An Application of Critical Chain and Lean Project Management to Improve Project Efficiency: A Case Study of Construction Project in Indonesia

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Abstract

A large of scaled development is ongoing in the industrial and infrastructure sectors in Indonesia. Megaproject especially in construction projects is considered disappointing due to over budget, delayed, and under quality. This lack of performance is due to the complexity and uncertainty of megaprojects. Therefore, the aim of this study is to discover how to use lean practices to maximize project value, shorten the project schedule, improve project quality, and reduce waste in the construction industry. This was achieved by analyzing a case study of a construction project in Indonesia. The case study revealed that implementation of critical chain project management as well as lean practices during the project, including the Last Planner System (LPS) and continuous improvement, all contributed to the improvement of project performance. To supplement the case study and to provide insights on the differences between local and international lean construction (LC) practices, interviews with project stakeholders and a questionnaire survey of global lean experts were conducted. Results indicated that interviewees and survey respondents both held the view that project waiting times and defects can be greatly reduced through the implementation of LC, and that improvement of construction workflow along with the project.

Keywords
Critical Chain Project Management, Lean Construction, Critical Waste, and Project Scheduling.

1. Introduction
The ability to manage concurrent projects in the dynamic and competitive modern economic environment becomes a key competence that may have a significant impact on building a company's competitive advantage. The construction industry is expected to contribute about 15 percent of the global Gross Domestic Product (GDP) and is projected to exhibit a growth rate of 4 percent annually over the next few years (Betts et al. 2015). This anticipated growth makes it one of the fastest progressing sectors in the coming decades. However, Hussin et al. (2013) argue the industry's growth has been constantly challenged by a wide variety of issues such as low productivity levels, varying profitability, lack of skilled workforce, project delays, and slow technology adoption. A high level of asset specificity makes construction projects uncertain and complex with multiple requirements to be met during the design and construction process. Making project management practices sustainable is an essential component of the broader mission of making the construction industry, as a whole, truly efficient as well as sustainable.
Multiple project management is characterized by the complexity of the issues related to planning, organizing, coordinating, and controlling a set of projects simultaneously. The dynamic, turbulent, and complex nature of the

construction industry (CI) leads to high uncertainty in construction projects and may adversely affect the performance of construction companies if uncertainty is not properly managed. This study is implemented as a case study in a construction company that considered as one of the largest property developers in Asia. For simplification, further reference used "*the company*" to refer this company case. The company has a significant problem needs to be addressed in the construction process, namely excessive waste. Waste from the construction industry side has a meaning as a form of inefficiencies caused by several aspects, such as time, human resources, materials, and Non-value Adding Activity. The company has a large construction project started in the early 2021. It is being planned to be finished within 1 year which will be referred further as "*the project*".

In order to deal with these problems, the Critical Chain Project Management (CCPM) and Lean Construction methods are applied. The Critical Chain Project Management method is used to improve development completion. In exploiting constraints, priority is given to each critical chain to ensure that all resources are ready when the next critical chain will start, it can also be subordinated to other resources to be used in the critical chain. This study integrates two methods to be applied in a construction management project. The first is the method which described by Araszkiewicz (2017). This method is used to determine the best way to reduce project work and increase the planned schedule. The second method is based on Bajjou and Chafi (2018) that develop a Lean Construction method that has two fundamental goals, namely: reducing waste and increasing value. Over time, this concept has proven successful and continues to be widely used in the construction industry.

The aim of this article is to present the issue of scheduling construction undertakings implemented in a multi-project environment with the use of the critical chain method. The second objective of the article is to present the results of a comparative analysis of the application of the critical chain project management (CCPM) and traditional scheduling established according to the critical path method (CPM) for the implementation in the construction.

This paper is organized as follows: Section 2 lists the literature review related to the study. Section 3 described the methodology being used. Section 4 describes the data collection process. Section 5 discussed the results. Finally, section 6 presented the conclusion of this study.

2. Literature Review

2.1. Critical Chain Project Management

Critical Chain is a project management method that focuses primarily on the management of the duration of activities, considering the allocation of resources, and is based on the principles of the Theory of Constraints (TOC). This method was initially proposed by Goldratt (1997) and later detailed by others (Blackstone et al. 2009; Leach, 2014; Wu and Min 2009; Steyn, 2001). Since its proposal, the CCPM method has been accepted by part of the project management community, as evidenced in work published by Rand (2000), Umble & Umble (2000), Newbold (2008), Tian et al. (2010), and Butler & Richardson (2011). These authors advocate the application of the CCPM method as a way to present concepts they consider innovative: a reduction of the initial time estimates \to avoid the appearance of the student syndrome and Parkinson's law, by using time buffers at the end of the project and providing ways to address uncertainty in activity planning. In addition, resource bottlenecks as system constraints and managing the project through the indicators of its time consumption should be taken into consideration. These considerations will provide a vision of the entire system, not only focusing on each activity individually but on the progress of the project as a whole. In the literature review, we have found that most of the work focuses on the analysis of the unique aspects of the CCPM method, such as time buffers (Bie et al. 2012; Gao et al. 2007; Tukel et al. 2006) and the application to individual projects (Balakrishnan 2009; Long and Ohsato, 2008; Wu and Min 2009).

2.2. Lean Construction

Several studies report that the adoption of lean construction led to timely project completion, enhanced profits, safe and efficient processes, and reduced variability in construction projects (Mao and Zhang, 2008; Salem et al., 2014). However, most of these studies have evaluated it, only on the basis of economic benefits derived because that has been the primary motivation for the implementation of lean construction. However, if lean philosophy focuses on reaping economic benefits alone in the form of reduced cost and increased profits, it might lead to negative impacts on the environment (Song and Liang 2011). Therefore, it is necessary to evaluate the impact of the philosophy beyond the economic perspective. However, the difficulties in quantifying the environmental benefits of lean philosophy hinder its exploration beyond the established boundaries (Bae and Kim 2008; Carneiro et al. 2012;

King and Lenox 2001). Nevertheless, the increasing emphasis on environmental protection in recent times is a potential background for evaluating the influence of lean construction on environmental parameters such as pollution, waste, natural resource consumption, and emissions.

The concept of promoting environmental sustainability in construction is mainly centered around reducing material wastage, water conservation, reducing pollution, dust control, use of environment-friendly materials and methods, and encouraging recycling (Plessis 2002). Subsequently, several studies have been highlighting a positive relationship between lean construction and environmental sustainability because, it is found to minimize resource depletion and pollution by eliminating waste and adding additional value to the customer in the form of lesser environmental impacts (Sertyesilisik 2014; Solaimani and Sedighi 2020).

3. Methods

In CCPM we develop a deterministic baseline schedule, i.e., identifying the critical chain as the set of tasks that determines the project makespan considering both precedence and resource dependencies, which is then protected by three types of buffers from the project uncertainties and resource bottlenecks. A single project buffer is placed at the end of the critical chain to protect the completion time of the project. Our work is apparently the first to approach buffer sizing through analytical decomposition of the project network, which enables detailed comparisons between critical and non-critical parts of the network, and guarantees the accuracy and mutual compatibility of the project and feeding buffers. Our work makes the following contributions.

- We decompose the project network to analyze the interactions of project network structure and buffers and provide a well-defined buffer sizing procedure that is implementable for any project network whose structure is known.
- We resolve the problem of a challenged critical chain, while simultaneously addressing situations with multiple critical chains.
- Based on extensive computational testing for both real and simulated data, our procedure delivers project schedules with a more accurate estimation of project makes pans and smaller feeding buffers than benchmark methods. Additional benefits of our methodology include delayed expenditure, and reduced working process, rework, and multitasking.

Based on the data that has been obtained, the project is scheduled using the Critical Chain Project Management (CCPM) method. The first stage is done by cutting the duration of all activities to 50%, also known as the Cut and Paste Method. This duration cut aims to eliminate things that cause additional time in the estimated scheduling that has been done. Cutting the duration in this scheduling method can pose a greater risk of delay, so it is necessary to add a buffer or buffer time to avoid delays. Next, calculations are made for the feeding buffer and project buffer. The feeding buffer is a buffer/time buffer that is placed at the end of the non-critical chain, while the project buffer is a buffer/time buffer that is placed at the end of project execution. The formula (1) used for the buffer calculation.

$$Buffer = 2 * \sqrt{\frac{(S-A)^2}{2}} \tag{1}$$

4. Data Collection

The project is started in February 2021 expected to be accomplished by July 2022. The interview and survey process is conducted 6 months prior to the project started. Several key stakeholders of the project operation such as project managers, supervisors, and foreman leaders were invited to provide insight by using interviews and survey. The project is originally planned using a total number of 153 workers.

5. Results

5.1 Waste identification in The Construction Project

The data in this lean construction research are in the form of the identification of waste variables obtained from several literature/journal studies and direct observations in the field. The list of waste type and its details on the project is shown in table 1. Furthermore, the waste variable is used as an interview question, namely with the foreman, field inspector, and the project manager concerned.

Table 1 The list of waste type and its details on the construction project

Waste Type	*Waste Factors in Project XYZ*
Waste Waiting	Delays in material or equipment arriving at the project site. Planning and scheduling have not been well structured. There is no stock of material manufactured in domestic factories, so imports must be imported from abroad. The quality of the material or tools is not up to standard. Unfavorable location or weather conditions. The COVID-19 pandemic affects resources due to government regulations.
Waste Defects	Negligence of the workers. Tool storage is not up to standard. Lack of maintenance on materials or tools.
Waste Material	Storage and use of materials are not up to standard. The difference in the size of the material needed with the size of the material available in the market or distributor. Rainy weather conditions make the material quickly damaged.
Waste Unnecessary Activities	Unemployed workers due to lack of tools that can be used. Undisciplined workers. Workers' rest time is too long. Lack of supervision from the foreman/field inspector. Accidental damage that requires workers to work overtime. Work accidents due to negligence of workers not wearing safety equipment.

5.2 Calculation of Defect Score Based on Waste Type

Table 2 show the calculation of waste score and its rankings. It is generated based on surveys filled by the respondents which in this case are the project managers, field inspectors, and foremen for the project. Each respondent were asked to rank a list of given waste from table 1 based on the impact to the project. The lower the rank indicate the higher the impact to the project, otherwise the opposite. This rank is used to calculate the defect score as described in formula (2). Take example of the defect score calculation for the waste type no. 1, the defect score is calculated as 1*2.0 + 1*1.0 + 1*0.0 which equals 3. Furthermore, a calculation of defect percentage is defined in formula (3). Finally, a Pareto Chart as shown in figure 1 is generated after the score and percentage values are obtained. The Pareto chart can show the waste type in order from the highest to the lowest score to determine critical waste.

$$Defect\ Score = \sum (Ranking * Weight) \tag{2}$$

$$Defect\ Percentage = \frac{Defect\ Score}{Total\ Defect\ Score} \tag{3}$$

Table 2. Waste type and its rankings and percentages

No.	*Waste Type*	Ranking	(1)	(2)	(3)	(4)	*Defect Score*	*Defect Percentage*
		Weight	3.0	2.0	1.0	0.0		
1	*Waste Defects*			1	1	1	3	15 %
2	*Waste Waiting*		2			1	6	30 %
3	*Waste Material*		1	2			9	45 %

4	*Waste Unnecessary Activities*				2	1	2	10 %
	Total						20	100 %

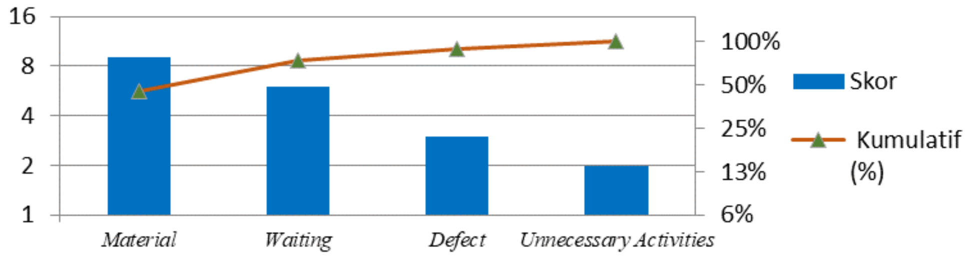

Figure 1. Pareto diagram for the critical waste in the construction project

5.3 Implementation of Lean Construction

The information regarding the application of lean construction tools in the property cluster development project was obtained from interviews and direct observations in the field. Table 3 shown the tools, prerequisite, and the explanation of the lean construction techniques implementation in the project. Some of the tools have changed after being implemented in the field and there are some tools that were not implemented by the contractor. Furthermore, the author analyzed the variables and waste factors with lean construction tools adapted from several experts from the literature review. Some tools that are not implemented or implemented by the construction side can affect the occurrence of waste.

The first tool is the Last Planner System with 5 requirements. The construction party applies the four tools except for the requirements in the Percent Plan Complete (PPC). PPC can be used as a standard to control production units, determine project schedules, implementation strategies, and others. Not implementing PPC causes waste waiting in giving work instructions to workers. The waste factor occurs because planning and scheduling are not well structured. If the PPC is implemented properly, the action plan will be achieved according to the standard.

The second tool is the Daily Huddle Meetings, a discussion of work between the project manager and the foreman on a regular basis or every morning before starting construction work. These tools provide a platform for driving cultural change and encourage the project team to refocus the weekly work plan as well as facilitate the recognition and resolution of problems on the project. This was not implemented by the construction party in Project XYZ, so it could cause errors in providing construction to workers because there was no briefing from the project manager with the foreman and caused work waste to be ineffective/slow. So it is very necessary to apply the Daily Huddle Meetings tools because two-way communication is very important in carrying out a job to foster and build teamwork and a sense of responsibility, identify obstacles so that they can be overcome, and declare problems in real time.

The last tool is 5S Process. The 5S Process has five stages of improvement that can help minimize waste, namely: Seiri (concise; sort), Seiton (tidy; straighten), Seiso (shine), Seiketsu (maintain; standardize) and Shitsuke (diligent; sustain). The contractor has implemented these tools in the office but has not been implemented by workers at the project site. This causes damage to civil materials or equipment that occurs in the storage area, causing wastage of civil work materials and tools. The factor for the occurrence of waste is due to the negligence of the foreman/field inspector in supervising workers so that workers do not use materials or civil work tools carefully/not according to standards, storage of materials or civil work tools is not neat/not in place, and lack of maintenance on materials. or civil work tools. This shows that in the process of storage, mobilization, and installation, it has not yet fully made concise, neat, and clean work as a useful standard to reduce damage to materials and work tools in the project site storage area. Therefore, it is necessary to have directives, routine evaluations, and strict supervision from the project head to the workers to carry out the 5S Process that has been implemented by the contractor.

Table 3. Implementation in Lean Construction Techniques

Tools	Prerequisite	Explanation
Last Planner System	*Master schedule*	*applying*
	Reverse Phase Schedule; scheduling plan starts from the target finish to the start time	*applying*
	Six-Week Look Ahead; work schedule with a period of 6 weeks	*applying in every 4 weeks*
	Weekly Work Plans; the most detailed plan with a period of 1 week	*applying*
	Percent Plan Complete; a measure of commitment in carrying out the work that has been planned	*Not applying*
Increased Visualization	*Commitment chart; performance targets*	*applying*
	safety charts; safety signs	*applying*
	Mobile charts; work schedule and work chart	*applying*
***Tools*/Teknik**	*All foreman meeting;daily discussion of contractor work with the project manager and foreman*	*Not applying*
	Start of the day meeting; briefing	*Not applying*
Plan Do Check Adjust/ First-Run Studies	*Show the process or illustration*	*Applying*
5S	*Sort; separate items by category*	*Not applying*
	Straighten; Store items in an easy-to-reach place	*Not applying*
	Shines; clean and tidy work area	*applying*
	Standardize; concise, neat, clean become the standard of work	*applying*
	Sustain; get used to discipline	*applying*
Fail-safe for Quality and Safety	*Check for Quality*	*applying*
	Check for Safety	*applying*
Daily Huddle Meetings	*All foreman meeting; discussion of contractor work with the project manager and foreman every day*	*Not applying*
	Start of the day meeting; briefing	*Not applying*
Plan Do Check Adjust/ First-Run Studies	Show the process or illustration	*Applying*
5S	*Sort; separate items by category*	*Not applying*
	Straighten; Store items in an easy-to-reach place	*Not applying*
	Shines; clean and tidy work area	*Not applying*
	Standardize; concise, neat, clean become the standard of work	*applying*
	Sustain; get used to discipline	applying
Fail-safe for Quality and Safety	*Check for Quality*	applying
	Check for Safety	applying

6. Conclusion

This study discussed the application of critical chain and lean project management to improve construction project efficiency. It is implemented in a case study of construction project of a large property construction company in Indonesia. The data being collected based on interview and survey process conducted prior to the project kick-off. The results shown that the critical construction path method is able to identify the activities considered as waste in the construction project. Addressing the waste with a proper lean construction tools shown that it is able to increase the project efficiency. The ability to manage concurrent projects in the dynamic and competitive modern economic environment becomes a key competence which may have a significant impact on building a company's competitive advantage. The construction industry contributes significantly to economic development and social equality of both developed and developing countries (Jiang et al. 2019); adding between 7% and 10% of Gross Domestic Product (GDP). A high level of asset specificity makes construction projects uncertain and complex with multiple requirements to be met during the design and construction process. Making project management practices sustainable is an essential component to the broader mission of making the construction industry, as a whole, truly efficient as well as sustainable.

The outcome of this study will have a very positive implication for both theoretical and practical body of knowledge in project management. Theoretically, this study will provide a deep understanding of lean concepts and will encourage the construction companies to start a lean journey for removing wastes and inefficiencies from existing management techniques. The removal of waste within the construction projects will make construction more sustainable and facilitate in preserving not only the natural material but also the effort required to undertake the work. Thereby having a huge positive impact in decreasing the environmental issues associated with the construction industry (Nicholas and Steyn, 2020).

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Biography

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