Implementation of Lean Construction to Eliminate Waste

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Implementation of Lean Construction to Eliminate Waste: A Case Study Construction Project in Indonesia

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ABSTRACT

Lean Construction (LC) presented innovative practices to maximize the production value and minimize the production waste during construction. The problem that frequently occurs in the project is delaying the schedule, leading to time and cost overrun. This research aims to eliminate waste that causes delay and inefficiency. Several LC techniques were carried out to improve the efficiency of this project, namely: Value Stream Mapping (VSM) to discover wastes and determine Process Efficiency Cycle (PCE); Waste Assessment Model (WAM) to identify the inter-relationship among wastes; Fishbone (Ishikawa) diagram analysis to get the root cause of the waste. Research results showed the three highest wastes: defect 14.06%, over production 21.44%, and the highest rank was unnecessary inventories 31.73%. After implementing LC techniques, the PCE increased from 72 % to 79%. The implication of this research is to provide recommendations to the project's stakeholders in running the building construction to avoid delay and inefficiency.

1. Introduction

The continual matter encountered by construction companies worldwide is the delay of construction projects leading to time and cost overruns, resulting in loss of profit and low performance [1-3]. In construction projects, problems of defective design, poor quality, bad working conditions and low safety arrangements cause variation, non-value-added activities, and wastes [4]. They are caused by the lack of effort in creating the flow of involved activities for the transformation process, in which materials are transformed into an actual construction [5, 6] argued that projects seldom finish on time, within budget, or at a quality level accepted by the customer. For construction companies, the planning result still needs to be achieved [7]. The construction industry is one of the largest sectors that directly affect human life. The numbers and sizes of physical structures in a nation typically provide the first indication of the rate of its development [8]. To survive in today's competitive market, it has become essential for construction companies to develop the quality of their work, increase work effectiveness, reduce costs and waste and increase profit [9]. One of the primary reasons for reducing productivity in construction projects is the presence of "waste", i.e., items that do not add any value to the existing construction process [1]. Waste may be defined as, "any inefficiency that results in the use of equipment,

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materials, labor or capital in larger quantities than those considered necessary in the production of a building"[10-12].

According to [13] the losses experienced by the construction sector are basically because the construction processes are not planned and managed correctly. Waste caused by incorrect or incompletely planned construction processes is among the biggest damaging factors in the construction industry. Studies show that causes of poor performance can be divided into external causes and internal causes. External causes, which are usually beyond the control of project teams, may include adverse weather conditions, unforeseen site conditions, market fluctuation, and regularly changes while internal causes of poor performance may be generated by the client, the designer, the contractor, the consultant and various suppliers who provide labour, materials and equipment. It can be argued that both external and internal causes happen because of project dynamics [14]. While traditional construction is schedule-based, considers the project as a set of activities and ignores the flow within and between delivery-focused activities, LC concentrates on flow and value generation[15].

LC provides innovative practices to manage construction projects while reducing waste and improving performance[16, 17]. Lauri Koskela introduced LC in 1993 at the International Group for Lean Construction (IGLC) conference [18]. Koskela defined LC as "A way to design production systems to minimize waste of Koskela defined LC as "A way to design production systems to minimize waste of materials, time, and effort to generate the maximum possible value" [19]. LC results from the application of a new form of production management to construction [20]. LC construction can effectively minimize, even if not fully eliminate the non-value adding tasks in construction [21]. Research conducted by [22] revealed that implementing lean practices during the project contributed to improving project performance. Companies utilizing Lean have reported several benefits: improved reliability of outcome and profit margin, higher quality construction, greater customer satisfaction, and reduced costs and improved schedules [23]. LC contributes to sustainable development in the field of construction and to develop an environment friendly construction industry [24]. LC has a significant impact on enhancing the construction schedule and improving project performance. It has enhanced the productivity of the workforce, effective coordination and communication, minimization of defect and reworks [25].

Several studies in implementing LC have been proposed over the ten years in different countries. Implementing LC techniques and management methods in Chinese projects using Just In Time framework [22]. In Egypt LC also has been implemented using Last Planner System [20] and Risk management and Risk response planning [26]. In Latin America LC was implemented in the constructing affordable housing production in Ecuador using formwork standardization and integration of information technology to support production processes [27]. Moroccan construction industry applied LC using a structured questionnaire survey [16]. Integrating LC and sustainability in the UK construction waste classified into eight groups: quality costs, lack of safety, unnecessary transportation trips, delay times, rework, long distances, wrong choice or management of methods or equipment, and poor constructability [28]. In Indonesia, even though still limited, some research related to LC was carried out and used different methodologies. [29] carried out LC using a five-why analysis. [30] implemented LC using Critical Chain Project Management (CCPM). Development of Lean Construction and an obstacle to implementing LC in Indonesia using literature review [30]. Study LC integration on Steel Construction Works of Warehouse Buildings using M-PERT [31]. LC applied on High Rise Building Construction Project using simulation [32]. Nevertheless, none of those researchers explore VSM to identify PCE in their methodology. Therefore, this study fills

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that research gap as the originality and novelty of the research. This research aims to eliminate wastes that occurred in the construction project. Using LC, wastes would be eliminated and it was expected the PCE would increase and could reduce the delay and increase cost efficiency.

2. Methods

In this research there were six stages to solve the problem using LC framework, namely: current Value Stream Mapping (VSM); determining current Process Cycle Efficiency (PCE) value; constructing Waste Assessment Model (WAM); performing root cause analysis; expected future VSM and determining the expected improvement PCE value. Current VSM was used to identify the material and information flow of all work elements in the project. Through VSM wastes occurred were identified. Wastes were causing inefficiency, so determining current PCE become important. Usually wastes did not come alone, they inter-related each other. So, the next important stage was constructing WAM. WAM consists of two instruments: Waste Relationship Matrix (WRM) and Waste Assessment Questionnaire (WAQ). WRM describes the strength of the direct relationship between wastes using a scale. A WAQ was developed to allocate waste in the project. After knowing the highest and dominant waste, then root cause analysis of waste was carried out using a fishbone diagram. Finally, since the root cause of the waste was determined, improvement steps were proposed. Expected future VSM was mapped and expected improvement PCE was calculated. The framework that describes integrating methods used to solve LC problems in Fig. 1.

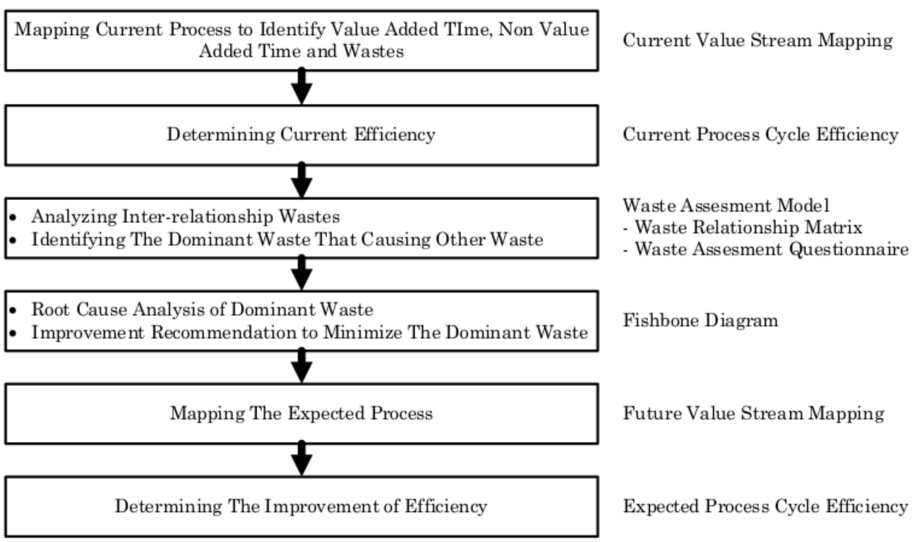

Fig. 1. Research Methodology Framework

2.1 Mapping current VSM

Studies have shown that flow activities in construction processes constitute 30–50% of the total project cost [33]. VSM identifies activities in three categories: non-value

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adding (NVA), necessary but non-value adding (NNVA) and value-adding (VA). The more the VA activities the more efficient the process cycle.

2.2 Determining current PCE

Efficiency is a key performance factor in measuring the performance of the construction process. The objective of assessing efficiency through a defined process is to achieve better performance by focusing on value creation and non-value elimination [33]. PCE can be calculated with Equation (1).

$$PCE = \frac{\text{Time for value adding activities}}{\text{Total cycle time/ lead time}} \times 100\% \quad (1)$$

2.3 Waste Assessment Model (WAM)

WAM consist of Waste Relationship Matrix (WRM) and Waste Assessment Questionnaire (WAQ). All types of waste are inter-dependent as shown in Fig. 2. [34], and each type has an influence on the others; and simultaneously is influenced by the others. There are three steps in conducting WAM:

2.3.1 Questioner distribution

Rawabdeh model [34] was used to identify waste relationship, shown in Fig. 2. , and to develop criteria for evaluating the strengths of waste relationships in the questioner as shown on Table 1.

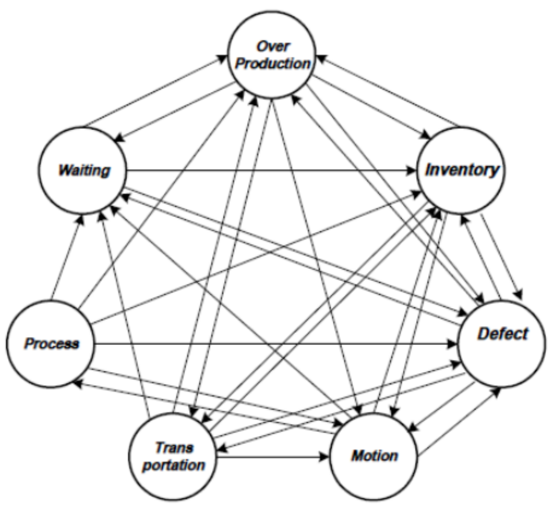

Fig. 2. Direct wastes relationship

2.3.2 Construction of WRM

The questionnaires that were distributed and collected were scoring and weighting. After the scoring process has been completed the weighting process is carried out, the weighting is carried out to know the relationship between wastes in the waste matrix. Through the result of this weighting, then the results are converted to letter symbol in WRM. There are symbols in the matrix, F symbolize from, T symbolize to, I symbolize inventory, D symbolize defect, O symbolize overproduction, T symbolize transportation, W symbolize waiting, D symbolize defect, P symbolize inappropriate process and M symbolize motion. If it is already converted then the relationship between wastes could be determined. The results from the converted weight were then used again to calculate the level of influence of each type of waste on other types of waste.

Table 1. The developed criteria for evaluating the strengths of waste relationships

No	Question	Answer choices	Weight
1.	Does *i* produce *j*	a. always b. sometimes c. seldom	= 4 = 2 = 0
2.	How is the relationship between *i* and *j*	a. if *i* increase so *j* increase b. if *i* increase so *j* constant c. Not necessarily, depend on the situation	= 2 = 1 = 0
3.	Impact on *j* because of *i*	a. look directly and clear b. takes time to appear c. doesn't show up often	= 4 = 2 = 0
4.	Eliminating the impact of *i* to *j* can be achieved by method of?	a. *engineering* Method b. simple and direct c. instructional solution	= 2 = 1 = 0
5.	The impact of *i* on *j* mainly influence?	a. product quality b. resources productivity c. *Lead time* d. quality & productivity e. quality & *lead time* f. productivity & *lead time* g.quality, productivity & *lead time*	= 1 = 1 = 1 = 2 = 2 = 2 = 4
6.	How big is the impact of *i* on *j* will increase *lead time*	a. very high b. average c. low	= 4 = 2 = 0

Note: *i* stands for any type of waste which has an effect on the other type of waste *j*

2.3.3 Construction of WAQ

The assessment questionnaire consists of 68 different questions, which were introduced to allocate waste [34]. The assessment questions were introduced so that each question represents an activity, a condition or behavior that may lead to a specific type of waste. Some questions are assigned a "From" note, which means that the question represents an existing type of waste that may lead to other wastes regarding the waste relationship matrix. Other questions are assigned a "To" note, which means that a question represents any existing type of waste that other types of waste may have caused. Each question has three answers and each was assigned a weight of: 1, 0.5 or zero. The questions were then categorized into four groups of man, machine, material and method since each relates to one of these categoriesThe complete steps are as follows [35]:

a. It starts with counting the "From" and "To" questions and original weights obtained from the WRM.
b. Calculating weight values for each type of waste by multiplying rows for each type of waste by the weight of each answer (X_k) obtained from the assessment questionnaire. Let W to be the weight of relationship and j the type of waste for

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each question number k. The values in each column under each type of waste were summed to obtain the new score (S_j) as in Equation (2).

$$S_j = \sum_{k=1}^{k} X_k \cdot \frac{W_k}{N_i} \text{ for each type of waste j} \quad (2)$$

where: S_j is the total score of the waste, and k ranges between 1 and 68.

c. Counting the number of non-zero cells in each column to obtain the frequency (f_j) for each type of waste

d. Calculating the initial indication factor of each type of waste using Equation (3). Y_j is the initial indication factor of each type of waste.

$$Y_j = \frac{s_j}{S_j} \times \frac{f_j}{F_j} \text{ for each type of waste j} \quad (3)$$

where: s_j is the score of each waste, and F_j is total frequencies

e. Calculating the final waste factor (YFj) by multiplying Yj by Pj as in Equation (4). Pj is the probability of "From" and "To" occurrences in the WRM.

$$YF_j = Y_j \times P_j = \frac{s_j}{S_j} \times \frac{f_j}{F_j} \times P_j \text{ for each type of waste j} \quad (4)$$

Then, YF_j is converted into percentages to obtain the rank of each type of waste

2.4 Root Cause Analysis Using Ishikawa or Fishbone Diagram

The Fishbone diagram is developed to identify the variability of a quality characteristic as an effect or consequence of multiple causes [36, 37]. After the root problem has already determined, some alternative solutions related to man, machine, method and material for improvements were proposed.

2.5 Expected Future VSM

The Map of the Future State is the last step of VSM. It is a drawing created from the analysis of the Current State Map. Map of the Future State depicts an "Ideal state", the best it could operate above the Current State Analysis.

2.6 The Case Implementation

To explore the power of LC techniques in minimizing waste during construction, a case study of research was conducted on one construction project in Indonesia. Al Fatih Islamic Center was a construction project in Pekanbaru, Indonesia. This building was designed for six floors. Considering the size of the project and research time, this research focused on the development of the first-floor structure of the building. The first-floor structure has an important role in constructing a high building. The bottom structure carries the load from the structure above it so the bottom structure should be sturdy in order structure above it does not to collapse.

Based on the preliminary research, there was a delay in the completion of the project from the schedule. This delay was resulting cost overruns or inefficiency. Cost inefficiency came from increased labor wages, increased material use, and additional processing time, which could cause delays for the overall project. The construction of the bottom structure has eight work elements: rebar cutting and bending, rebar assembly and column, making formwork, brick laying on the production floor, casting, scaffolding installation, formwork, and rebar installation.

This research used direct observation using a stopwatch to make VSM. Another instrument used to collect the data is the questionnaire. Two types of questionnaires follow the WAM framework: a questionnaire related to WRM and questioner related to WAQ.

The respondents in this research are the site manager, logistic supervisor and foreman in charge of the project.

3. Results and Discussion

Through the current VSM, six types of waste occurred along the eight work elements: waiting, excessive transportation, inappropriate processing, overproduction, unnecessary inventory and unnecessary motion. The current VSM identified VA and (NVA time during the work elements. It was recorded PCE 72 %. The type of waste and the description can be seen in the current VSM shown in Fig. 3.

Based on scoring the results of respondents' answers to the questionnaire using Rawabdeh's criteria for evaluating the strengths of waste relationships from Table 1, the weighting process is carried out and the weighting matrix is shown in Table 2. Through the result of this weighting, then the results are converted to letter symbols in WRM. If it is already converted then the relationship between wastes could be determined, namely: necessary, especially important, important, ordinary closeness, unimportant and no relation, as shown in Table 3. The questioner weighted were transform into symbol as shown on Table 4 which would be continued to development of WRM.

Table 2. Questioner Weighting

T / F	Waste						
	O	I	D	M	T	P	W
O		14	10	14	12	0	5
I	8		18	16	14	0	0
D	11	14		10	9	0	12
M	0	11	7		0	12	16
T	9	12	7	12		0	12
P	16	10	10	12	0		14
W	10	12	9	0	0	0	

Table 3. WRM Symbol for Strength of Direct Relationship of Wastes

Range	Relationship Type	Symbol
17 – 20	Absolutely necessary	A
13 – 16	Especially important	E
9 – 12	Important	I
5 – 8	Ordinary closeness	O
1 – 4	Unimportant	U
0	No relation	X

Based on Table 5, on the side "From" it is known that the highest percentage come from inappropriate processing (P) as amount of 16.4 %. It means this waste has the biggest effect to others wastes. As an example, based on fields study, if the process of column was not appropriate so it was causing defect and re-work and finally causing delay and over budget. Therefore, this waste has high impact on the occurrence of other wastes. On the other side "To", it is known that defect has the highest percentage as amount of 17.2%. It indicates defect was the most consequences waste caused by other wastes.

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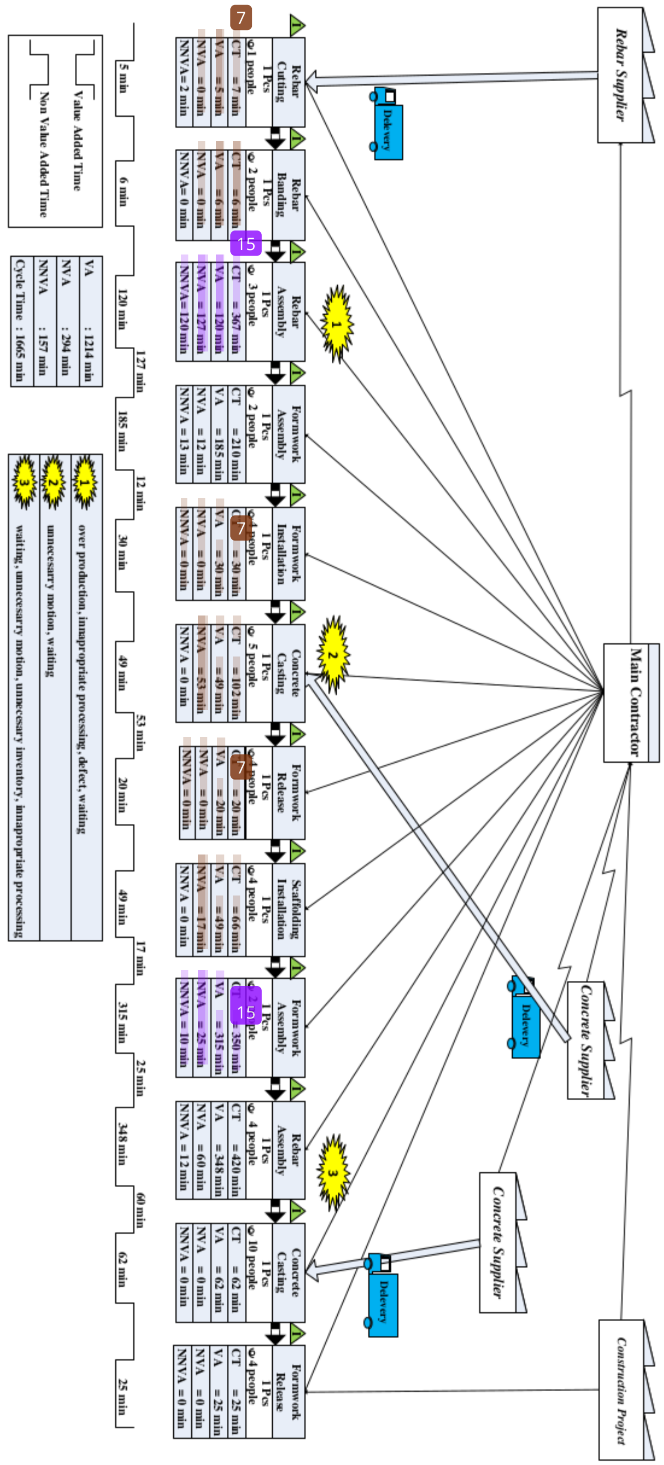

Fig. 3. Current State Value Stream Mapping

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Table 4. WRM Symbol Conversion

F \ T	O	I	D	M	T	P	W
O		E	I	E	I	X	O
I	O		A	E	E	X	X
D	I	E		I	I	X	I
M	X	I	O		X	I	E
T	I	I	O	I		X	I
P	E	I	I	I	X		E
W	I	I	I	X	X	X	

Table 5. Waste Relationship Matrix

F \ T	O	I	D	M	T	P	W	Total	(%)
O	10	8	6	8	6	0	4	42	15,7
I	4	10	10	8	8	0	0	40	15
D	6	8	10	6	6	0	6	42	15,7
M	0	6	4	10	0	6	8	34	13
T	6	6	4	6	10	0	6	38	14,2
P	8	6	6	6	0	10	8	44	**16,4**
W	6	6	6	0	0	0	10	28	10,4
Total	40	50	46	44	30	16	42	268	100
(%)	15	19	**17,2**	16,4	11,2	6	15,7	100	

The summary of WAQ calculation is shown on Table 6. The most dominant waste with the highest influence degree is unnecessary inventories (31.73 %). Unnecessary inventories in onstruction project have led to another waste. From WAM, it is identified that there are inter-relationship among the waste. In the context of Al Fatih construction project the dominant waste that is inter-related are Inappropriate processing, Defect and Unnecessary Inventories.

Table 6. Results of the Waste Assessment Questionnaire (WAQ) Calculation

Description	O	I	D	M	T	P	W
Yj	5.07	6.20	2.90	3.14	3.2	2.47	2.47
Pj factor	235.5	285	270.04	213.2	159.04	98.4	163.28
Yj final	1193.8	1767	783.11	669.44	508.9	243.04	403.30
Final Result	21.44%	**31.73%**	14.06%	12.02%	9.13%	4.36%	7.24%
Rank	2	1	3	4	5	7	6

In the context of case study, the dominant waste that occurs and were interconnected (inappropriate processing, defect and unnecessary Inventories) must get serious attention. For example, unnecessary inventories in the project has caused the project area to be overcrowded and causing material accumulation that caused defect to material and because of that caused inappropriate processing. Inappropriate processing was finally causing delay. Delay was causing time and cost inefficiency. Take it into consideration, site manager, logistic supervisor and foreman must have good project management knowledge to reduce waste occurred to minimize loss.

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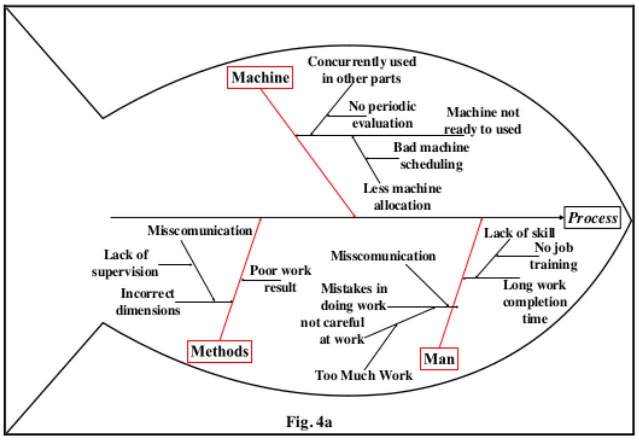
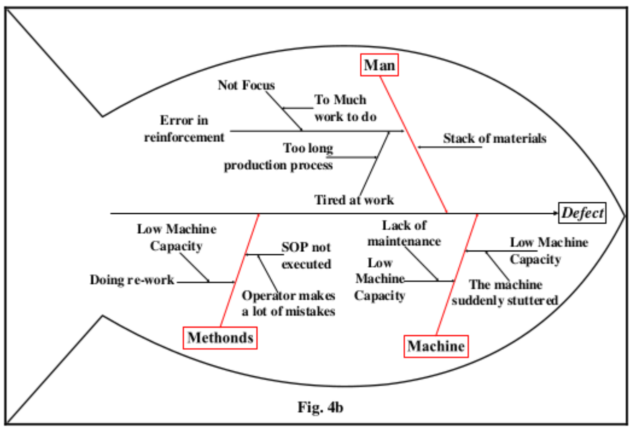


Fig. 4a. Fishbone Diagram Inappropriate Processing



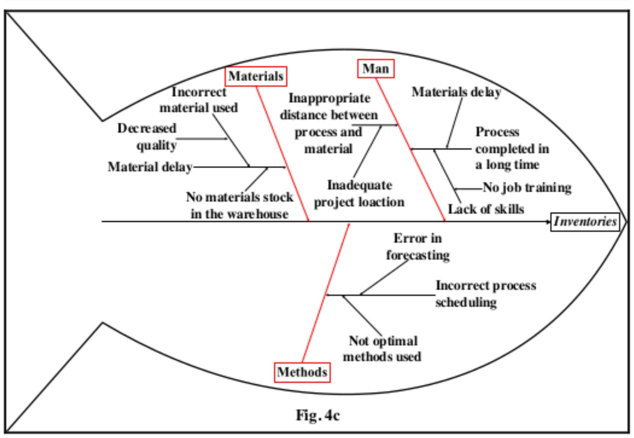


Fig. 4b and 4c. Fishbone Diagram Defect and Unnecessary Inventor

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To assist the site manager, logistic supervisor and foreman in reducing waste, an analysis of the root cause of the problem was established and focused on four categories: machinery, human resources, material and method. The root cause analysis in the case study construction project was conducted using a fishbone diagram. Root cause analysis for inappropriate waste processing, defect and unnecessary inventories are shown in Fig. 4a, Fig. 4b and 4c. Based on the fishbone diagram, the root cause of the waste was determined and several alternative solutions were offered to the project implementer to eliminate waste, as shown in Table 7.

Table 7. Root Cause Analysis

Root Cause	Solutions or Improvement to Eliminate Wastes
Man	Assign a qualified site manager and site consultant to manage and make job site arrangements and submit drawings so that the placement of materials and ordering materials that are indented and ordering urgent materials can be carried out properly and the output can reduce waste on the project.
Method	Related to the dominant wastes that cause delay, namely: inappropriate processes and unnecessary inventories that cause defects and finally cause delay, the method of processing flow should be communicated well among consultant, site manager, foreman and workforce to work properly without defects. Unnecessary inventory could be reduced through good communication with suppliers to supply the material with the Just in Time system.
Material	Efficient inventory management means that there is no excessive stock of goods (raw materials, WIP, and finished goods), reducing the risk of producing defective, damaged, and unsuitable goods. Efforts to minimize material waste are carried out by taking preventive measures that include optimizing the use of materials, implementing effective and efficient construction methods and increasing the accuracy of estimates and ordering. This can be realized in an effective and sustainable implementation if it is supported by a commitment from the implementing contractor, namely by adding a special division or person in charge of it.
Machine	To avoid inappropriate processing and defect, it was recommended to do preventive maintenance. Based on observation on site, the project has experienced problems: machines that stop working because they were broken. Routine maintenance by the operator or workforce on machines and tools is suggested, such as machine cleaning and checking daily or weekly. Maintenance activities can be carried out such as dismantling the inside of the machine to check the often damaged parts and repairing or replacing parts that turn out to be damaged.

Suppose the proposed solution was implemented in the project. In that case, it is expected to reduce NVA time and increase the PCE to 79 %. The expected increase of PCE is from the expected Future State VSM, as shown in Fig. 5. If the PCE value increases, waste is expected to be reduced, and delay can be avoided.

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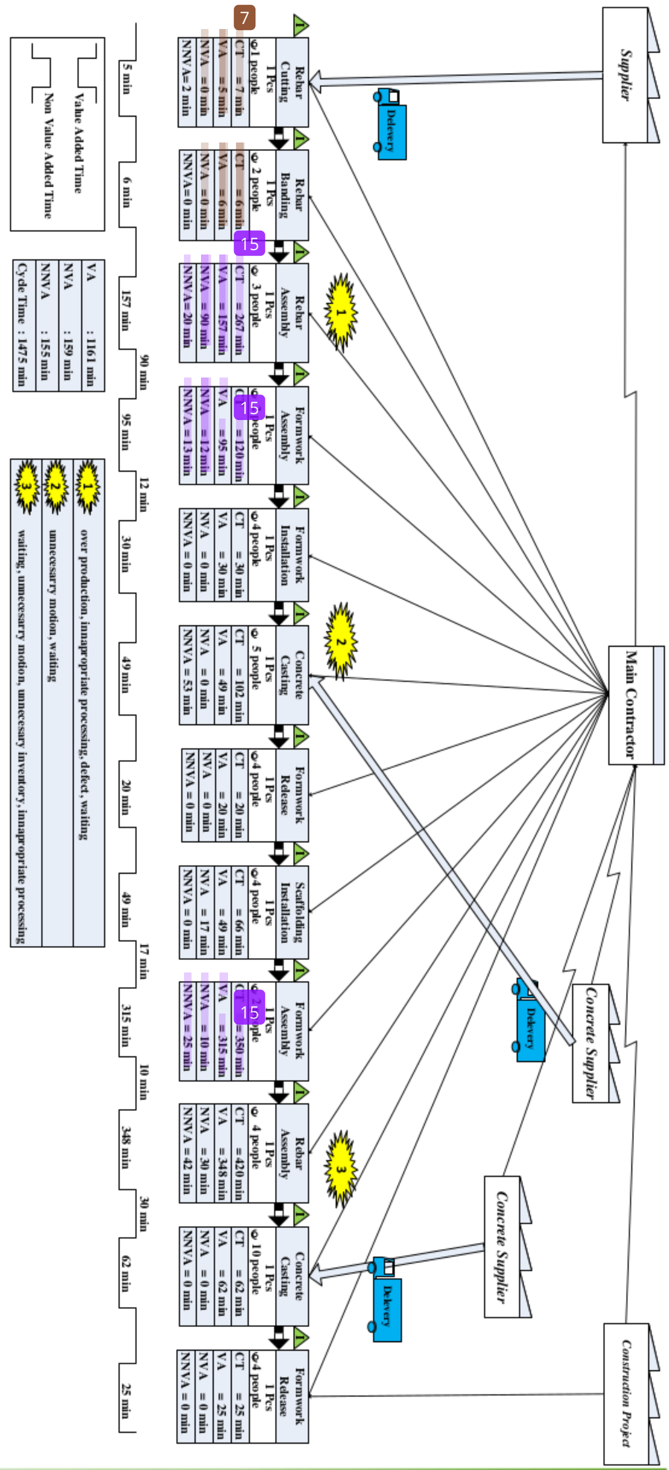

Fig. 5. Future State Value Stream Mapping

4. Conclusion

Lean Construction is a technique for building projects while maximizing value, minimizing waste, and pursuing perfection. Implementing lean construction in the case study construction project was intended to eliminate waste that caused delays in project completion time. Lean construction uses certain lean tools: VSM, PCE, WAM (WRM, WAQ), and Fishbone diagram. Those fundamental techniques could determine the inter-relationship among waste and define the most dominant waste: defect 14.06%, overproduction 21.44% and the highest rank were unnecessary inventories with a percentage of 31.73%. Finally, the PCE is expected to increase from 72 % to 79 %. Further research using another technique and approach related to LC is needed concerning the rapid growth of building construction in Indonesia which needs time and cost efficiency.

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Declarations

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