APPROPRIATENESS OF LEAN PRODUCTION SYSTEM FOR THE CONSTRUCTION INDUSTRY

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ABSTRACT

The manufacturing industry has been a constant reference point and a source of innovation for construction over many decades. The lean concept is one of such strategies adopted by the construction industry from the manufacturing industry to improve performance. In order to take benefit of lean techniques developed in the manufacturing industries, it is important to identify which categories of manufacturing systems are best applicable to construction. Many research studies have identified construction as a lean resistant industry because it differs from manufacturing due to site production, temporary multi-organisation and one-of-a-kind nature projects. The main objective of this study is to find different characteristics of construction processes and how lean techniques can be adopted to them. The method used for this study is a practice oriented research approach where it compares the characteristics of two construction processes with manufacturing process characteristics. In the attempt of visualising the existing process, value stream mapping techniques were used. It is identified that the construction process is a combination of fabrication and assembly processes with different characteristics such as layout, material flow, information flow, and work element. It can be concluded that certain construction techniques like pre-fabrication soften the construction peculiarities.

Keywords: *Assembly, Construction, Fabrication, Lean, Manufacturing.*

1. INTRODUCTION

The manufacturing industry has grown significantly through increasing productivity and product quality while reducing product lead time (Diekmann *et al.,* 2004). The improvements in the manufacturing sector have been achieved through process management strategies. These strategies stress the significance of basic theories and principles related to production management (Koskela, 1997) involving technology, employee, process, product, material and management based techniques (Kumar, 2006). They include reduction of human efforts, space, engineering hours, lead time and inventory and increase of quality, product variety and operation flexibility (Diekmann *et al.*, 2004). With the development of a tripartite view of production, transformation-flow-view by Koskela, the construction industry was inspired with a new process management approach (Elfving, 2008). Different methodologies have also been introduced to the industry and they include total quality management, time based competition, lean and concurrent engineering (Koskela, 2000). Earlier, these developments were beneficial to the process management in manufacturing (Polat and Ballard, 2004). Same practices have been promoted as productivity improvement strategies in construction to reduce waste and maximise value.

Based on the results of lean transformation developed by Womack and Jones as cited in Taguchi (2004), it can be seen that lean implementation derives great benefits within manufacturing and other industries. However, the implementation of manufacturing concepts in construction has often been unsuccessful due to peculiarities of construction projects compared with the manufacturing processes (Bjornfot and Stehn, 2007). Koskela (2000) come to a similar conclusion that long production time and cyclical nature is the major peculiarity in the construction sector. Distinct characteristics of the construction sector continue to isolate it from other industries and sustain the belief that it is quite different from the other sectors (Dos

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Santos and Powell, 1999). As a result the performance of construction in terms of productivity, quality and product functionality is low compared to other industries. The low rate of innovation has been the major cause for this situation (Winch, 2003). Furthermore, construction workers also experience a higher incidence of non-fatal injuries than workers in the other industries (Cain, 2004). Due to the unique nature of the construction sector, adopting the manufacturing practices directly into construction may not be appropriate. This uniqueness results from properties of construction projects.

The primary objective of this research is to assess the differences and similarities between a construction project and a manufacturing process. Similarities between the manufacturing and the construction cases can use to explain the suitability of the lean concept in construction. Furthermore, the differences between manufacturing and construction can use to show why the lean concept does not fully suit to construction. To support these two claims, the two distinct construction cases are identified and the study examines process characterises of two construction cases in order to identify the production type of these construction processes. Then, the most relevant techniques of lean manufacturing and lean construction are reviewed.

The paper is divided into five sections including this introduction section. The next section explains the main principles underlying performance improvement initiatives in construction and the comparison between the manufacturing and construction process characteristics. The third section illustrates the methodology adopted for this study and fourth section assesses the process characteristics of two process studies conducted in the case study project. The final part assesses the similarities and differences between process studies and manufacturing process characteristics identified in the literature review and states the extent to which adaptability of lean concepts in construction projects.

2. LITERATURE REVIEW

Given the origins of lean thinking in the automotive sector, the application of lean without appropriate adaptation for construction sector has been widely questioned. This is due to the specific characteristics of the industry. Therefore this section discusses the main differences between construction and manufacturing sector by considering its nature of operation. Construction is a project centric industry operating within an environment of considerable complexity and uncertainty (Koskela, 2000) due to the fragmented structure of the supply chain (Picchi, 2001) and short term , adversarial trading relationships (Barret, 2005). Contrary to manufacturing, the final product has its very own nature because construction projects are unique, static and big in size (Koskela, 2000) whereas manufacturing produces repetitive, large volume and movable products. Furthermore, the workforce in manufacturing has regular workers with high employment security. Due to the long term nature of the employment contract and the long lifecycle of a product, the employees gain job specialisation with high experience. On the other hand, in the construction industry, job security is low and workers perform a range of tasks during a project (Salem *et al.*, 2006).

The scope of operations in manufacturing is well defined from the beginning and operations plan is in great detail based on many trials. However, construction operations are partly defined and details are un-examined (Howell and Ballard, 1997). This is mainly due to the short term nature of the projects. Unlike manufacturing activities where the rhythm of production is fundamentally governed by the machines used in the manufacturing processes, construction depends on the management of information and resource flows of mainly labour and non-stationary equipment (Alarcón, 1997). In construction, contractors generally prefer to rent or lease their machineries (Clough *et al.*, 2000) due to short project duration, temporary nature and high investment cost. However, in manufacturing, it is preferred to purchase machineries because of the long product life cycle and repetitive nature of production. Unlike manufacturing, there is less protection from environmental conditions for construction work since it usually operates outdoor (Koskela, 2000) which causes interruptions to construction works.

Quality in manufacturing is achieved through controlling the processes while quality of construction is primarily related to product conformance based on specifications and drawings (Salem *et al.*, 2006). In manufacturing, defective products are largely discarded rather than reworked due to the simplicity and flexibility of the product. In construction, rework is a common practice since only one final product is delivered (Salem *et al.*, 2006). Moreover, the labour intensity increases the risk of human error and quality issues are widespread in the industry. In manufacturing, manufacturer-supplier relationships are clear, more manageable and open to repetition. However in construction, these relations are more dynamic and complex. Subcontracting is a common practice in construction. The subcontractor performance can highly affect a finished product in construction due to the interrelations between processes. The incapability to improve the productivity level of construction projects is mainly perceived by people in the industry due to project characteristics (Koskela, 2000) and identified differences are summarised in Table 1.

Table 1: Differences between the Manufacturing and Construction Work Characteristics

Features	**Manufacturing**	**Construction**
Type of industry	Process centric	Project centric
Type of work	Discrete components	Assembly
Mode of production	Machine intensive	Labour intensive
Production volume	Large and repetitive	Single and unique
Production rate	Depend on machines used	Depend on information and resource flows
Operations	Well defined	Evolving, learning from the initial stages
Product quality	Assures from process quality Less rework	Conforms to specification High rework
Workers	Regular and long term	Irregular and short term
Supplier relationship	Clear, manageable and repetition	Dynamic and complex
Layout	Static	Dynamic
Environment	Mainly indoor, factory setup	Mainly outdoor, site setup

In the recent past, other industrial sectors have made significant progress through the adoption of "lean thinking" but research investigations show that several obstacles account for the low uptake of lean principles in construction. Many practitioners are resistant to lean principles due to the fact that the industry as a whole is unique (Hook and Stehn, 2008). Therefore they believe that extension of specific manufacturing techniques such as lean to construction is uncertain. However, most of the studies consider the short term nature and unique project. Conversely, researchers have listed a number of similarities between the two industries such as both industries consist of socio-technical systems (the combination of human and technical elements) and construction is similar to the manufacturing area of new product development (Kagioglou *et al.*, 1999). Koskela (1999) states that lean construction shares the same goals of lean production: elimination of waste, cycle time reduction, and variability reduction. Therefore before generating a range of theories related lean implementation for the construction industry, it is worth to consider the ability to transfer of lean manufacturing practices and theories to the construction industry. There is a lack of studies that explicitly address the above issue.

To gain an understanding of the differences in lean principle between manufacturing and construction, the fundamental differences between manufacturing and construction had to be investigated. Before converting the principles and techniques, it is good to look at the construction process characteristics through real examples. The direct transfer of knowledge from manufacturing to construction could be possible for some particular types of construction. While previous studies related to lean construction provide some insights, they are inadequate for understanding what actually happens in the construction site particularly in infrastructure, long term project. Therefore, this study has compared two case studies conducted at infrastructure construction project sites and identified the situation in the construction.

3. METHODOLOGY

The study reviews the position of the construction industry from a theoretical and practical point of view. The research methodology adopted for this study basically follows two distinct and independent investigation steps, which are literature review and a case study approach. The literature review is based on published literature in construction management to analyse the difference between construction and manufacturing industries in theory. Then the study used participant observation as a research technique from a series of site visits at two construction processes to identify characteristics of each process. Consequently, the identified process characteristics compared with different resource inputs required for construction. The participant observation acts as a data collection tool as well as an analytic tool. Therefore, it enhances the quality of the data obtained during fieldwork and interpretations of data. It helps to find answers to 'how' questions (Robson, 2002). This research approach was supported by process mapping tools to get a clear picture of the process flow of selected case study processes namely pre-cast segment production and parapet construction of a motorway project.

4. ANALYSIS

In a construction environment, there are multiple resource inputs or conditions that need to be satisfied simultaneously for a task to be able to be started and completed (Fearne and Fowler, 2006). It can be identified that there are nine common inputs that are required to carry out a single task in construction projects. They are:

(1) Materials

(2) Output from preceding task (Work in progress)

(3) Labour

(4) Plant and machinery

(5) Information – what needs to be done

(6) Space – access to the working area and space in which to work

(7) Method – as in how the works are done

(8) Permissions – in terms of planning, building regulation and statutory authority approvals

(9) Environment - as in weather conditions

Two construction process studies are compared with the above nine input factors in order to determine the characteristics of these construction processes.

4.1. PROCESS DETAILS

4.1.1. PROCESS STUDY 1

The pre-cast concrete segment construction process was selected for the first case study. The data collection was started from the raw material receiving bay and it continued through each of the individual processes identifying the linkages between the states of production and establishing the flow of information and material resources. The overall process mainly consists of re-bar fabrication, mould set up, concrete pouring and remedial work and process maps for the main activities is shown in Figure 1. The pacemaker of the process is the mould setup task and only one product can fit into a machine at one time.

4.1.2. PROCESS STUDY 2

This study focuses on a parapet construction of a bridge. The process consists of pre-cast element installation, parapet formwork installation and concrete pour and removal of formwork. The process map for the main activities is shown in Figure 2. The pacemaker for the process is the parapet formwork installation operation and the aim was to produce two units at once. This is mainly determined by the number of formwork available at the site.

Process photo					
Operation description	Rebar fabrication	Rebar cage lifting	Mould set up	Survey (segment, pre pour, as built)	Concrete pouring
Process photo	No photograph				
Operation description	Crack segment	Remedial work	Transfer to yard	Final inspection& sign off	

Figure 1: Process Map for Process Study 1

Process photo				
Operation description	Lifting pre cast barrier	Tie reinforcement and lighting duct	Prepare stop end	Install temporary hand rails
Process photo				
Operation description	Clean and apply release agent in the formwork	Install formwork	Pour concrete	Remove formwork

Figure 2: Process Map for Process Study 2

4.1.3. COMPARISON BETWEEN TWO STUDIES

The two process studies are compared with the nine input factors as shown in Table 2. In the first process, the material flows through workstation to workstation and the material flow is transparent. During the production, two material flows can be clearly visible namely main raw materials and intermediate components. Frequent production stoppages are happening due to the absence of verification against the delivered materials. In this process, there is a permanent storage place for required materials and they are placed at the best possible location to reach all the workstations. On this site, the product is movable and it flows through different workstations where fixed and stationary worker-teams are engaged in a particular task. Therefore, it has a fixed position layout throughout the operation.

In the second process, the material also flows through workstation to workstation with two material flows namely main raw material and intermediate components. But due to moving workstations around the site, the material flow is complex and invisible. Since workers and workstations are moving as the work proceeds, most of the input materials and equipment are stored in temporary storage positions. Sometimes this improper storage results double handling of materials and it has been observed that the materials were manually moved from one workstation to another which causes a productivity reduction. This dynamic nature of the layout causes workstation congestion. In this study, it is found that the worker idling time is mainly caused by poor layout. In this process, the final product is stationary and it proceeds through different assembly tasks.

Table 2: Comparison of Two Construction Processes in Terms of Construction Inputs

Input factors	Process 1	Process 2
Materials	Flow through workstations Flow is transparent Interruptions due to material shortage Stores in permanent location	Flow through workstations Flow is less transparent Less interruptions due to material shortage Stores in temporary location
WIP	Product moves through workstations Product movable One piece flow	Product proceeds through assembly phases Product immovable Multiple piece flow
Labour	Stationary team One team is working on the product Defined work with specialisation Temporary and regular	Team moves throughout the process One part worked with several work teams Different work elements Temporary and irregular
Plant	Production depends on machine capacity High setup time and some breakdowns	Production depends on labour efficiency No setup time and breakdowns
Information	Design drawings, production schedule. Information displayed at fixed positions and near to workstations	Design drawings, production schedule. Need to move information display boards as work proceeds
Space	The site is not an input resource to final product Fixed position layout Less congestion and obstruction from material and WIP	The site is an input resource to final product Dynamic layout High congestion and obstruction from material and WIP
Method	Sequential work Structured improvements Unclear production methods at the beginning of the production	Flexibility in out of sequence work Very little structured improvements Clear production methods at the beginning of the production
Permissions	Requires inspection acceptance	Requires inspection acceptance
Environment	Less effect from the weather No traffic related issues	Direct effect from the weather Need to consider traffic related issues

In the first process, the pacemaker activity is an equipment intensive process and therefore the production rate is restricted by the machine capacity. Machine breakdown and setup time are relatively frequent and cause variability in the process cycle time. Furthermore, "right at first time" is important to this process since the process follows a one product sequential flow. As quality defects will cause bottleneck conditions, it is necessary to assure quality at the source which is a distinct feature of this process. Therefore workers detect any visible deviation and attend to quick rectification to reduce any interruption that could cause quality rejections. Since one team is working on one product at one time, it is easy to visualise quality defects and reduce quality issues.

In the second process, the pacemaker activity is a labour intensive process. Therefore the production rate is dependent on the labour efficiency. Since there are no process restrictions, the production follows multiple unit flows with multiple worker teams. Most of the time, this process performed out-of-sequence due to its flexibility in the operation sequence and product design. Therefore, several different work teams work on one product unit at a time and it provides less opportunity to assure the quality at source due to lack of transparency. The first process was new to the workforce and they have no experience in such a production. Workers learn from the initial production runs and streamline the production process and planning. Even though the second process contains clear production methods at the beginning of the construction and it is a familiar process to the workforce, they go through a rapid learning curve starting from the initial assembly phases.

Both the processes require design details and production schedule details to start with. However, the information required for workers to conduct their work could be displayed closer to the workstation. Unlike in the first process study, it is difficult to allocate specific permanent locations for the second process due to its dynamic layout. In the latter case, the site is a necessary input resource for the final product and the initial case site is not an input resource for the final product. Due to the lack of shelter on the site area, the second process is disturbed by the environmental conditions but the first process is not affected by weather conditions since most of the activities are conducted under a roof. Since the second process study is conducted at the highway construction, some activities are carried out during night time. This is mainly to reduce the impact on the travelling public if the work is carried out during daytime hours. However, the first process does not need to consider these traffic related issues since it operates in a separate, isolated place similar to a manufacturing setup.

5. Discussion and Conclusions

The identified characteristics of two construction processes are synthesised into the factors used to compare the two sectors namely manufacturing and construction. By analysing the above two processes as shown in Table 3, it can be found that the first process is similar to a fabrication type process with product layout arrangements while the second process is similar to an assembly type process with a fixed position layout. Even though most of the literature mentions that the construction industry is distinct from the manufacturing industry, the above study found that the construction process contains a mix of fabrication and assembly type work. Containing the characteristics of both “fabrication” and “assembly" processes, lean manufacturing techniques with or without further modifications depending on the characteristics can be accommodated.

In the illustrated process study one has eliminated the construction peculiarities mainly site production and therefore external uncertainties (example: weather changes) and internal uncertainties (example: layout changes) could be controlled. These kind of processes is mainly found due to the use of a pre-fabrication technology where major parts of the construction work are transferred to a manufacturing set up to simplify the assembly process. Therefore, most of the lean manufacturing techniques could be applied to such construction processes without any modifications since they are similar to a manufacturing environment. For example, due to the fixed position layout nature of work centres facilitates the application of visual management tools for without any changes. Moreover the repetitious nature of pre-cast segment production eliminates one- of- a- kind peculiarity in the construction process and it enhance the possibility of continuous improvement. In these cases, the techniques are very similar to the lean manufacturing techniques. It can be concluded that pre-fabrication is a good strategy to ease the lean implementation in construction.

With reference to the second process study, due to the dynamic nature of the layout particularly in assembly type construction processes, several waste activities can appear due to inefficient material handling and less transparency. Therefore in this type of construction process, the direct transfer of knowledge from manufacturing to construction is not possible under the lean construction initiative. For example, due to the dynamic nature of the site layout the application of visual management tools for material and process flow may not be sustained. Therefore efficient handling and storing of materials, standardisation of material storage and work standardisation are vital to such processes. Moreover, the particular process may not be repeated in the next project, due to the large scale of the project it is feasible to implement continuous improvements. In that case, it could be concluded that the peculiarities of construction act as a barrier for lean implementation. However, the implementation of lean manufacturing techniques could be appropriate and advantageous with relevant customisations to the context.

Through considering the differences and similarities between the two construction processes we have shown that for some particular types of construction, the direct transfer of lean manufacturing techniques to construction has been evidenced. Consequently, the application of the lean construction seems to be easy in this kind of processes because the lean manufacturing techniques can be applied directly. The findings of this study present an opportunity to understand how the construction processes deviate from the manufacturing processes and appropriateness of lean manufacturing with certain modifications.

Table 3: Summary of Comparison of Two Construction Process

Description	Process 1	Process 2
Type of process	Process centric	Project centric
Type of work	Fabrication	Assembly
Mode of production	Labour intensive	Labour intensive
Production volume	Large and repetitive products Unique to the project	Single and unique Repetitive tasks
Production rate	Depend on machines capacity	Depend on information and resource flows
Operations	Well defined; learning from the initial stages	Evolving, learning from the initial stages
Product quality	Conforms to specification High rework	Conforms to specification High rework
Workers	Regular and short term	Irregular and short term
Supplier relationship	Dynamic and complex	Dynamic and complex
Layout	Static	Dynamic
Environment	Mainly indoor, factory setup	Mainly outdoor, site setup

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