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Analysis of lean construction practices at Abu Dhabi construction industry

Raid Al-Aomar [1]

Abstract

Question: What are the current construction wastes in Abu Dhabi (AD) construction industry and what are their main causes? What are their impacts on construction projects cost, quality, and speed? Is the industry familiar with lean construction concept and methods? What are the currently used lean techniques in AD construction industry? Does the industry need to adopt lean construction techniques?

Purpose: The purpose of this paper is to analyze the current lean construction practices amongst Abu Dhabi construction companies and to develop a practical framework for adopting lean construction techniques and measuring lean performance.

Research Method: An industry survey is used to collect information and data from local construction companies in Abu Dhabi area. Collected data and information are organized, analyzed, and used to answer research questions.

Findings: this study identified and categorized 27 construction wastes in AD construction industry, specified 18 key causes of these wastes, and estimated their extent and impact on project cost, quality, and speed. The study also analyzed the extent and impacts of 23 lean techniques in AD construction industry. The study found that only 32% of surveyed companies are currently familiar with and/or already using lean construction techniques and concluded that the industry is in high need for a practical framework, such as the LPDS of LCI, for adopting lean techniques.

Limitations: The credibility of the research results and findings is dependent on the accuracy and reliability of collected data from construction companies.

Implications: This research identified current construction wastes and their causes, analyzed the current uses of lean techniques, and developed a practical framework for effectively adopting lean techniques in AD construction industry.

Value for industry: this study will increase the awareness of lean construction practices amongst AD construction companies. It will also help the industry understand the impacts and causes of current construction wastes and provide the industry with a practical framework for adopting lean techniques. This study also may serve as another model for other countries that are starting to implement lean construction.

Keywords: lean construction, construction management, lean techniques, lean Six Sigma.

[1] Director of Master of Engineering Management, College of Engineering & Computer Science, Abu Dhabi University. +971 2 501 5763 raid.alaomar@adu.ac.ae Abu Dhabi, UAE

Introduction

To survive in today's competitive market, it has become imperative for construction companies to improve the quality of their work, increase work effectiveness, reduce waste and costs, and increase profit. This is particularly more pressing under the current financial crisis and economic recession. Consequently, the combination of project speed, high quality, and low cost has become a key engineering and managerial effort in facing the growing competition in the construction business. Most construction managers agree that the industry is susceptible to multiple wastes, overruns, delays, errors, and inefficiency. As a result, construction projects seldom finish on time, within budget, and at a quality level accepted by the customer (FMI/CMAA, 2005). Thus, several project management approaches have emerged to improve construction performance including lean construction, lean project management, and value-engineering.

Lean construction, as defined by the Lean Construction Institute (LCI), is a production management-based project delivery system emphasizing the reliable and speedy delivery of value (LCI, 2012). Lean construction adopts the concepts of lean thinking and lean principles drawn from production management (originally developed at Toyota production system in the 1950s) to create a new way to manage construction projects (Womack and Jones, 2003). The goal is to build the project while maximizing value, minimizing waste, and pursuing perfection. In the context of both construction and production, waste is primarily defined in seven categories: defects (errors), delays, over-processing, over-production, excess inventory, unnecessary transport and conveyance of materials and equipment, and unnecessary motions and movement of people (Ohno, 1988).

Although this concept is still new to many construction industries, previous studies showed that cost reduction using lean techniques can be substantial compared to the traditional project management approach (Koskela,1992, Ballard and Reiser, 2004). According to Ballard and Howell (2003), countries such as UK, Australia, USA and Brazil have gained significant benefits by adoption of Lean Construction concepts. Examples of lean construction studies and applications can be found in Thomassen *et al.* (2003), Höök and Stehn (2008), and Senaratne and Wijesiri (2008). Details of lean project management based on the approach of the Project Management Institute (PMI) can be found in Leach (2006). Further details of the lean construction approach can be found in Alarcon (1997), Diekmann *et al.* (2004), Salem *et al.* (2006), Koskela (1993), and Conte and Gransberg (2001).

The lean project management is focused on implementing the guidelines of Lean Project Delivery System (LPDS) ™ developed by the LCI (Ballard, 2008). According to LCI, the main modules of project delivery system include, but not limited to, lean design, lean supply, lean assembly, lean production, and lean delivery system. As shown in Figure 1, these modules interact at the construction site to form a lean construction environment and platform. The lean definition provides a value-based scope of work (SOW) and effective Master Production Schedule (MPS) and cost estimations. At the construction site, the MPS is executed as small work-chunks pulled as needed from a look-ahead plan.

The lean design phase transforms the conceptual design of the project definition into a lean product and process design that is consistent with project scope and design criteria. The lean supply module consists of detailed engineering of the product design, the fabrication or purchasing of components and materials, and the logistics of deliveries and inventories. Lean assembly ranges from the delivery of tools, materials, and components to commissioning and project delivery to the client. Lean construction keeps an eye on the Value Added (VA) element of the construction process (conversion) as well as the None-Value-Added (NVA) elements (flow, delay, and errors). A lean delivery emphasizes a cost-effective and on-time handover with no delays or rejects or quality issues.

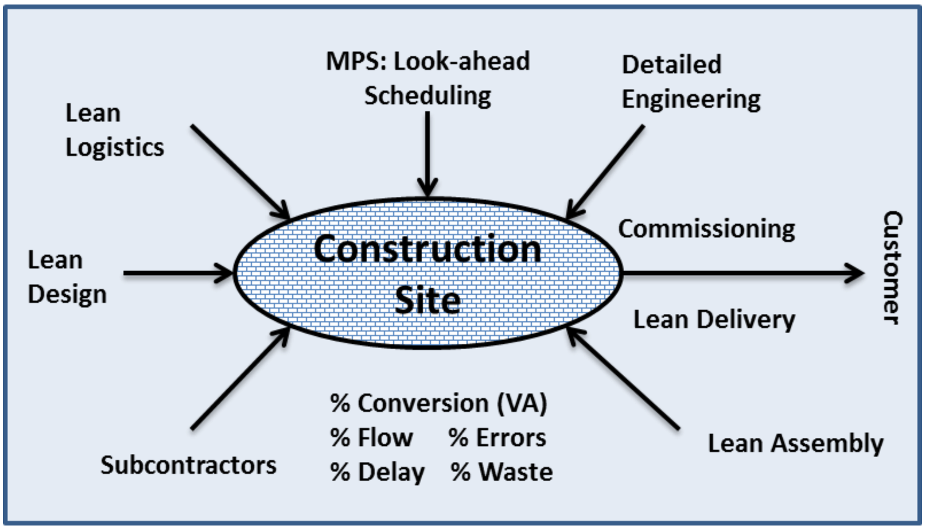

Figure 1. Lean Construction Process

Six Sigma concept and method can be relevant to all industries including construction as it seeks to improve quality and reduce variability and errors (Pheng and Hui, 2004). Similar to lean manufacturing and lean services, Six Sigma can play a complementary role to lean construction. Improving quality in the construction context contributes to the lean focus on speed delivery and cost effectiveness by reducing reruns, delays, and re-works in the completed tasks and ensuring the quality of delivered materials to the work site (Aoieong *et al.*, 2002). Similarly, lean construction contributes to the quality focus of Six Sigma by reducing process variability, streamlining the work flow, and increasing the transparency of the work site. A combined lean and Six Sigma application to construction projects can be used similar to that of manufacturing (George, 2002). The objective is to improve the construction process through lean techniques (less waste and cost) and Six Sigma DMAIC process (less variability and high quality).

From a research perspective, reviewed literature showed that lean construction efforts have been focused on proposing and applying lean methods and tools in the various sectors of construction industry. This can be, for example, seen from the body of knowledge contributed by the community of the International Group for Lean Construction (IGLC, 2012). However, few researchers have actually addressed how to evaluate the impact of lean practices on the quality, speed, and cost of the construction project. There have been limited published studies on incorporating Six Sigma in the application of lean construction practices. Examples of research that focused on incorporating Six Sigma in lean construction can be found in Abdelhamid (2003), Abdelhamid and Thanveer (2005), Han *et al*. (2008), and Oguz *et al*. (2012).

Thus, this paper aims to investigate and categorize the different types of wastes in the construction industry and to develop a lean construction framework with Six Sigma rating that can be used to quantify and assess the quality, cost, and schedule implication of lean construction practices. Empirical results obtained through a locally funded research project are used to analyze lean construction practices in Abu Dhabi (AD) construction industry, provide lean construction performance measures, and clarify the practical aspect of the proposed framework.

Lean construction in Abu Dhabi

This study aims at analyzing lean construction practices in Abu Dhabi (AD) construction industry. It is worth mentioning that the construction process in AD has a different context from that in the UK and the US which may reflect on the types of wastes and the applicability of lean construction techniques. The comparison of different industry contexts is, however, not within the scope of this study. The study adopted an industry research for collecting empirical data from construction companies mainly involved in residential and commercial building projects. Construction managers of 60 companies in AD area were approached to assess lean construction practices in their construction projects by filling a survey. However, only 28 filled surveyed were obtained and qualified for being used in the analysis. Although it was made clear to construction managers that the study is confidential and the results will not be disclosed, the majority of construction managers preferred not participate in the study. This is mainly due two reasons; lack of awareness and interest in the concept and value of lean construction in addition to their sensitivity to disclose information regarding the kind of wastes they encounter in their projects. Surveyed companies include small, medium, and large construction companies. The distributed survey is set to identify the types of waste currently exist in the industry, investigate the causes and impacts of these wastes, check the familiarity of the industry with lean techniques, measure the extent and impact of currently used lean techniques, and to check for the obstacles of adopting lean construction techniques. The results obtained from the survey are presented as follows:

- **Waste Analysis**:

The survey identified 27 wastes that currently exist in AD construction industry. Construction managers were asked to check if these wastes exist in their construction projects. A Pareto diagram of these 27 wastes is shown in Figure 2.

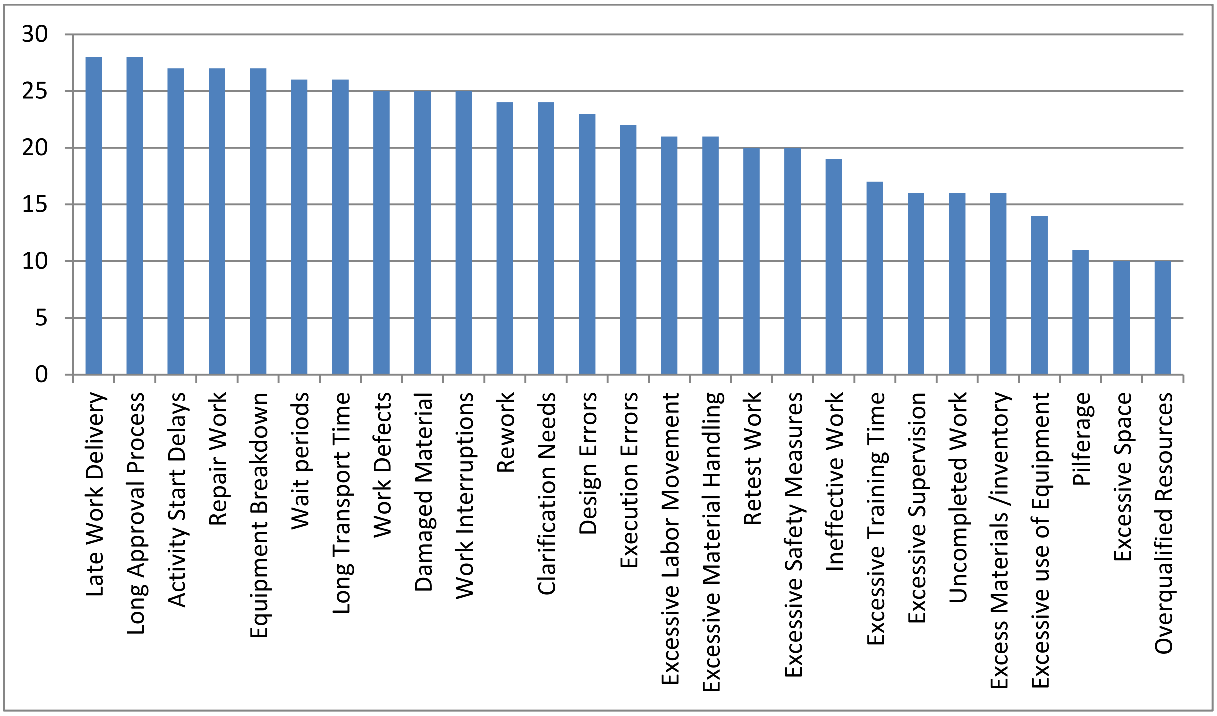

Figure 2. Pareto diagram of 27 construction wastes

As shown in Figure 2, late work delivery and long approval process top the list of AD construction wastes. The top 10 wastes range from work interruptions to late work delivery and represent 46.5% of construction wastes. This percentage represents the cumulative relative frequencies of the top 10 waste types. The question on waste occurrence (Always, Frequent, Rare, None) was asked at each waste type in all surveyed companies. Figure 3 shows the overall extent of the 27 construction wastes in terms of the % (relative frequency) of each occurrence in all answers. As shown in Figure 3, 75% of construction managers believe that these wastes exist in their project either rarely, frequently, or always.

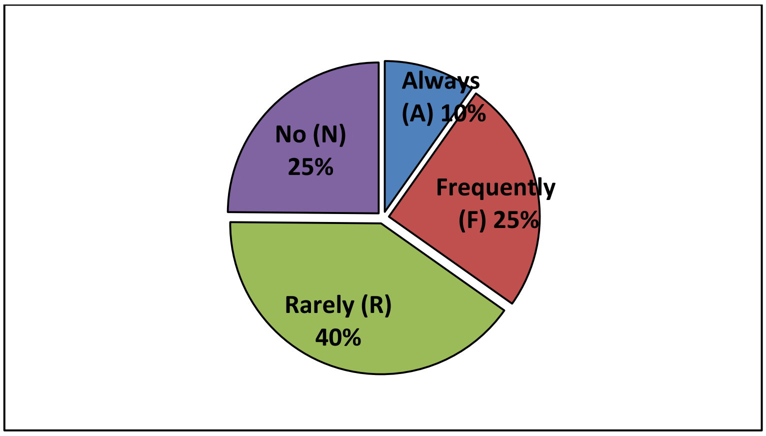

Figure 3. The overall extent of construction wastes

The 27 identified wastes were classified into the typical 7 waste categories of lean production (defects/errors/correction, delay, over-production, over-processing, excessive inventory, excessive conveyance, and excessive motions). Table 1 shows the categories of identified construction wastes.

Table 1. Categories of identified construction waste

Correction	**Over-processing**	**Delay**	**Inventory**	**Conveyance**	**Over-production**	**Motion**
Repair Work	Long Approval Process	Late Work Delivery	Damaged Material	Transport Time	Idle periods	Labor Moves
Equipment Breakdown	Clarification Needs	Activity Start Delays	Excess Materials	Material Handling	Excessive Space	
Work Defects	Excessive Safety	Work Interruptions	Pilferage			
Rework/ Re-run	Excessive Training Time	Ineffective Work				
Design Errors	Excessive Supervision					
Execution Errors	Excessive use of Equipment					
Retest Work	Overqualified Resources					
Uncompleted Work						

Figure 4 shows a Pareto diagram of the 7 categories of construction wastes. As seen from Figure 4, correction of errors and defects is on the top of waste categories followed by over-processing and delay. The three represent 72.5% of all construction wastes. This percentage represents the cumulative relative frequencies of the first 3 waste categories. This clarifies the status of current wastes in AD construction industry and provides guidance of the improvement process.

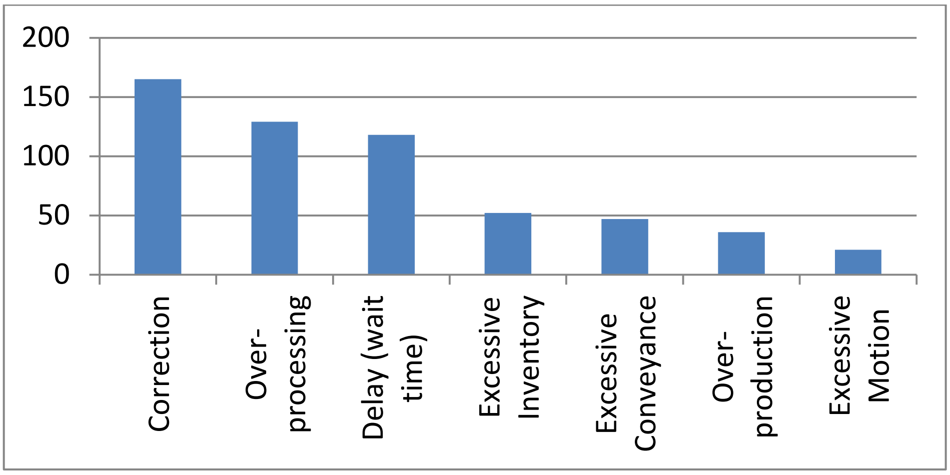

Figure 4. Pareto diagram of the 7 categories of construction wastes

- **Impact Analysis:**

The survey analyzed the impact of the identified 27 wastes on the construction project. Construction managers were asked to assess the impact of these wastes on the cost (C), quality (Q), and speed (time, T) of the construction project. Impact is classified as High, Medium, Low, or Zero. Results of impact analysis are shown in Figure 5.

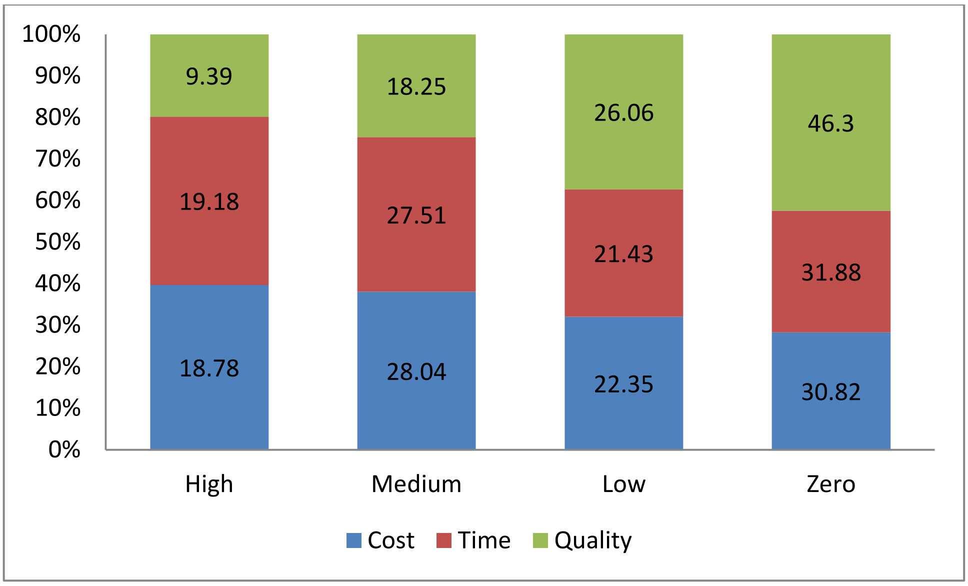

Figure 5. Impacts of construction wastes

As shown in Figure 5, the majority of construction managers (about 65%) believe that the identified wastes have some impact on project cost, quality, and time. Only 30.82% believe that construction wastes have zero impact on cost and 31.88% believe that they have zero impact on time. However, 46.3% of construction managers believe that the identified construction wastes have zero impact on quality. This contradict with the finding that correction of errors and defect (quality issues) is the waste category with highest frequency (refer to Figure 4). This can be explained by the majority of construction mangers still do not consider repair, rework, retest, and other hidden quality issues as a quality concern. Based on Figure 5, about 36% considered these wastes to have no impact on the three aspects (Q, T, C). This also shows that about 1/3 of construction managers cannot link several construction wastes such as over-processing and excessive conveyance of material and equipment to the three project success criteria (Q, T, C).

- **Causes Analysis:**

Many causes were reported by construction managers at each waste type. These causes were organized into 18 different types as shown in the Pareto diagram of Figure 6. The first 4 causes represent 38% of all causes. Those are related to material shortage, unskilled labor, poor supervision, and bad storage. This confirms the expectations of the surveyed construction managers and directs their waste reduction effort towards improving the coordination with suppliers, increasing the on-site labor training, improving the on-site supervision, and using effective storage systems.

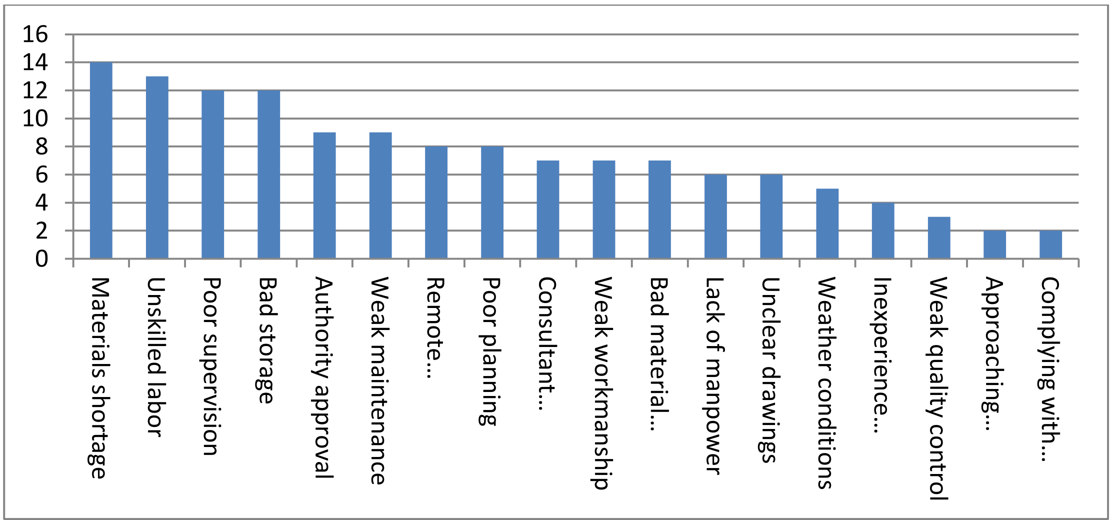

Figure 6. Pareto diagram for the causes of construction wastes

The main causes of waste construction were then linked to the 10 top wastes as shown in Table 2. This actually provides insight on how to address each waste type in a continuous improvement process.

Table 2. Main causes of top 10 construction wastes

Top 10 waste types	**Main cause**
1- Late Work Delivery	- Lack of manpower & labor resources
2- Long Approval Process	- Consultant approval

3- Activity Start Delays	- Materials supply delay & shortage
4- Repair Work	- Bad workmanship
5- Equipment Breakdown	- Lack of proper maintenance procedure
6- Wait/idle periods	- Waiting for authority approval/permits
7- Long Transport Time	- Long distance procurement/remote site
8- Work Defects	- Poor/bad supervision
9- Damaged Material	- Bad storage/ storing method
10- Work Interruptions	- Weather conditions

- **Techniques Analysis**:

After identifying and categorizing construction wastes in AD construction industry, analyzing their impact on project's (C,Q,T), and identifying their main causes, it is essential to assess their familiarity with lean concept and techniques and verify their need for adopting lean techniques.

Only 32% of surveyed companies claimed to be familiar with lean construction concept and methods and were able to fill the survey section on lean techniques. Other companies are assumed to be less or unfamiliar with lean construction practices. Companies familiar with lean construction either in their early stages of using lean techniques or have been using them for the last 5 years, on average. Users consider lean techniques to be highly effective, effective, or moderate. Only about 15% are using the majority of lean techniques fully in their projects (i.e., have become a standard operating procedure). Reported main benefits of using lean techniques include the following:

- Creating a smooth workflow without waste
- Improving the project C, Q, & T
- Deleting NVA and reducing waste from the project activities
- Achieving performance excellence & quality awards
- Delivering projects on time or in some cases ahead of schedule
- Increasing profit and market share
- Having lean as a competitive advantage
- Increasing team empowerment and improving safety and workers morale
- Improving relations with vendors and improving customer satisfaction

Lean techniques analysis showed that 23 lean techniques are currently being used in AD construction industry (in various degrees and forms). Figure 7 shows a Pareto diagram of currently used lean techniques. Workflow analysis and quality-at-the source took the lead amongst used lean techniques followed by a set of equally used lean technique that includes: lean design, setup time reduction, worksite layout design, Kaizen, and team work. The second class of lean techniques include work structuring, lean supply, lean assembly, labor cross-training, using work standards, visual aids, and Total Productive Maintenance (TPM). These two classes represent 70% of used lean techniques. This percentage represents the cumulative relative frequencies of the lean techniques in the two classes.

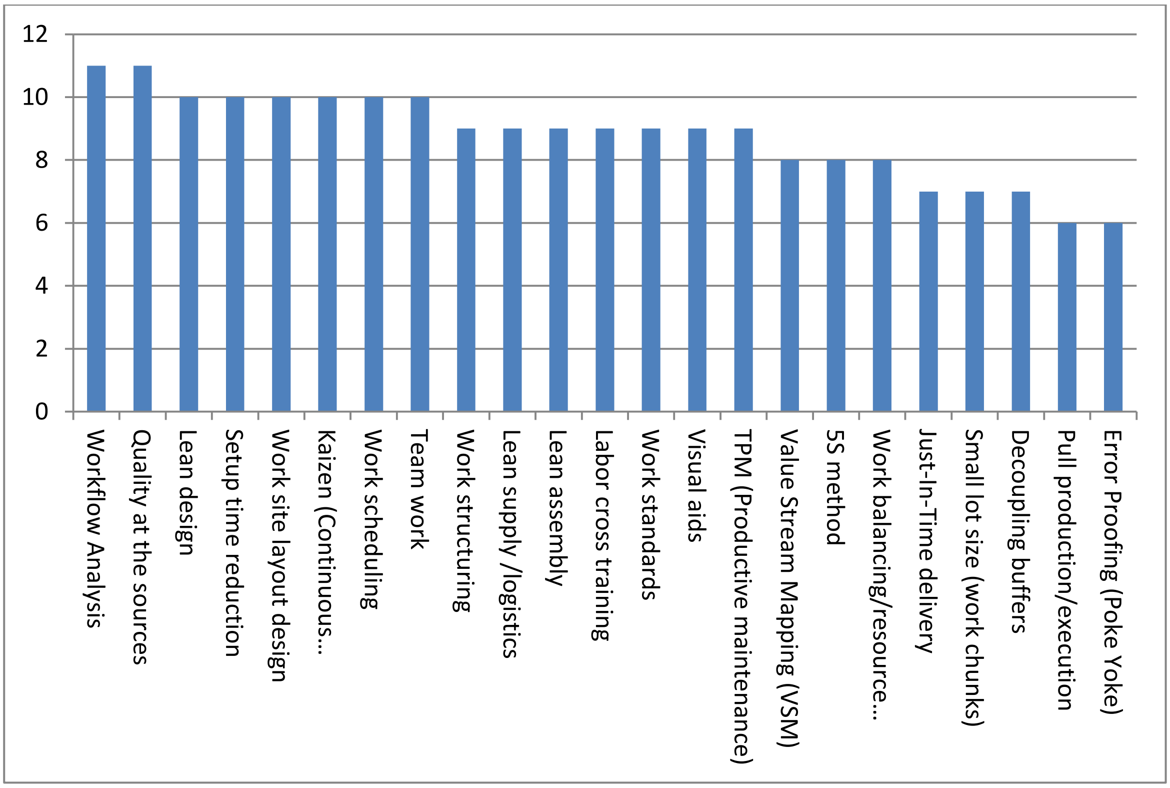

Figure 7. Pareto diagram for used lean techniques

The question on using each of the 23 lean techniques (Always, Frequent, Rare, None) was asked in all surveyed companies. Figure 8 shows the overall extent of the 23 lean techniques in terms of the % (relative frequency) of each occurrence in all answers. As shown in Figure 8, 87.5% of companies that are familiar with lean technology are using some or all of these lean construction techniques. Indeed, 48% are using these techniques in all projects. This shows that once the company is aware of lean techniques and has the lean know-how they will use these techniques to a large extent.

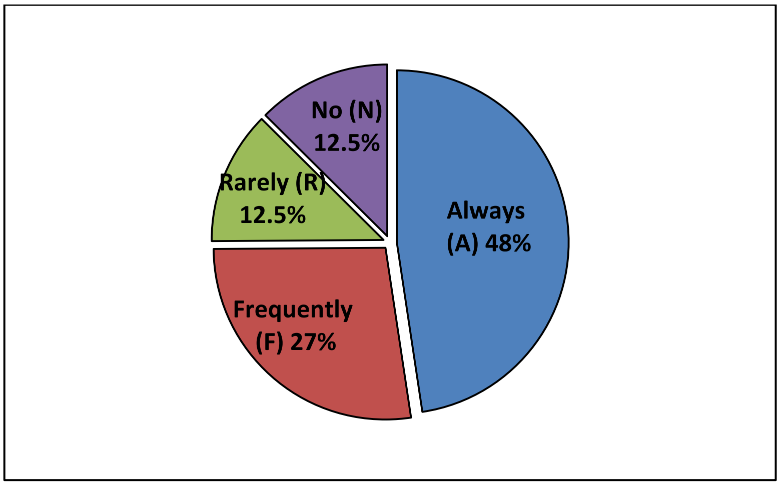

Figure 8. **Overall extent of lean techniques**

The impact of adopting lean techniques on project (C,Q,T) is shown in Figure 9. The figure shows that the majority of construction managers (about 75%) believe that lean techniques have some impact on the (C,Q,T) criteria. Only 20.35% believe that they have zero impact on cost, 23.45% on time, and 30.53% on quality. Construction managers who believe that lean techniques have high impact on the project (C,Q,T) divided the impact almost equally among the three project criteria with a little more focus on quality followed by time. Those who gave medium and low impact preferred cost to quality and time.

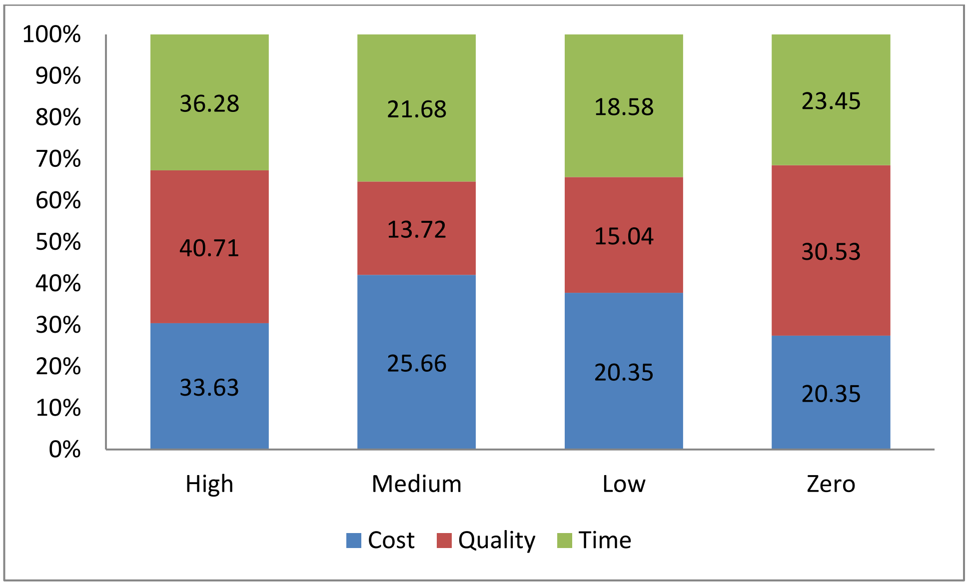

Figure 9. Impacts of lean techniques

Further analysis of current lean techniques showed that companies that are familiar with lean concept and methods pressed a need for adopting lean techniques in all projects. Highly needed lean techniques include: Value Stream Mapping (VSM), Just-In-

Time (JIT), and 5Ss (Sort, Set, Shine, Standardize, Sustain), standard work procedures, quality-at-the-source, cross-training, visual aids, team work, lean design, lean supply, lean assembly, buffers, small work packages, look-ahead planning, and work scheduling. Key reported obstacles of adopting lean techniques include:

- Lack of lean awareness amongst workers and management
- No adequate training and high cost of lean training
- Lack of lean specialist and expertise
- The current financial crisis
- Work pressure and fear of failing in the implementation
- Lack of workers skills and workers are not easy to educate
- Management considering lean initiative as an added cost
- Workers' attitude and resistance to change
- Multi-cultural workforce and language barrier

Results Analysis

Waste analysis unveiled the existing wastes in AD construction industry. Some of these wastes are common in the construction industry in AD such as long approval process which usually includes the delays and bureaucracy involved in obtaining permits from local authorities. Over-processing impact was obvious in terms of complicating the construction process by requiring many approvals, clarifications, excessive training and safety measures, etc. Many construction managers complained about these issues and these concerns were validated in the results of the survey. It is worth mentioning that construction managers were too sensitive in revealing the wastes existing in their projects considering that their clients may get the idea that they are not efficient or cost conscious.

In terms of work categories, errors and corrections have the highest frequency. This includes repair, retest, rework, and other hidden defects in the construction process. This was not surprising since most construction managers complained about the amount of hidden costs which negatively impact the profit margins of their construction projects. A lot of these wastes are also related to the unskilled labor where language and cultural barriers prevent creating an awareness of lean thinking and first-time-through production (i.e., doing things right from the first time without the need for reworking tasks). The labor recruitment process needs to be revised to address this challenge. Further research can be directed to better understand the causes and costs of shortage in the skills of imported labor and to propose improvement schemes. This also highlights the owners quality concerns in the work performed. A quality measure such as Six Sigma rating (SR) will be of a great value to quantify defects and guide quality improvement.

In terms of lean construction impact, the potential is high as seen from the impact of current wastes on the project cost, quality, and time (speed). Construction managers are quite aware of the impacts on cost on timing but not on quality. Again this is due to the difficulty of identifying hidden costs or relating many errors to project quality. Construction managers were less capable of linking lean techniques to their impact on the three project measures. That is due to lack of knowledge and experience in lean techniques. These facts highlight the need for increasing the awareness of AD construction industry with lean techniques and practices. Since most practitioners agree that these techniques can be best learned by doing (implementing lean techniques), a practical framework such as the LPDS of LCI is highly needed to guide the industry in creating a lean culture and adopting lean techniques in AD construction industry.

AD construction companies can first adapt the LPDS framework to their specific needs and implement the set of lean techniques that is most relevant and effective to their projects. Improvement is attained incrementally until lean methods are integrated into the each company's standard operating procedures. This framework, however, should be supported by easy to measure and understand performance measures that assess impact of adopting lean techniques. Based on this study, we proposed a set of lean construction measures to be used alongside the LPDS framework and clarified the practical implications for adopting lean techniques in the AD construction industry successfully.

A- Lean construction KPIs

The proposed Lean Construction Key Performance Indicators (LC-KPIs) are expressed in terms of five important aspects of the construction project. In addition to the typical (Quality, Speed, and Cost) project management measures, the proposed KPIs include Waste and Value indices. These aspects are shown in Figure 10.

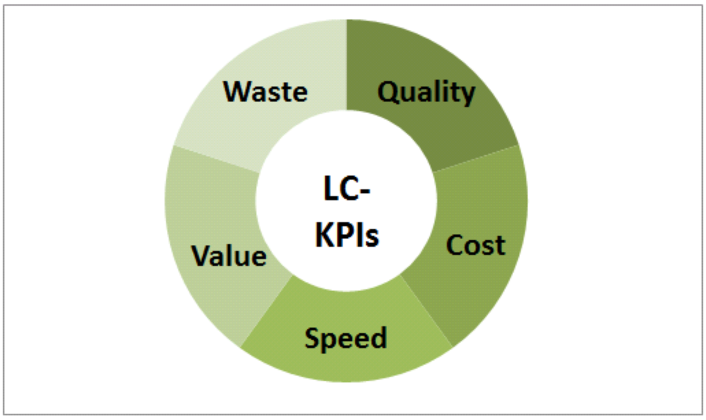

Figure 10. Lean Construction KPIs

The following is a description of the proposed five LC-KPIs:

- Sigma Rating (SR): The quality of work completed internally or through the subcontractors is reviewed at the end of each look-ahead period. The quality level is measured through a Sigma rating to emphasize the complementary function of lean and Six Sigma methods. The obtained SR value is compared to a certain company standard or benchmark value of Sigma rating to decide if a DMAIC Six Sigma improvement study is needed.
- The project speed and cost effectiveness are key aspects in lean construction. Both Schedule Performance Index (PMI) and Cost Performance Index (PMI) are typical performance measures in the Earned Value Management System (EVMS) at the project review (i.e., the end of look-ahead period in our case). EVMS is a technique

that reports the project status by relating project resources to schedule and technical performance.

- Finally, the value and waste indices are crucial to measure the tangible impact of adopting lean techniques in the construction process. In addition to less defects and higher cost and schedule effectiveness, lean construction practices should translate on the floor into less material waste, low inventory levels, and less conveyance and movement of labor and material.
    - As discussed in Thomas *et al.* (2002), a project Waste Index (WI) can be used to indicate waste in material and working hours. The difference between the amount of procured and used material is referred to as ending inventory in production and is typically carried over to the next look-ahead period. Thus, low values of this index indicate more frequent JIT shipments are delivered to the site and low inventory levels are eventually maintained.
    - The value Index (VI) compares the duration of the effective work (conversion time) to the total duration of the look-ahead period. The focus is on increasing the amount of time spent in performing conversion activities (value-adding work) and minimizing delays, interruptions, and the time spent in unnecessary conveyance and movement of material and labor. The periodic review of this index checks the amount of work spent in value-adding activities during the look-ahead (review) period.

B- Practical implications

Results showed that AD construction industry is in high need for a practical framework that helps the industry adopt lean construction practices. Based on the LPDS framework, the stages of the traditional project management process (define, design, supply, assemble, and deliver) are enhanced to become lean (faster and more effective with less waste). Emphasizing the lean thinking at all project stages is imperative towards the development of the lean construction framework. After adopting the framework, a transformational roadmap is needed to integrate the lean practices at each project stage. In general, and for a successful implementation of the lean construction framework, the following practices need to be emphasized during the look-ahead period:

1. Split work packages to smaller units/tasks (toward a single-unit-flow) with reduced variability and less simultaneous work (i.e., small work chunks) to reduce cycle time.
2. Set up the layout of the work site to achieve a seamless work-flow and clean up and organize the work site daily using 5S techniques.
3. Reduce changeover from one task to another (i.e., apply SMED technique) and prevent machine and equipment failures (i.e., apply TPM technique).
4. Balance work resources (add/remove resources) based on work flow, rely on smaller teams, and adjust relations and logic of work tasks accordingly.
5. Arrange for the availability of resources (material, labor, equipment, etc.) for all work packages, use less internal logistics, remove obstacles, implement multi-tasking and cross training. The objective is to be fully ready before the release of each task in the work package (i.e., no delays, no shortages, no errors, etc.).

6. Use buffers (cost, time, capacity, space, etc.) to absorb work flow variability. For example, feeding buffers can be used to synchronize for the rights start and finish of tasks in order to avoid delays (gaps) and overproduction (delivering work that is not needed at a particular time).
7. Adopt a quality-at-the source policy so that no bad work is passed down stream (i.e., stop the work, if needed). Integrating the Six Sigma into the lean construction framework enables such policy where the focus is on improving the Sigma rating by reducing the defects.
8. Pull/release tasks from one station/worker to another when required and all resources are ready, preceding tasks are completed, and simultaneous tasks are synchronized.
9. At the end of the look-ahead period, determine the five LC-KPIs, compare to targeted threshold values, and recommend adjustments or improvements accordingly.
10. Proceed until the project is completed and delivered to the client. Check the overall Quality, Schedule, and Cost performance and document best practices and lessons learned.

Finally, and as guidance for improvement, project or construction managers need to set threshold or benchmark values for the LC-KPIs and to link them to the typical seven categories of the identified wastes. The KPI values can be established based on a combination of the nature of the work, the level of company sophistication, the establishment of the client's expectations and goals for the project, and the approach of the project delivery team in managing project risks. The construction company can then update these threshold values yearly based on the achieved progress and the benchmark studies. The company can also include a safety-related KPI to maintain high safety standard. Table 3 links LC-KPIs to waste categories and shows examples of their threshold values for a hypothetical project. For example, SR can be set to at least 3.0 so that about 99% of the work meets the specifications and accepted by the customer. CPI can be set to at least 1.15 so that we have about 15% cost buffer and SPI to 1.1 to have about 10% time buffer. WI can be set to zero or in some cases to a maximum 5% to limit the amount of ending inventory and prevent accumulation of material due to large shipments and overproduction. Finally, the VI can be set to 75% to emphasize the conversion tasks and limit the flow activities.

Table 3. Examples of LC-KPIs threshold values for a hypothetical project

<table>
<tr><th>Waste Category</th><th>LC-KPI</th><th>Threshold Value</th></tr>
<tr><td>Defects/Errors</td><td>SR</td><td>≥ 3.0 (99% of work is defect free)</td></tr>
<tr><td>Delay/Ineffectiveness</td><td rowspan="2">SPI</td><td rowspan="2">≥ 1.10 (10% time buffer is maintained)</td></tr>
<tr><td>Overproduction</td></tr>
<tr><td>Overprocessing/Cost effectiveness</td><td>CPI</td><td>≥ 1.15 (15% cost buffer is maintained)</td></tr>
<tr><td>Conveyance</td><td rowspan="2">VI</td><td rowspan="2">≥ 0.75 (A maximum of 25% conveyance & movement)</td></tr>
<tr><td>Movement</td></tr>
<tr><td>Inventory/ Material</td><td>WI</td><td>≤ 5% (no more than 5% ending inventory)</td></tr>
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Conclusion

Analysis of of AD construction industry revealed 27 types of construction wastes. These wastes were categorized into the commonly used seven types of wastes in lean production. Defects (errors and corrections) are found to be the most common type of construction waste in the surveyed companies. This called for the integration of a structured and data-driven quality improvement method (namely, Six Sigma) into the lean construction framework. The second common types of wastes are over-processing and delays. The majority of surveyed companies confirmed the existence of these wastes in their construction projects and acknowledged their impacts on projects cost, quality, and speed.

As only 32% of the surveyed companies were found to be familiar with and using lean techniques, the majority emphasized the need for a practical framework for adopting lean techniques. To help the industry in the further establishment of lean practices, the study addressed 18 main causes of construction wastes, analyzed the extent and impacts of 23 lean techniques, and discussed the practical aspects of adopting a framework for lean construction in AD construction industry. The paper also recommended the assessment of a set of LC-KPIs to measure and guide improvement (in terms of project quality, cost, speed, value and waste) at the end of each "look-ahead" planning period. Worker incentives in a reward system are also recommended to achieve lean construction objectives. The results of the study will be shared with the AD construction industry to get feedback and provide the industry with a starting point for further adoption of lean construction practices.

Directions for future research include addressing the identified causes of wastes and tracking their root causes to existing business practices in scoping, planning, and decision making as well as to the labor issues such as training, language barriers, and cultural aspects. Future research could also focus on providing guidelines for construction managers for addressing quality concerns, enhancing and testing the assessed LC-KPIs including the addition of a safety indicator, and quantifying the costs and gains of adopting the lean construction framework.

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