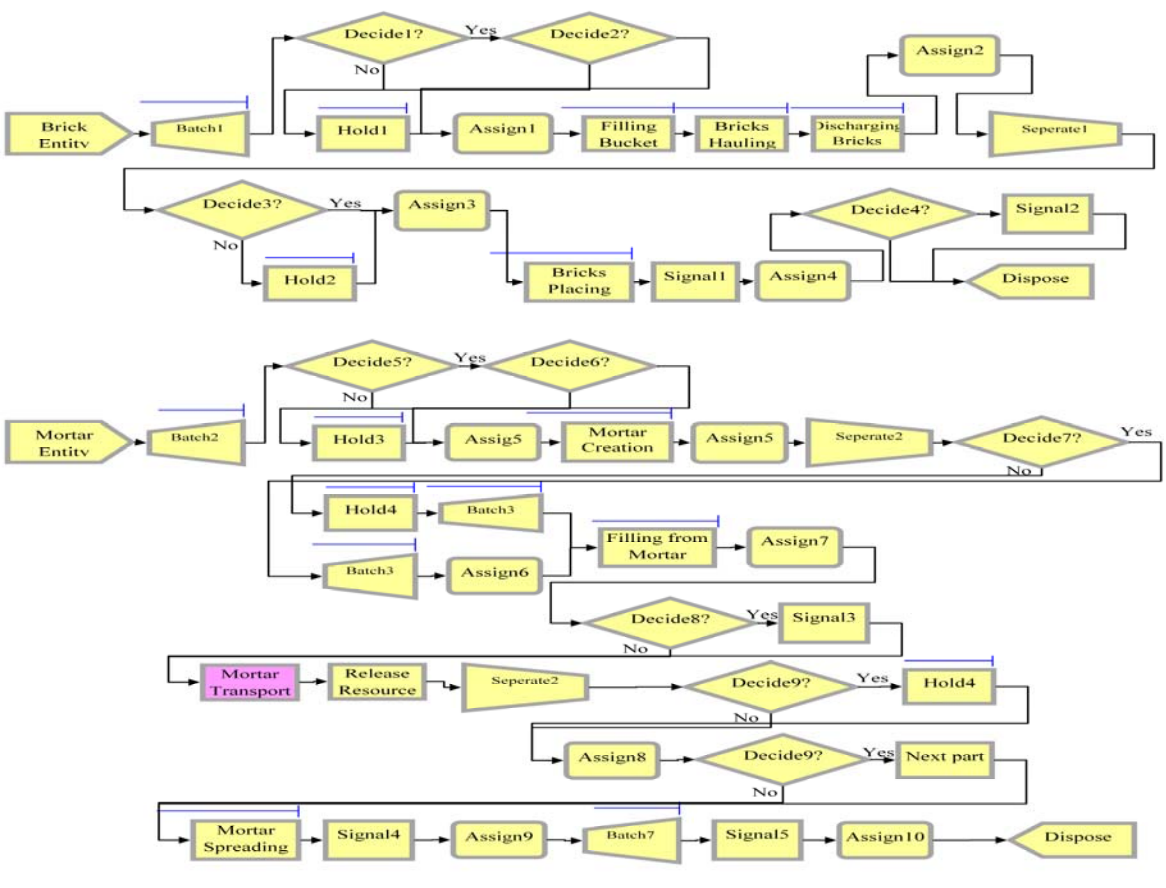
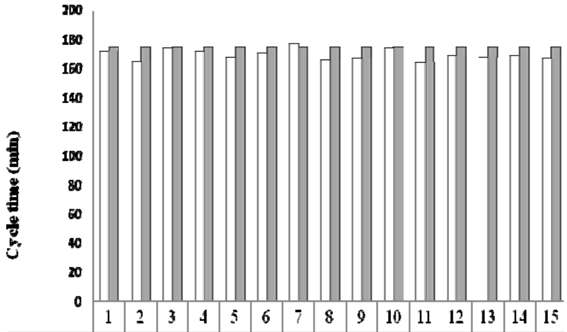


Fig. 3. Simulation model of brick work operations with ARENA

The output variations of final validation are between -6% and +1% (with an average 3%) and are acceptable according to [16]. Now, the base-line model is ready for lean principles application.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Simulated	172	165	174	172	168	171	177	166	167	174	165	169	168	169	167
Actual	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175

Replication

Fig. 4. Validation of cycle time for final simulation model

B. Applying Lean Principles to Simulated Base-Line Model

Eliminating waste in a process is one of top priorities in lean construction theory [1], [3], [5], [7], [9], [13]. The labor time and costs spending on non value-adding activities is numerously mentioned as the resources of wastes in a construction process [18]-[20]. According to the resource outputs of ARENA for base-line model (actual model), the average percentages of labor time spending on activities without value, and waiting, are 29 and 36% (totally 65%) and only 35% of total labor time is dedicated to the value-adding activities. Lean thinking attempts to reduce the 65-percent share of non value-adding time through its principles. Increase the labor time spending on value-adding activities leads to cycle time reduction and productivity improvement.

There are many techniques implemented to achieve a lean process depended on the process features. Simplification, just-in-time delivery of materials and optimized utilization of labors and crews, are the most appropriate principles to make the brick work process lean.

1) Simplification

The presence of waste and excessively complex operations makes things more time consuming and costly than needed. Simplifying the process by minimizing the number of steps, parts and linkages can reduce the complexity of a process [4]. Unnecessary tasks were eliminated, site layout were optimized and the process were designed in the way that value-adding activities done efficiently and with least disruptions. It leads to increase the value is transferred in a cycle time of the process and productivity improvement.

2) Optimized utilization of labors and crews

Inefficient use of resources, cause to more than 10% of the projects' production cost [19]. Thomas et al [21] determined that the most significant cause of loss of labor efficiency on the project they researched on, relates to the labor resource, specifically labor flow, i.e., insufficient work to perform and overstaffing. The most right makeup of labor resources should be obtained for the process. It was done through comparison of the model outputs when it was run for various combination of labor resource.

3) Just-in-time delivery of materials

One of the most common problems in construction is the inability of the contractor to deliver materials at the right time and the right place which cause to waste generation [4], [18], [20]. "Pulling" is a lean production principle to ensure just-in-time coordination between upstream and downstream tasks. The term "pulling inventory" means that material is delivered to the process as soon as it is needed. In the construction domain, this principle can be interpreted as supplying materials, labor, and equipment only as they are needed [3]. Sooner Delivery of materials than needed causes large inventories of materials on site and labor time misspending. Needless to say that delivery of materials later than needed cause to increase waiting times which directly decrease the productivity. Therefore, the model and its labor resources were designed in the way that waiting time is minimized.

VI. LTS AND REMARKS

Flow processes are easily thought of and measured in terms of time [13]. Time is a more useful and universal metric than cost and quality because it can be used to drive improvements in both [22]. On-time completing of construction processes leads to on-time completing the project. In addition reducing the duration of a process, make it more productive and efficient. Therefore, cycle time comparison of construction process alternatives can be an appropriate evaluation totally. Furthermore, the time spend on value and non-value adding activities and also waiting time can be compared to demonstrate the reasons of cycle time reduction. Table1 depicts the comparison of outputs between base-line and lean model.

TABLE I: COMPARISON OF OUTPUTS BETWEEN BASE-LINE AND LEAN MODEL

	Base-line	*Lean*[a]	*Improvement*
Cycle time (min)	175	144	18%
Average value-adding labor time (%)	35	51	16%
Average non value-adding labor time (%)	29	20	9%
Average waiting time (%)	36	29	7%

a.Output of the lean model is the average of 15 replications.

As can be seen, the cycle time was decreased noticeably due to implementing the lean principles. The Average value-adding labor time affect directly on the cycle time of the process. Therefore, attempts to increase the labor time spending on the value-adding activities by lean principles led to decrease the total cycle time of the project.

The work process improvement obtained on the same-equipment installations and the same number of labors utilized. That is, this improvement achieved without any cost for contractor.

VII. CONCLUSION

The research contained in this paper presents an approach for the application of lean production theory in construction process at construction phase using computer simulation models. This is accomplished through development and experimentation of the brick work operations model using ARENA.

It has been shown that a useful tool may be a computer simulation model. The computer simulation model in this paper revealed noticeable results in cycle time improvements within brick work operations. Computer simulation as an engineering tool can be existed in each construction site and make remarkable improvements through construction phase of a project.

The lean techniques applying to a construction process can have different results depending in the process features. Simplification, just-in-time delivery of materials and optimized utilization of labors and crews, are the appropriate techniques to make a process lean, while applying together. Results of the simulation models showed that lean principles enhanced the performance of the selected processes by decrease the total time of the project and also improve process efficiency, i.e., increase the time, labors spent on value adding activities.

Finally, it should be concluded, while this study is just dedicated to one of many operations in a construction project, it can be predicted that the construction operations have high potential of optimizing through application of lean principles and simulation which finally lead to drastic promotion in construction industry.

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