Waste Processing Framework For Non-Value-Adding Activities Using Lean Construction

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Abstract- **The construction industry has been suffering from low productivity and poor performance compared to other industries. There are a lot of wastes in construction processes, which were left unnoticed. In an attempt to improve its performance, industry practitioners and researchers have looked at the manufacturing industry as a point of reference and a source of innovation. Previous studies have shown that tremendous productivity improvements can be achieved by simply targeting at reducing or eliminating those wastes. Wastes that are mentioned are identified by Taiichi Ohno as the seven wastes that are part of the lean manufacturing. Lean construction results from the application of this new form of production management to construction, which has the goal of meeting the customers' needs while using the least of everything. As a beginner, there is no necessity to start off a project with total implementation of lean management method. It is recommendable to embark with the basic principle, which is identifying and eliminating the wastes in construction process rather than just focusing on the reduction of construction material waste. Thus, a construction process waste management framework is proposed as the early introductory lean guide for those practitioners who wish to start their lean journeys.**

Keywords- Lean Construction; Lean Principle; Construction Process Waste; Non-Value-Adding Activities

I. INTRODUCTION

Poor project performance in Malaysia construction industry is not an uncommon scenario as the construction industry involves numerous parties, lengthy process and different stages. The Malaysian construction industry had carried out several mega projects in the past two decades but most of these projects were not cost, time and quality effective [1, 2]. Productivity levels within the construction industry have consistently lagged behind other sectors of the economy, especially manufacturing industry [3].

The distinction between good and poor project performance was defined by the project team's meeting time, cost and quality objectives [4]. However, in reality, the construction industry has an unfortunate reputation of delivering projects that are unpredictable in terms of delivery on time, within budget and to the pre-specified quality, whilst concurrently attempting to ensure a zero accident rate [5].

There are many factors which will affect the project performance as the process is getting complicated with the combination of various parties' endeavors, many stages of work and carrying a long period till the completion [6]. Construction industry poor performance was due to a gateway waste of not measuring and/or using wrong, inappropriate or insufficient measures for performance appraisal [7]. Furthermore, other main reasons for construction industry low performance were due to the temporary organizational structure of construction team and inefficient construction process.

There are an increasing number of construction companies applying actions to improve their projects' performance by reducing all kinds of waste during the construction process [8]. As most construction executives know, the industry can be susceptible to wasteful spending, delays and project inefficiency. Many criticisms have been directed to the construction industry, generally on poor workmanship. Not only the final product is subjected to criticisms but also the processes, the people, the materials,etc. are under tremendous pressure for better quality in construction [9]. Since construction has a major and direct influence on many other industries by means of both purchasing the inputs from other industries and providing the products to almost all other industries; eliminating or reducing waste could yield great cost savings to society [10]. Many project management approaches have emerged to improve performance such as value-engineering, partnering, design-build, etc.

In the past two decades, great performance improvements have been achieved in the manufacturing industry in the means of increasing productivity. A major factor in this achievement is the implementation of the new production philosophy, often known as 'lean production', which provides continuous improvement in the production process by removing various types of waste. In the 1940s, lean construction methodology evolved as Lauri Koskela made the transition from the development of new production management from manufacturing to construction industry.

The potential impact of lean production philosophy on construction effectiveness is well documented. Lean techniques are applicable not only in manufacturing, but also in service-oriented industry and service environment. Every system contains waste. Whether you are producing a product, processing a material, or providing a service, there are elements which are considered 'waste'. The techniques for analyzing systems, identifying and reducing waste and focusing on the customer are applicable in any system, and in any industry

Essentially, lean construction aims to reduce the waste caused by unpredictable workflow, where waste is defined in Ohno seven categories: defects, overproduction, waiting, transporting, movement, inappropriate processing and inventory. Implementation of lean principles to the Malaysian construction industry does improved operational performance. Besides that, their study also reveals that there is a correlation between lean principles and operational performance [11].

Lean concept has been introduced into the construction industry with varying levels of success for different projects. However, currently there are no practical guidelines for the application of the lean concept in the Malaysian construction industry. Numerous researches and case studies using lean construction theories and principles have been carried out to formulate models and frameworks by the means to evaluate the performance and productivity in various aspects of the construction industry. However, both the flow improvement and waste reduction/elimination concepts remained the major areas of study among the researchers as they viewed them as the value enhancement to the whole construction production processes.

II. LEAN PRINCIPLES

The concept of lean production was developed based on the original Toyota Production System, which aimed to produce what the customer wanted at the time when they needed it with minimized waste [12]. Lean is about designing and operating the right process and having it right the first time. Essential to this is the elimination of waste – activities and processes that absorb resources but create no value. The primary focus is on moving closer and closer to providing a product that customers really want, by understanding the process, identifying the waste within it, and eliminating it step by step. In short, lean is focused more on value instead of cost, which it seeks the removal of non-value adding activities whilst improving those add value.

Lean adopters [13, 14] have refined and expanded the lean concept for construction and have outlined the basic lean thinking principles. The followings are the summarized five topmost principles of lean thinking:

Value – Precisely specify value from the perspective of the ultimate customer;

Value Stream – Clearly identify the process that delivers what the customer values (the value stream) and eliminate all non value-adding steps;

Flow – make the product flow or organize the production in a continuous flow;

Customer Pull –customer pull means do not make anything until it is needed, then make it quickly;

Perfection – manage towards perfection by continuous improvement and deliver on order a product meeting customer requirements with nothing in inventory.

III. LEAN CONSTRUCTION

The emerging concept of lean construction is concerned with the application of lean thinking to the construction industry. In the past ten years, there have been growing interests among the international academicians in lean construction. Such researchers seek to investigate the extent to which the Japanese model of lean production can be applied to the construction industry. From the study of lean construction background, lean construction is resulted from the adaptation and implementation of the Japanese manufacturing principles within the construction practices, which lean construction assumes construction to be like a production process – a special one [15]. The concept of lean production is introduced to the construction industry following its success in the manufacturing industry. Consequently, the terminology of lean construction is formed [16].

Lean construction is a concept which is still new to many construction industries in the world. Essential features of lean construction include a clear set of objectives for the delivery process, aiming at maximizing performance for the customer at the project level, concurrent design of product and process, and the application of production control throughout the life of the product from design to delivery.

Lean construction aims to maximize the customer's satisfaction through concurrent design of both the constructed facilities and the construction process that delivers these facilities, and through the consequent control of each stage in the construction process [16]. Furthermore, lean construction is the continuous process of eliminating waste, focusing on the entire value stream, and pursuing perfection in the execution of a constructed project. Lean also focuses on how one activity affects the next [17]. In a nutshell, lean construction features include many fundamental aspects of a lean philosophy. It is a philosophy that requires a continuous improvement effort that is focused on a value stream defined in terms of the needs of the customer. Improvement is, in part, accomplished by eliminating waste in the process.

Having applied the lean production principles in the construction industry, many positive results have been achieved worldwide in many areas of the construction industry, such as enhanced value, reduced costs, and increased customer satisfaction. For example, Ballard (1994) [13] achieved a 30% productivity increase by matching labors with the workflow of backlog and by shielding direct production from upstream variation and uncertainty. Moreover, lean principles were also deployed to improve the productivity in installing metal wall frames and in building ganged forms for digester tanks.

There are three features to distinguish the lean construction practice from a conventional construction management, namely: a) lean construction focuses on reducing wastes that may exist in any format in the construction process, such as inspection, transportation, waiting, and motion; b) lean construction aims to reduce variability and irregularity so that material and information can flow in the system without interruptions; and c) construction material is expected to be on site only when it is needed.

Lean construction is about managing and improving the construction processes to deliver profitably what the customer needs. Because it is a philosophy, lean construction can be pursued through a few different approaches. However, the lean principles can only be applied fully and effectively in construction by focusing on the improvement of the whole process. This means all parties have to be committed, involved, and worked to overcome obstacles that may arise from the traditional contractual arrangements.

Many project management approaches have emerged to improve performance such as value-engineering, partnering, design-build, etc. Lean combines concepts from these approaches with principles that are drawn to form a production management that creates a new way to manage projects [17]. In addition, by focusing on the workflow, lean construction is able to unplug the clogs in the project stream. Thus, construction processes like planning, engineering, designing, constructing, producing and delivering of materials are all better coordinated to deliver maximum value for the project owner.

IV. WASTE IN CONSTRUCTION

Lean is about designing and operating the right process and having the right first time. Essential to this is the elimination of waste – activities and processes that absorb resources but create no value. While working at Toyota, Taiichi Ohno identified two kinds of activities: value-adding activities and non value-adding activities. Activities that do not add value are simply a waste and should be eliminated [18]. Hines and Rich (1997) [19] further break down the production activities into three categories: value adding, non-value adding and non-value adding but required. Hines and Rich (1997) [19] defined these activities as follow: a) non-value adding activities are pure wastes and involve unnecessary actions which should be eliminated completely; b) necessary but non-value adding activities are operations that may be wasteful but are necessary under the current operating procedures. In order to eliminate them, partial changes are needed to improve the standard operating procedures; and c) value-adding activities involve the conversion or processing of raw materials or semi-finished products to the final product.

Waste in the construction industry has been the subject of several research projects around the world in recent years. However, most studies tend to focus on the waste of materials, which is only one of the resources involved in the construction process. In spite of this, waste in construction is not only focused on the quantity of waste materials on-site, but also related to several activities such as overproduction, waiting time, inventories, defects, movement, processing, transportation and substitution.

Serpell and Alarcon (1998) [8] have defined waste as any construction process/activities that incur cost but do not directly or indirectly add value to the construction projects. Meanwhile, Tersine (2004) [20] defined waste as undesirable, time, money and/or resources consuming, and non value-adding to the product. Waste also includes anything that does not add value from the perspective of the customers. Generally, the concept of waste is directly associated with the use of resources that do not add value to the final product. This is very much different from the construction practitioners' view of waste where waste is referred to material waste and there are no significant attempts to separate the construction activities into value-adding or non value-adding activities.

In the context of lean production, seven common types of wastes have been identified [18]: overproduction, producing defective products, inventories, motion with no value to the product, waiting, extra process, and transportation. Waste in construction and manufacturing includes delay times, quality costs, excess inventory, lack of safety, rework, unnecessary transportation trips, long distances, setup, moving, handling, inspecting, expediting, prioritizing, queue time, improper choice or management methods or requirement and poor constructability [20].

Waste elimination will be one of the most effective ways to increase the profitability of any business. Profit can be increased while costs can be reduced simultaneously with a positive compounding effect on the performance by eliminating unwanted waste [20]. To eliminate waste, it is important to understand exactly what waste is and where it exists. While construction production significantly differs with factories production, the typical wastes found in production environments are quite similar. For each waste, there is a strategy to reduce or eliminate its effect on a company, thereby improving overall performance and quality. Constructions processes can be divided into either add value or waste to the production of goods or services. The primary step in the lean thinking process is the identification of which steps in the process add value and which do not. Once the classification of these two categories is done, it is then possible to implement the action by improving the former and eliminating the latter.

The followings are the seven deadly wastes originated in Japan, where waste is known as "muda". "The seven wastes" is a tool to further categorize "muda" and has been originally developed by Toyota's Chief Engineer Taiichi Ohno as the core of the Toyota Production System, also known as Lean Manufacturing [18]. The first five wastes refer to the flow of material; meanwhile the two last ones refer to the work of men: overproduction, defect, material movement, processing, inventory, waiting, and motion [18].

Waste of Overproduction (Unnecessary work) related to the production of a quantity greater than required or making it earlier than necessary. This often caused by quality problems, a company knows that it will lose a number of units along the production process so produces extra to make sure that the customer order is satisfied. An example of this kind of waste is the overproduction of mortar that cannot be used on time. This may cause waste of materials, man-hours or equipment usage. Overproduction issue can be tackled by using mistake proofing methods (Pokayoke) and by understanding the machine process capabilities of the production equipment.

Waste of Rejects (Defect/Unsatisfactory work) occurs when the final or intermediate product does not fit the quality specifications. This is the simplest form of waste that construction industry produces, where components or products made do not meet the specification [21]. Defects may lead to rework or the incorporation of unnecessary materials to the building (indirect waste); for example, excessive thickness of plastering. Defective product costs the same as it does to produce a prize product. Besides the obvious losses, there are many other costs associated with rejects that make this a particularly important category of waste to eliminate. Defects can occur through a wide range of reasons such as poor design and specification, lack of planning and control, poor qualification of the team work, lack of integration between design and production, etc. New procedures to handle defects have to be implemented and verified. New waste management processes must be added in an effort to reclaim some value for the otherwise scrap product. He further states that it is not to be surprised to find out that 99% of all activities carried out are non-value adding if there is documentation of all the non-value added activities carried out in a typical manufacturing company.

Waste in Transportation (Material movement/Conveyance) is concerned with the internal movement of materials on site where poor workplace layout or a lack of process flow creates many stops and starts in a production cycle. Construction site layouts can often be the fundamental cause of excess transportation. Excessive handling, the use of inadequate equipment or bad conditions of pathways can also cause this kind of waste. Every movement should have a purpose since items being moved incur a cost [21]. Interruptions to work flow can substantially add to your transportation costs. This defects are: waste of man hours, waste of energy, waste of space on site, and the possibility of material waste during transportation. Appropriate re-laying out the machines within a factory from a functional to a cellular layout has been proven that help not just reduce transportation waste but also reduce Work in Progress (WIP) and waiting. This also can apply to the construction industry where proper site layout plan would able to reduce the excessive material movement.

Waste of Processing (Overprocessing) is related to the nature of the processing (conversion) activity, in which the material movement waste that kinks in construction process flows and does not add value to the product or service from the customers' point of views. This is always caused by the quality problem of the work done. The most obvious example of overprocessing is rework relating to surface finishes. Techniques such as 5 whys, Statistical Process Control (SPC) and mistake proofing (Pokayoke) are available to help identify and eliminate causes of quality defects. This waste can also be avoided by changing the construction technology.

Waste of Inventory is related to excessive or unnecessary inventories which lead to material waste (by deterioration, losses due to inadequate stock conditions on site, robbery, vandalism), and monetary losses due to the capital that is tied up. Excess inventory is regarded as waste since there is no value added by stocking inventory. In addition, inventory takes up space, ties down capital, incurs storage (and security and insurance) costs and raises the risk of damage during storage as well as the risk of obsolescence [3]. Companies always order more than required to fulfill an order. He further stressed that this might be due to the quality problems along the production process or the often mistaken belief that it saves money by ordering larger quantities. It might also be a result of lack of resource planning or uncertainty on the estimation of quantities.

Waste of Waiting (Delays) is related to the idle time caused by lack of synchronisation and leveling of material flows, and pace of work by different groups or equipments. Whenever goods are not moving or being processed, the waste of waiting occurs. Idle time maybe created during the waiting for raw materials, quality assurance results, engineering, maintenance, scheduling of equipment, etc. in which all these are forms of waste. Waiting waste can be dramatically reduced by linking up the processes together to one which feeds directly into the next.

Waste if Movement (Motion) is related to ergonomics and is seen in all instances of bending, stretching, walking, lifting, and reaching. Motion of this waste is concerned with the unnecessary or inefficient movements made by workers during their jobs, which might be caused by inadequate equipment, ineffective work methods, or poor arrangement of the working place. Traveling too far within a work site to accomplish assigned tasks is a waste of time and effort and also creates increased opportunities for accidents, injuries, and their associated costs. Lean Thinking looks to eliminate poor housekeeping, lack of organization, inefficient layout of machinery, and inconsistent or ineffective work methods. Thus, with a proper layout of a work area, the unnecessary motion of employees can be minimized, creating an opportunity for saving on costs. Jobs with excessive motions should be analyzed and redesigned for improvement with the involvement of plant personnel.

Subsequent to the introduction of Ohno's seven wastes, numerous researchers have introduced the eighth waste category. Making-do is one of the wastes in construction process. Making-do is referred to a situation where a task is started without all its standard inputs or the execution of a task is continued although the availability of at least one standard input has ceased. In making-do waste, the inputs are negative, yet the processing is started before the input has arrived.

Womack and Jones (2003) [22] have also added the eighth waste, which is the design of goods and services that do not meet the end users' needs. In addition, Burton and Boeder (2003) [23] have added waste of human potential as the eighth category of waste. Human potential waste is related to the failure in fully utilizing the skills of people. Burton and Boeder (2003) [23] believe that once people are trained to identify the waste, they are able to eliminate it. Other wastes include burglary, vandalism, inclement weather, accidents, etc.

However, this research will only study the Ohno's seven wastes as other types of waste can almost always be included in one of the seven types, or they are a cause of the waste rather than a waste itself. For example "waste in human potential", this is more a cause of other types of waste such as processing waste or the waste of defects that result from the lacking skill of the people. Besides that, the seven wastes introduced by Taiichi Ohno are links between the root causes (human behaviors) and the loss of profit.

V. MANAGING CONSTRUCTION PROCESS WASTE USING LEAN TECHNIQUES

Toyota is perhaps best known for its highly effective production system, dubbed "lean manufacturing" by an MIT study in the 1980's. The lean techniques from manufacturing industry are successfully used in other industries throughout the world and are currently used in general construction projects throughout the United States [24]. The most efficient method of production (lean techniques) was not born from a sudden brainstorming; rather, it evolved into its present state over decades of sustained, high level of continuous improvement activity [25].

Lean techniques are a broad term that encompasses a variety of tools, strategies and technologies. Lean techniques provide continuous assistance and support at all stages of the project [24]. For example, during construction stage, lean techniques enhance collaboration between project parties and foster a culture of continuous improvement. In addition, projects that utilize lean techniques can be completed in less time and with fewer costs than typically required.

However direct application of lean techniques from manufacturing industry (like kanban, poka yoke concepts, etc.) would not be very successful because the environments of high volume manufacturing and constructions are quite different [25]. Hence, careful consideration of the tools and why they work, then adapting the appropriate tools to construction environments may result in significant breakthrough in operational efficiency [25]. Thus, it is important to carefully select the lean techniques/tools to be inserted into the proposed construction waste management framework.

VI. PROPOSED CONSTRUCTION PROCESS WASTE MANAGEMENT FRAMEWORK

The major reason behind schedule delays and cost overruns in design and construction projects were caused by construction process waste (non-value-adding activities or necessary-non-value-adding activities) [26]. Thus, to successfully execute design and construction projects, one should pay attention to minimize the amount of wasteful activities (non-value-adding activities or necessary-non-value-adding activities) while maximize the amount of value-adding activities. However, literature review shows that construction industry is lacking of a systematic construction process waste management system that can guide the implementation of lean construction. Waste must be removed from the process, which if not removed, it will thrives and multiples, and eventually crowding out operational effectiveness since the waste tends to proliferate and generate ancillary or secondary support wastes [20].

Activities should be first identified and quantified in order to prepare an effective management plan for minimizing wasteful activities [26]. However, systematic identification and quantification of waste is often one of the most challenging aspects in lean construction advocates. The identification of the incidence of non-value-adding activities during the process enables the construction managers to easily identify the best solutions and ways to apply any new technique for reducing the amount of waste, leading to increased project productivity. Construction management often fails to identify or address waste in the construction waste due to its poor recognition of waste and the absence of appropriate tools for measuring waste or value. Thus, a construction process waste management framework (Refer to Figure 1) was proposed to the construction practitioners as an introductory lean implementation guideline.

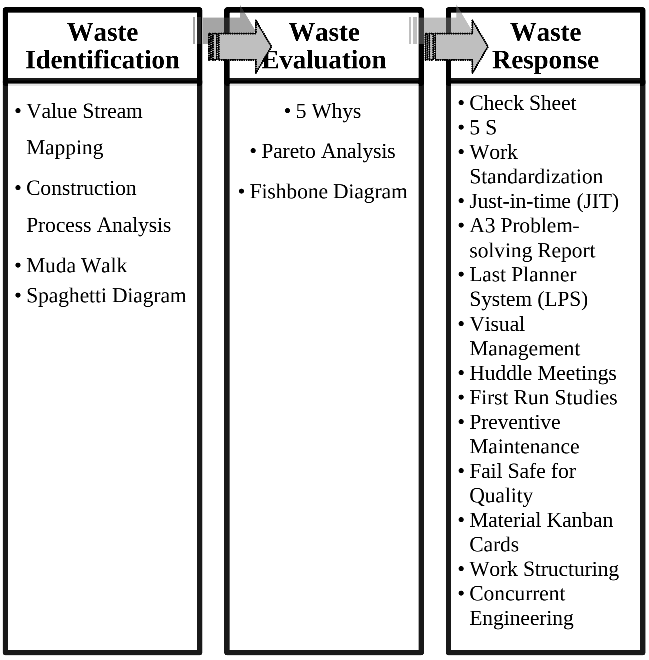

Figure 1 Proposed construction process waste management framework

Waste reduction can only take place after wastes have been identified and waste reduction efforts also typically focus on the value stream processes, which its goal is to eliminate the waste and maximize value to the customer base by striving for elevated or ultimate standards of performance [20, 23]. Thus, as pointed out above, the proposed construction process management framework was divided into two categories, namely, waste diagnostic and waste response. The first step for waste management system is diagnostic the problem. Waste diagnostic can be separated to two areas, waste identification and waste evaluation. When a problem arises, waste identification can be used to identify the waste occurs in the particular problem. Factors that cause construction process variability must be identified and constantly minimized, which at the same time, the process must be brought to a higher level of productive performance. He further explained that any key event that can significantly interfere with the process must be identified, and action taken pro-actively to minimize their impact. The premise is that a competitive construction work process requires work activity that adds maximum possible value to resources – by converting them efficiently, effectively and safely into a completed project that satisfies the customer.

After waste had been identified, construction practitioners need to evaluate the problem to find out the root causes of the problem. The danger of not identifying the root cause is that a superficial symptom of the underlying problem may be viewed as the core problem to be solved.

After that, construction practitioners can proceed to the waste response. By identifying the root causes, the construction practitioners will be able to choose the best measures to control the waste. However, it is neither possible nor necessary for the construction practitioners to implement all the lean techniques suggested in the framework. In each of the waste category, the author suggests few lean techniques that are appropriate and easy to use. However, it has to bear in mind that using lean practices alone is not enough to minimize waste. It must be combined with other lean principles and lean tools to truly achieve improvement in the performance. In addition, the construction practitioners need to understand the underlying concept of each lean technique in order to obtain the best result.

VII. CONCLUSION

This paper intends to expose and recommend the potential application of lean principles to enhance the Malaysian construction performance. The successfulness of lean principles in enhancing performance was due to its concept of optimizing and eliminating wastes, rather than minimizing them. Wastes that are mentioned in this paper are identified by Taiichi Ohno as the seven deadly wastes in production: overproduction, defect, material movement, processing, inventory, waiting, and motion. Lean construction includes many fundamental aspects of a lean philosophy. It is a philosophy that requires a continuous improvement effort that is focused on a value stream defined in terms of the needs of the customer. Improvement is, in part, accomplished by eliminating waste in the process. Toyota uses few decades to fully implement the lean principle to their manufacturing industry. They start the application in a few stages. Thus, there is a dire need for the Malaysian construction industry to take their first step in implementing lean construction.

REFERENCES

[1] H. Abdul-Rahman, & M.A. Berawi, “Power quality system: A new system for quality management in globalization towards innovation and competitive advantages”, Quality Assurance, vol. 9(1), pp. 5-30, 2002.

[2] J.B. Hussein, “Emerging challenges of project management in Malaysia”, Master Builders, vol. 4, pp. 82-85, 2003.

[3] S.P. Low, & J.C. Choong, “A study of readiness of precasters for just-in-time construction”, Work Study, vol. 50(4), pp. 131-140, 2001.

[4] D. Baccarini, "The logical framework method for defining project success", Project Management Journal , vol. 30 (4), pp. 25-32, 1999.

[5] L.J. Smith, I. Jones, & I. Vickridge, Increasing construction productivity through total loss control, COBRA, RICS Research Foundation, 1999.

[6] T.C. Choo, “Construction client attributes in affecting the project performance in local construction industry”, Published Master thesis, Johor, Malaysia: University of Technology Malaysia, 2005.

[7] S.M. Leong, & P. Tilley, “A lean strategy to performance measurement: Reducing waste by measuring “NEXT” customer needs”, Proceedings of the 16th Anual Conference of the International Group for Lean Construction (IGLC-16), Manchester, pp. 757-768, 2008.

[8] A. Serpell, & L.F. Alarcon, “Construction process improvement methodology for construction projects”, International Journal of Project Management , vol. 16 (4), pp. 215-221, 1998.

[9] W.Y. Wan-Mahmood, A.H. Mohammed, M.S. Misnan, Z. Mohd-Yusof, & A. Bakri, “Development of quality culture in the construction industry”, Proceedings of the International Conference on Construction Industry (ICCI). Padang, Indonesia, 2006.

[10] D. Arditi, G.T. Akan, & S. Gurdamar, “Reasons for delay in public projects in Turkey”, Journal of Construction Management and Economics , vol. 3 (2), pp. 171-181, 1985.

[11] G. Imtiaz, & A.R. Ibrahim, “Lean production system to enhance performance in operations: An empirical study of Malaysian construction industry”, Proceedings of the 15th Anual Conference of the International Group for Lean Construction (IGLC-15), Michigan, USA, pp. 147-156, 2007.

[12] J.P. Womack, The machine that change the world: How Japan’s secret weapon in the global auto wars will revolutionize western industry, New York: Harper Perennial, 1991.

[13] G. Ballard, The last planner, Monterey, California: Lean Construction Institute, 1994.

[14] J. P. Womack, & D. Jones, Lean thinking, New York: Simon and Schuster Ltd., 1996.

[15] S. Bertelsen, “Lean construction: Where are we and how to proceed”, Lean Construction Journal , vol. 1, pp. 46-49, 2004.

[16] X.M. Mao, & X.Q. Zhang, “Construction process reengineering by integrating lean principles and computer simulation techniques”, Journal of Construction Engineering and Management , vol. 134 (5), pp. 371-381, 2008.

[17] L. Pinch, “Lean construction: Eliminating the waste”, Construction Executive, vol. 11, pp. 34-37, 2005.

[18] T. Ohno, Toyota production system: Beyond large-scale production, Cambridge, MA: Productivity Press, 1988.

[19] P. Hines, & N. Rich, “The seven value stream mapping tools”, International Journal of Operations and Production Management, vol. 17 (1), pp. 46-64, 1997.

[20] R.J. Tersine, “The primary drivers for continuous improvement: The reduction of the triad of waste”, Journal of Managerial Issues , vol. 16 (1), pp. 15-29, 2004.

[21] I. Henderson, 7Ws elimination of waste – Management training article, PHS Management Training, London, 2004.

[22] J.P. Womack, & D. Jones, Lean thinking: Banish waste and create wealth in your corporation, 2nd ed., United Kingdom: Simon and Schuster Ltd., 2003.

[23] T.T. Burton, & S.M. Boeder, The lean extended enterprise: Moving beyond the four walls to value stream excellence. Boca Raton, Fla: J. Ross Publications, 2003.

[24] A.S. Hanna, M. Wodalski, & G. Whited, “Applying lean techniques in delivery of transportation infrastructure projects”, Proceedings of the 18th Annual Conference of the International Conference of Lean Construction (IGLC-18), Haifa, Israel, pp. 609-619, 2010.

[25] D.K. Sobek, & C. Jimmerson, “A3 Reports: Tool for process improvements”, Proceedings of the 2004 Industrial Engineering Research Conference, Houston, Texas, 2004.

[26] S.W. Han, S.H. Lee, M.G. Fard, & F. Pena-Mora, “Modeling and representation of non-value adding activities due to errors and changes in design and construction projects”, Proceedings of the 39th conference on Winter simulation, Piscataway, NJ, USA: IEEE Press, pp. 2082-2089, 2007.