LEAN METHODOLOGY TO REDUCE WASTE IN A CONSTRUCTION ENVIRONMENT

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ABSTRACT

Productivity and waste factors are interdependent of each other. Waste is a major problem in the construction industry which amounts to 60% of the construction effort. A study focused on the construction efficiency by the National Institute of Standards and Technology in the UK has documented 25% - 50 % of waste relates to coordinating labour and managing, moving, and installing materials. Therefore the main aim of this study is to find out the possibilities of waste reduction in the construction industry through lean construction applications. The method adopted for this study is a case study research approach where it concludes the results obtained from a major construction project in New Zealand. A pilot case study was carried out to understand the existing practices. The research study substantially followed the process mapping method to identify the level of concern in waste minimisation on a construction site. Outcomes from the studies indicate that one third of non value adding activities are resulting from factors under the control of management. This study concludes that there are more opportunities to eliminate waste and add value to the construction process. Hence by improving management practices through a lean implementation the non value adding time of a construction project can be reduced and thereby productivity can be improved significantly.

***Keywords**: Lean Methodology, Process Map, Value, Waste.*

1. INTRODUCTION

Major construction industry review reports and recent initiatives have identified lack of performance improvement as a key issue in the industry (Robinson *et al*., 2002). Performance improvement opportunities can be addressed by adopting waste identification and waste reduction strategies in parallel to value adding strategies (Alarcón, 1997). Keys *et al*. (2000) mentioned that reasons for waste within the construction industry are widespread and complex. The basic motivation of eliminating wastes is that it is the best way to raise industry's profit margin (Cain, 2004a). The greatest obstacle to wastes removal in general is failure to recognize it. This is prevalent in the construction industry because it is not well understood by construction personnel (Alwi *et al*., 2010). In particular, waste is generally associated with waste of materials in the construction processes while non value adding activities such as inspection, delays, transportation of materials and others are not recognized as waste (Alarcón, 1997). Most of these waste activities are intangible (Senaratne and Wijesiri, 2008) and invisible (Tanskanen *et al*., 1997). Therefore fewer attempts have been made to minimise the wastes in construction (Koskela, 1997). Many analysts (Horman and Kenley, 2005; Mossman, 2009) stated that major portion of time in construction is devoted to wasteful activities. Therefore waste measurement is important in the management of production systems since it is an effective way to assess their performance and allows areas of potential improvement to be pointed out (Formoso *et al*., 2002). For that reason a study is necessary to find wastes

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existing in construction sites and how these wastes can be eliminated. This study considers improvement potential in construction through waste reducing initiatives, such as those supported by lean construction.

2. LITERATURE REVIEW

Productivity and waste factors are interdependent of each other (Koskela, 2004a). Waste identification is significantly weak (Senaratne and Wijesiri, 2008) and waste is a major problem (Polat and Ballard, 2004) which amounts to 60% of the construction effort (Mossman, 2009) in the construction industry. A study focused on the construction efficiency by the National Institute of Standards and Technology in UK as cited in (Gillen and Gittleman, 2010) has documented 25% - 50 % waste in coordinating labour and managing, moving, and installing materials. The construction process remains highly labour- intensive, therefore, any savings in this regard could reduce construction costs significantly.

Suzaki as cited in (Simonsson, 2008) described waste as anything other than the minimum amount of equipment, materials, parts, space, and workers time, which are absolutely essential to add value to a product. Alarcón (1997) explained it as an activity that produces cost directly or indirectly, but does not add value or progress to a product. Womack and Jones (1996) described waste as any human activity which absorbs resources but creates no value. According to Dolcemascolo (2006), waste is referred to anything that creates no value for the owner/client/end-user. Therefore, it is clear that waste is a relative term which can be defined in terms of value. Based on the above definitions, it can be concluded that in lean thinking waste is identified in a wider scope in terms of worker productivity and customer value. However according to Formoso *et al*. (1999) most studies in the industry focus on the waste of materials and neglect other resources involved in the process. Therefore fewer attempts have been made to minimise the activity wastes in construction.

The famous categorisation of wastes was identified by Ohno namely overproduction, waiting, transportation, over processing, inventory, movement and defects (Senaratne and Wijesiri, 2008). Subsequently, researchers suggested more waste types, “make do” by Koskela (2004b), “not taking advantage of people’s thoughts" by Macomber and Howell (2004) and “behavioural waste” by Mossman (2009). An analysis of Serpell *et al*. (1997) shows that work inactivity (slow work) and ineffective work (rework) are the major factors that produce waste of productive time in construction. Cain (2004b) mentioned poor quality of work, lack of constructability, poor material management, material waste, non productive time, suboptimal conditions and lack of safety as waste types. In summary, we can categorised waste types in the construction industry as overproduction, waiting/idling, transportation, over processing, inventory, movement, defects, neglecting people’s thoughts, behaviour (slow work/ ineffective work), material waste and make do.

There is great evidence in the literature concerning non value adding time measurements to explain its significance. But only a few concluded with a complete methodology beyond such detection for elimination of waste activities. Alarcon (1997) developed several tools such as work sampling, resource balance charts and waste diagnostic survey to identify and reduce wastes. Koskela (2000) identified techniques to eliminate waste activities such as eliminating work in progress, reducing batch size, changing plant layout, synchronising the flows, changing activities from sequential order to parallel order and decreasing organisational layers. Koskela and Leikas (1997) have developed a waste minimisation process as identifying waste, measuring waste in terms of value loss, identifying causes for waste and redesigning the process. This study does not explain the tools and techniques used for waste identification and solution generation. Serpell and Alarcón (1998) presented a structured framework for process improvement at the project level. The speciality of this model is the cyclical process of waste minimisation. But the major drawback of the methodology is that it ignores the prioritisation of waste issues. Model developed by Alwi *et al*. (2002) overcomes that limitation by adopting a scoring system for identified waste depending on its frequency and effect on the business performance. This study might have been more useful if the authors had included waste measurement techniques, identification tools and alternative solution generation methods. Furthermore this model was not validated through any case study application. Considering all the strengths and weaknesses of the above approaches this research study focuses on a process improvement methodology. Additionally, this paper illustrates the application of this methodology through a selected case study.

3. Research Methodology

The objective of this paper is to demonstrate how a waste elimination methodology can properly be used in a construction site using a case study based approach. This research is an exploratory study of a construction project, asking the questions "What are the waste activities?", "Why do these wastages exist? (Causes for waste)" and "How these wastages can be eliminated through lean application?". In answering these questions, a case study strategy was chosen due to a number of reasons which is also supported by the methodology suggested by Yin (2003). Firstly, the research questions of this research project are either 'how' or 'why' type questions. Secondly, the researcher had no degree of behavioural control over the subjects. Finally, the research has a contemporary focus and is looking at the present state of the project in finding ways of improvement. Another argument supporting the adoption of case study methodologies, as put forth by Lasa et al. (2008), is many of the breakthrough concepts and theories in operations management, from lean production to manufacturing strategy, have been developed through field case research.

4. Brief Description of the Case Study

The Newmarket Viaduct is a six-lane state highway in Auckland, New Zealand. Due to concerns of its robustness with seismic events and its increasing inability to cater for the peak traffic demand, it was proposed to replace it with a stronger and wider structure which was started in 2009. Other factors were the very low safety barriers which are also insufficient to prevent debris from falling onto the properties beneath and the fact that the existing viaduct is a prohibited for heavyweight vehicles, diverting more heavyweight vehicles through the city streets. To eliminate above issues this new structure was proposed at an estimated cost of NZ$ 150 million. The new structure is to be built causing the minimal effect to the traffic flow as this is a crucial motorway link. This is to be done by first constructing a new viaduct of four southbound lanes to the north-east of the existing structure, then demolishing the existing three southbound lanes. Then in that recovered space the three new northbound lanes will be constructed and finally demolishing the three old northbound lanes. It is a segmented structure built from 468 pre-cast concrete sections constructed off-site and moved into the place with a lifting gantry truss.

5. Research Development

In particular, this study investigates the installation of parapets into motorway deck. The parapet construction process is done after completing the "cantilever erection" and "continuity stressing process". The parapet construction process is done over two shifts. Barrier lifting and concrete pouring are carried out only during the night shifts and all other work is done in both the shifts. The parapet is about 30m long and it covers approximately half of the segment. There are eight to ten workers on average each day/shift and the duration of the whole process is approximately 122 days (18 weeks). The construction process consists of 122 parapets into the south bound deck in the motorway. Therefore even a small saving per parapet would create a big impact on the overall project performance. In order to do that a systematic methodology for waste reduction was followed as shown in Figure 1 and elaborated subsequently.

Phase 1: Process study preparation

In this stage, a quick walkthrough along the entire process was done in order to get a sense of material and process flow. A general template was used for each and every process which includes a series of questions to gather background information of the process flow. It was designed to gain more detailed information about the process with regard to its suppliers, customers and operational steps so that a greater understanding can be obtained. The general information for a section such as working days, working hours, work force and previous production data was collected from task force discussions and secondary data. After the walkthrough visit the process boundaries are determined .The major process is divided into micro-processes as follows and analyzed separately.

1. Pre-cast element installation-Before design inspection
2. Pre-cast element installation-After design inspection
3. Parapet formwork installation
4. Concrete pour and removal of formwork

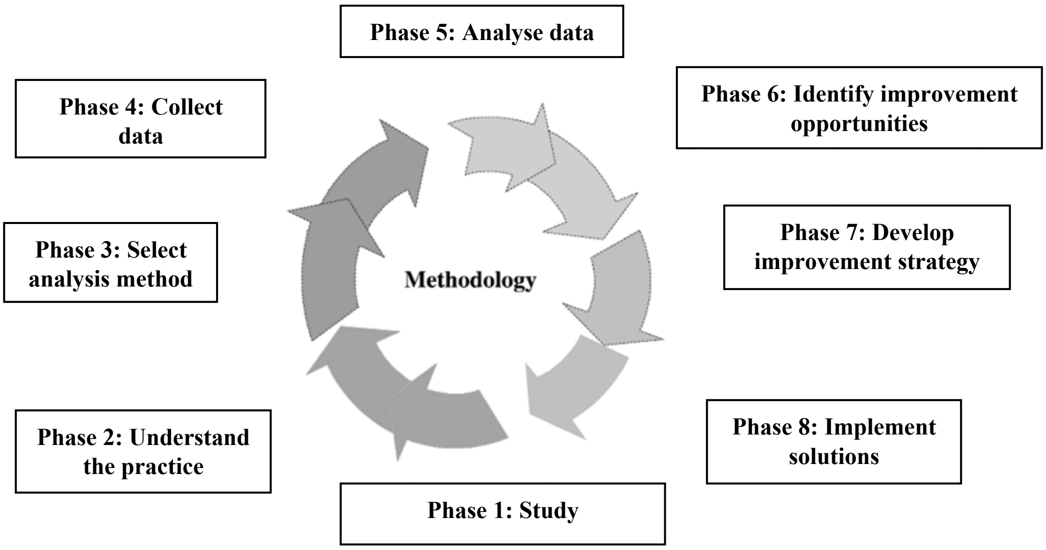

Figure 1: Systematic Methodology for Waste Reduction

Phase 2: Understanding the practice

In this stage all the process steps were observed in order to identify and categorise value adding activities (VAA), non value adding necessary activities (NVANA) and non value adding unnecessary activities (NVAUA). The rule used in the classification of these activities is that the activities which add value to the customer from the customers' point of view are considered as VAA. Furthermore, any activity that is not adding value to the customer but necessary to do, are considered as NVANA and finally the activities that are not belonging to any of the above classifications are categorised as NVAUA. Crew composition and their job description were obtained for the entire working time span at this stage.

Phase 3: Selection of an appropriate analysis method and Phase 4: Collection of data

Depending on the nature of the sub- processes different analysis methods were selected and appropriate data collection sheets were prepared as summarised in following Table1. Most of the time measurements were taken on the spot while workers were engaged in their normal work duties without influencing their normal working pattern. The elapsed time for each task was recorded with the judgment of whether the task was VAA, NVANA or NVAUA. The activity sampling technique was used when several operators were jointly completing a task or an activity. The video records were taken to provide a means for a more detailed analysis of the activities. Whenever a specific waste activity is identified a suitable data collection tool was used in order to quantify the wastages. For example, a movement study was conducted in order to measure the material and equipment transportation frequency, time and distance.

Table 1: Analysis and Data Collection Method

Operation	Analysis method	Data collection tool
Lifting pre-cast barrier and formwork	Operator- Machine	Multiple activity chart
Installing pre cast barrier	Operator- Operator	Time study and activity sampling
Installing the handrail inserts	Process- Operator	Time study
Preparation of formwork	Process- Operator	Time study
Connecting formwork to deck	Operator- Operator	Time study and activity sampling
Design inspection	Process- Operator	Time study
	Information- Process	Information flow map
Pouring of concrete	Operator- Operator	Time study and activity sampling
Removing formwork	Operator- Operator	Time study and activity sampling

Phase 5: Data Analysis

Process Summary Sheet

The summary of the standard cycle time for basic work and added work (ineffective work) were calculated as shown in following Table 2 and Table 3.

Table 2: Basic Work Content Summary

Sub-process	**Workers**	**Cycle time (min)**
Pre- cast element installation -Before designer inspection	4	62
Pre- cast element installation- After designer inspection	2	83
Parapet formwork installation	3-4	95
Concrete pour	2- 4	106
Basic work content (min)	**346**	

Table 3: Added Work Content Summery Sheet

	Added work content	Cycle time (min)
A	Work content added by poor product design or material	
A1	Due to pre -cast segment	20.0
A2	Due to pre -cast barrier	5.25
A3	Due to formwork	60.00
	Sub-total-1	85.25
B	Work content added by inefficient methods of operation	
B1	Poor layout	130.0
B2	Inadequate material handling	17.5
B3	Ineffective method of work	57.5
B4	Inadequate housekeeping	10.0
	Sub-total-2	215.0
C	Work content added mainly from workers	
C1	Accidents	0
C2	Absenteeism	0
C3	Lateness	7.5
C4	Poor workmanship	20.0
	Sub-total-3	27.5
	Total ineffective time	**328**

The basic work content is the time taken to perform work elements if the process was perfectly carried out (mentioned in the method statement). The added work content is the time taken to perform unnecessary work elements. The impact of all the factors mentioned above under headings A to C is shown in Figure 2. If these factors can be eliminated, the operation can be improved.

Figure 2: Basic and Added Work Composition

Field Rating Index

The field rating was used to determine through an activity sampling technique whether a worker is engaged in some work or not. The field rating index calculated for this process amounts to 68% after allocating 5% allowance for personal time.

Activity Categorisation

The general work distribution of the parapet construction process was analysed based on the value perspective as shown in

Table 4. Based on the work composition data, the process efficiency is calculated which amounts to 6 % for this process. This figure can be used as a key performance indicator (KPI) for individual work centres.

$$Process\ Efficiency\ (PE) = \frac{(Value\ Added\ Activities \times 100)}{(Total\ Observation)} \quad \text{(Eq.01)}$$

Table 4: Work Composition-VA/NVA

	VA	NVAN	NVAU	Total observations
Activities	65	436	599	1100
Percentage (%)	5.9%	39.6%	54.5%	100%
Process efficiency				**6%**

Phase 6: Identifying opportunities for improvement

The NVAUA were selected as the first candidate for improving process performance and the main sub categories of NVAUA time were analysed as shown in Figure 3. It was found that 68% of the time contributed by the idling time of workers, unavailability of workers and transportation of materials and equipment. Therefore these three areas were selected as major improvement areas of concern. Furthermore, causes for these activities were analysed with the use of lean tools like cause- effect analysis, 5why analysis, and crew balance chart. From the analysis shown in Figure 3, it is found that worker idling time is mainly caused by poor layout. Because of the materials and tools storage located in a fixed position, workers' travel distance to access equipment keeps increasing as the work points are moving away from the store with the bridge construction progresses. The study reveals that there are at least twelve visits to the stores and average time taken per visit is ten minutes. Meantime it is observed that material or tool unavailability during that time causes idling of other workers. All waste activities are summarised into waste record forms and categorised them into seven wastes according to the lean terminology. Depending on criticality of the activity (bottleneck or not) and easiness of correction the waste activities are prioritised for further improvement.

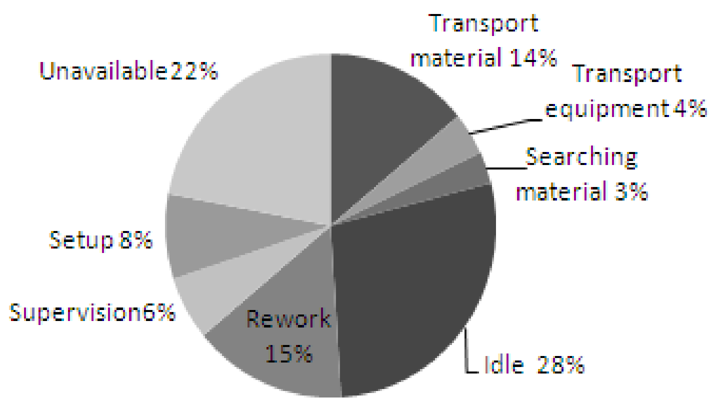

Figure 3: Distribution of Non Value Adding Unnecessary Activities

Phase 7: Development of improvement strategy

In order to develop improvement strategies lean tools such as ECRS (eliminate, combine, rearrange, simplify) and 4W (What, who, why, where) were used. Once suggestions for improvement areas were identified, a focus group discussion was conducted using the "plus- delta" analysis. This provided opportunities for brainstorm among all the members and agrees on feasible solutions for each waste activity. The goal of this kind of discussion is to make everyone, who is affected, aware about the process change. The developed solutions for identified waste activities are shown in

Table 5.All the issues listed here directly or indirectly contribute to the low productivity of this process.

Table 5: Solutions for Identified Waste Activities

#	Issues	Comments / Suggestions
1	Transportation of material and equipment Average visits to stores- 12/day Time taken to visit- 10 min Sometimes other worker waiting for that material	Alternative 1- arrange another temporary storage area in middle of the bridge Alternative 2- Workers advised to bring necessary, routine material in advance by the use of material/equipment check list Alternative 3- Assign material /equipment set up done by foreman Alternative 4- Provide mobile storage trolley to transport necessary equipment and material
2	Transportation of concrete for construction of temporary barrier	Alternative 1- Synchronize the temporary barrier construction area with parapet construction area Alternative 2- Provide efficient transportation method to transfer concrete (other than the wheelbarrow)
3	Seam deconstruction	Find way to modify formwork to eliminate the bottom seam
4	Al plate cutting Time taken - 5 min	Communicate with supplier and place the Al at required dimensions (remove 25-30mm strip in Al plate)
5	Rework due to lack of skills	Create standard procedure to be followed by all workers
6	Rework due to imperfection of pre- cast segment	Implement communication method to communicate defects of segments to upstream processes (Pre-cast segment plant)
7	Waiting time	Prepare backlog work list for workers
8	Searching material and tools	Introduce and practice proper housekeeping system
9	Working environment Non-optimal layout with wasted movements (eg: long way to go to washrooms and rest rooms)	Conduct meetings from time to time with all crew members on the site to understand the ground level problems of crew members Provide welfare facilities closer to workplaces
10	Working practices Late arrival and early departure to/from construction area	Encourage worker involvement in housekeeping issues Introduction of performance-based incentive scheme might improve team work

Phase 8: Implementation of Solutions

Once feasible solutions were identified, process owners need to execute required tasks and complete them by deadlines. After implementation the results are evaluated, conclusions are drawn and further improvements can be launched.

6. DISCUSSION AND CONCLUSION

This study concludes that there is much opportunity to eliminate waste and add value in construction. Analysis of the construction process indicated that construction activities can consist of 55% of NVAUA. One third of these activities are resulting from factors under the control of management. For example frequent rework occurrences happened on the site while fixing errors originally made in the pre- cast fabrication yard. There should be an effective and timely feedback system between field personnel and the pre- cast fabrication yard management in order to discuss any field changes that could lead to rework. If such feedback is considered and necessary modifications are duly incorporated, re-fixing of wrong pieces of material on the site would not be required and the related wastes can be eliminated. Therefore there is an urgent requirement of a waste elimination method which provides a significant competitive advantage for the industry participants.

This study yields a methodology for waste detection and improvement of a construction process. By combining traditional industrial engineering tools (time study, activity sampling, spaghetti diagrams and process maps) and lean techniques (continuous improvement, mistake proofing and standardisation) a waste minimisation model was developed. The major advantage of this model is the simplicity which doesn't require in-depth training. Since the study was conducted by a researcher, in order to sustain such waste minimisation systems there should be an inbuilt mechanism at the construction site itself. There are two approaches for such systems. The first approach is introducing "Waste Walk" where site engineers are asked to walk through the construction site daily at least for one hour to observe waste evidences. This should take place to find opportunities for improvement. Then improvement ideas can be generated at the daily tool box meetings to explore alternative ways of doing work. However during focus group discussions with site engineers and foremen, it is noted that there is little time available to devote for such studies due to a high administrative work load and other routine work. Therefore the second approach can be adopted of establishing a dedicated unit/section which is assigned the task of conducting such improvement projects. A similar approach is used in manufacturing sector which is known as the "work study department/team" which can be incorporated to the construction sector as well. Therefore such team can follow the same methodology which is discussed in this study to gain performance improvements.

The key success factors for such a model implementation are commitment of the process participants at every organisational level and promoting a problem solving culture. In order to establish a waste minimisation culture, waste minimisation can be linked with reward mechanisms by introducing "continuous improvement projects" as a key result area. As previously elaborated, process improvements can be achieved by systematically identifying and eliminating non value adding activities.

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