Analysis of Waste of Cost Factors During Engineering Phase of EPC Project with Lean Thinking (Case Study: PT.XYZ)

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ABSTRACT

An engineering, procurement, and construction (EPC) company is challenged to compete in a cut-throat industry with many competitors and slim profit margin. Previous studies revealed that 70% of activities in a construction project are non-value adding which diminish productivity and profitability. As well as at PT. XYZ, the historical results showed that most of projects run by this company ended up in delay and cost overrun. Those previous studies had concluded that the most common factor that leads to project delay and cost overrun was poor design in engineering phase. This paper aims to identify the waste factors affecting cost during the engineering phase of EPC project at PT. XYZ. Lean information framework was utilized to identify and analyze the waste factors. Based on the extensive literature review, it was identified that there were 28 waste factors which can be classified into six groups of wastes. A questionnaire was designed and distributed to 48 participants to be filled out to investigate the dominant waste factors. The factor analysis, correlative test, descriptive and relative index analysis were then carried out. The results showed that the dominant waste factors are waiting for the needed documents, the long and far meetings, waiting for feedback information, waiting for the document approval, outdated information, and producing dummy document. The managerial implications are PT. XYZ should focus on efficient planning, streamlined information flow, pull-based planning activities, continuous improvement, and human resource development.

Keywords: *EPC, engineering phase, waste, lean information*

1. INTRODUCTION

Engineering, procurement, and construction (EPC) is one of the most common types of project in which the EPC company will undertake a large engineering service, materials procurement, and construction activities on behalf of its clients [1]. The typical projects include industrial plants, power plants, and oil & gas processing facilities. The market for EPC company grows parallelly with the expansion of economy. According to BCG report in 2015, the high complexity of EPC project diminishes productivity and profitability of EPC company. In fact, most of projects ended up in delays and cost overrun. A lean approach is identified as a tool to reduce complexity and uncertainty

by eliminating non value-added activities. BCG data revealed that lean implementation have reduced project completion time by 30% and reduced cost up to 15% [2]. However, many EPC companies have still suffered from not implementing lean approach during EPC project, including PT. XYZ.

Several lean tools have been implemented to identify waste in the construction project and to improve project delivery performance in previous studies. Based on that, this study aims to identify and analyze cost waste factors that happen during the engineering phase of the EPC project using lean approach. Lean information framework will be utilized to identify all contributing factors of waste. The benefit of the waste analysis on this study is to provide a new framework and tool for the engineering manager to identify the non value-added activities during engineering phase and cut them.

2. MATERIALS AND METHODS

2.1. Literature Study

Engineering, procurement, and construction (EPC) is one of the most common contracts in a construction project in which the contractor will carry out all activities from design to construction on behalf of its project owner [1]. Generally, the EPC project includes three main phases: engineering, procurement, and construction, when in practice, all three will run concurrently at some points [3]. Several studies had concluded that the most common factor that leads to project delay and cost overrun was poor design in engineering phase before construction [3-5].

The lean concept made its way to fame after being developed and implemented in the manufacturing industry in the 1950s by Toyota, and since then has significantly improved productivity and quality [6]. Lean manufacturing emphasizes on delivering customer value and reducing waste. There are five principles of lean thinking to gain maximum advantage: (i) specify value; (ii) identify the value stream; (iii) flow; (iv) pull; and (v) perfection (1). The success of lean manufacturing started the discussion on the applicability of lean in a broader industry. In 1992, lean concept was adapted in the construction industry with paradigm of transformation, flow, and value generation as a lean construction since the construction industry is characterized as a low-entry barriers with low-profit margin business caused by tons of non-value-adding activities [7].

Lean construction refers to the application and adaptation of lean thinking in the construction industry [8]. The underlying concepts and principles of lean construction are: (i) elimination of process waste [9]; (ii) effective management of value stream and alliances of supply chain [10]; (iii) maintaining continuous flow of product and process [11]; (iv) pull-based planning and control [12]; (v) just-in-time delivery of material and service [13]; and (vi) continuous improvement [14]. Seven types of waste in construction are identified [15] as follows: (i) overproduction; (ii) waiting; (iii) transportation; (iv) over processing; (v) inventory/stock; (vi) motion of human; and (vii) defective product. Lean project delivery system (LPDS) developed by Glenn Ballard in 2000 is one of the most popular tool of lean construction. The fundamental objectives of LPDS are to deliver the product, maximize value, and minimize waste. The phases in LPDS [16] are as follows: (i) project definition; (ii) lean design; (iii) lean supply; (iv) lean assembly; (v) use; and (vi) production control. Lean design in LPDS covers the engineering phase of EPC project.

The research of Tribelsky & Sacks [17] explained that information flow is a critical determinant of design engineering products quality. Information can be found as informal communication and formal document. The information flow ensures all stakeholders get the valuable information they need to generate value out of their work. Inefficient information flow will result: (1) rework; (2) waiting for information; (3) delayed local cycle of iteration; and (4) over design. So, information management is an essential building block of lean thinking [18]. The waste category in information management based on previous studies [17-19] is shown in Table 1.

Table 1. Waste category in lean information compared to lean manufacturing

WASTE CATEGORY			
Lean	[19]	[17]	[18]
Inventory			Stock
Motion			Motion
Overproduction	Flow excess	Rework	Overproduction
Waiting	Flow demand	Waiting	Waiting
Over processing	Failure demand	Negative iteration and over design	Process
Defects	Flawed flow		Defects
Transport			

The framework from Redeker & Kipper [18] combines lean manufacturing concept and framework of Hicks [19] into six waste categories, which are:

- Stock. This waste happens when information is stockpiled. Stockpiled information can lead to unprocessed information and loss of information.
- Motion. This waste typically concerns any unnecessary human movement to get the needed information.
- Overproduction. This waste happens when producing the information that is not needed yet and there are several sources producing the same information.
- Waiting. This waste category concerns about idle time generated from doing nothing or working slowly while waiting any information needed.
- Over processing. This waste occurs when there is more than required value added when processing the information. The waste needs corrective effort afterwards and this effort leads to delays and cost overrun.
- Defects. This waste occurs as a product or information that deviates from requirements or specifications or as an incorrect information.

2.1. Research Methodology

The research is focused on the engineering division in EPC project of PT. XYZ. The engineering division produces engineering deliverable products to be the inputs of the procurement and construction division. Engineering division consists of several disciplines: piping, civil, mechanical, process, electrical, and instrument. Each engineering discipline consists of several engineers and designers. The information flow occurs among each discipline, among disciplines, among divisions, between engineering discipline and vendor, and between engineering division with client.

The identification of information waste factors was conducted by literature review from which a list of waste factors was extracted and classified into six categories. The extracted version was structured into questionnaire that aimed to identify relevant factors that occur in the engineering phase of the EPC at PT. XYZ. The final list of information waste factors constituted the core content of the questionnaire design, as shown in Table 2. The main variable of the research is cost overrun (PB) occurred during the engineering phase, as shown in the following formula:

$$PB = \frac{Actual\ cost - Budget}{Budget} \times 100\% \quad (1)$$

The scale of cost overrun is as follows:
1: Cost overrun <10%.
2: Cost overrun in range of 10%-20%.
3: Cost overrun in range of 20%-30%.
4: Cost overrun in range of 30%-40%.
5: Cost overrun > 40%.

The primary data collection was collected through the questionnaire. A non-probability sampling method was selected to get the appropriate respondents. The selected respondents must have a minimum of 6- year engineering experience, engineering discipline leader in a project, and a bachelor’s degree. A 5-point Likert scale was employed to evaluate the frequency of occurrence and impact of these waste factors. The secondary data needed for this research was obtained from project document, macroeconomics data, company reports, and other company documents.

Table 2. Waste in information flow

NO	WASTE FACTOR	SOURCES
Stock (X_a)		
X1	Too many documents that are not needed yet.	
X2	Difficulty in finding certain document.	
X3	The needed document is lost.	[18]
X4	The information/document needed is halt.	
Motion (X_b)		
X5	The meetings are too far and too long.	
X6	The inspections are too far and too long.	
X7	The meetings are not productive.	[18]
X8	Manual searching of information/document.	
Overproduction (X_c)		
X9	Producing the documents that are not needed.	
X10	Producing the documents with incomplete information.	
X11	Unrealistic planning.	
X12	Producing the documents with over specification.	
X13	Producing the documents with outdated information.	[17-19]
Waiting (X_d)		
X14	Waiting for the needed documents.	
X15	Waiting for the documents' approval.	
X16	Waiting for the confirmation of information.	
X17	Waiting for the feedback of information.	[17-19]
X18	Waiting for the work (idle).	
Over process (X_e)		
X19	Producing document that is not in the contract.	
X20	The document change is not communicated.	
X21	Manual work instead of automated.	
X22	Person in charge is not capable.	[17-19]
X23	Producing the dummy document to meet target.	
Defects (X_f)		
X24	Error of provided information.	
X25	Outdated of provided information.	
X26	The provided information is not standard.	
X27	The provided information is not complete.	[18-19]
X28	The information system error.	

The result of data collection via a questionnaire was analyzed as follows:

a. The validity and reliability test

The factors shall be considered as reliable if the Cronbach Alpha value was more than 0.6. The factors shall be considered as valid if produce a component factor loading of more than 0.5. The valid and reliable factors were used for further analysis. SPSS version 25 is used as analysis tool.

b. Correlation test

The bivariate Pearson test was performed. The correlation coefficient was calculated to measure the correlation of each factors toward the main variable. Then, the multivariate correlation test was performed. The test showed the correlation between each waste category and the main variable. The value of 1 indicates a perfect positive correlation, the value of -1 indicates a perfect negative correlation, meanwhile the value of 0 indicates no correlation. SPSS version 25 is used as analysis tool.

c. Descriptive Statistic Analysis

The descriptive analysis was conducted to determine the frequency, mean, maximum, minimum, and standard deviation. SPSS version 25 is used as analysis tool.

d. Relative Index Analysis

The relative index analysis was employed to determine and rank the dominant factors. The relative index for frequency of occurrence, severity of impact, and the importance of factors are calculated by the following formulas:

$$RFI = \frac{\sum Fi}{A.N} \quad (2)$$

$$RSI = \frac{\sum Si}{A.N} \quad (3)$$

$$RII = \frac{\sum Wi}{A*N} \quad (4)$$

Where:

- RFI is relative frequency index.
- Fi is the mean of score given to the frequency of occurrence of each factor.
- RSI is relative severity index.
- Si the mean of score given to the impact of each factor.
- RII is the relative importance index.
- Wi is Fi times Si.
- A is the largest score.
- N is the number of responses.

e. Managerial Implications

The managerial implications of the dominant waste factors are presented to help the engineering manager in identifying and managing the waste factors.

3. RESULTS

3.1. PT. XYZ Company Profile

PT. XYZ is one of the biggest EPC companies in Indonesia with specialization in industrial plant, power plant, and oil & gas plant projects. PT. XYZ runs a business of engineering, procurement, construction, commissioning, project management consulting, and trading. When PT. XYZ is awarded with project from the project owner, the operation department will form the project team that is led by project manager. The project team will execute the project as per contract. The beginning phase of EPC project is engineering phase.

The engineering division of EPC project is led by engineering manager. This division consists of several engineering disciplines which are process, mechanical, piping, civil, electrical, and instrumentation. Each discipline is dependent of information from other disciplines or other divisions. The information flow that occurs are: (1) among engineering discipline members; (2) among different engineering disciplines; (3) between engineering discipline and another division; (4) between engineering discipline and vendor; and (5) between engineering discipline and client.

3.2. Results of Data Collection

As mentioned before, the data collection was conducted using a questionnaire-based survey. The questionnaire was distributed to 63 respondents and 48 responses were obtained. All the respondents are experienced in engineering phase as a leader. This indicates their knowledge and skill in managing project budget.

3.3. Results of the Validity and Reliability Test

The validity test was performed using the frequency and impact data of each waste factor. 25 factors are considered valid, meanwhile three factors are not valid. The result is presented in Table 3. Then, the reliability test was performed using the frequency and impact data of each waste category. All categories are considered as reliable and consistent as a research instrument. The result is presented in Table 4.

Table 3. Validity test result

Category	Valid (Factor Loading > 0.5)	Not Valid (Factor Loading < 0.5)
Stock	X2, X3	X1, X4
Motion	X5, X6, X7, X8	-
Overproduction	X10, X11, X12, X13	X9
Waiting	X14, X15, X16, X17, X18	-
Over process	X19, X20, X21, X22, X23	-
Defects	X24, X25, X26, X27, X28	-

Table 4. Reliability test result

Category	Cronbach's Alpha	
	Frequency	Impact
Stock	0.687	0.831
Motion	0.76	0.815
Overproduction	0.814	0.802
Waiting	0.866	0.883
Over process	0.852	0.794
Defects	0.92	0.859

3.4. Results of the Correlation Test

Bivariate and multivariate correlation test were performed using valid factors from previous test. The bivariate test showed the correlation between individual waste factor and the cost overrun. The result is there are 17 waste factors with significance of 95% that correlate positively with cost overrun. Each factor has a medium correlation level. The result is shown in Table 5. These 17 factors were analyzed further. The multivariate correlation test measured the correlation between cost overrun and each waste category. The result showed that motion, waiting, and defects categories are strongly and positively correlated with cost overrun. The result is shown in Table 6.

3.5. Results of the Descriptive Analysis

The descriptive analysis resulted mean, standard deviation, minimum value, and maximum value of each factor. The mean and maximum value were used later for relative index analysis. The mean for main variable PB is

2. This indicates that the level of cost overrun currently occurring is between 10-20%.

3.6. Results of the Relative Index Analysis

The relative index analysis was carried out to determine the dominant waste factors using RII ranking. The analysis used frequency and impact data of 17 factors that showed positive correlation with 95% significance level in the previous bivariate correlation test. RFI, RSI, and RII was then calculated using formula (2), (3), and (4). The result of RII calculation is ranked. The mean of RII of all factors is 0.4. The factor with RII bigger than 0.4 is considered as a dominant factor. Seven dominant waste factors were determined which are waiting for the needed documents, the long and far meetings, waiting for feedback information, waiting for the document approval, outdated information, and producing dummy document. The result of RII calculation and ranking of factors are presented in Table 7.

Table 5. Bivariate correlation test result

Category	Factor	Correlation	Sig. 2 Tailed
Stock	X2	0.302	0.037
	X3	0.255	0.081
Motion	X5	0.361	0.012
	X6	0.403	0.004
	X7	0.436	0.002
	X8	0.297	0.041
Overproduction	X10	0.192	0.19
	X11	0.167	0.256
	X12	0.105	0.477
	X13	0.319	0.027
Waiting	X14	0.335	0.02
	X15	0.393	0.006
	X16	0.258	0.077
	X17	0.388	0.006
	X18	0.297	0.04
Over process	X19	0.182	0.215
	X20	0.35	0.015
	X21	0.323	0.025
	X22	0.242	0.097
	X23	0.319	0.027
Defects	X24	0.401	0.005
	X25	0.372	0.009
	X26	0.303	0.036
	X27	0.347	0.016
	X28	0.122	0.409

Table 6. Multivariate correlation test result

Category	Correlation	Sig. 2 Tailed
Stock	0.321	0.086
Motion	0.511	0.01
Overproduction	0.345	0.233
Waiting	0.525	0.016
Over process	0.414	0.147
Defects	0.511	0.022

Table 7. RII analysis result

Variable	N	RFI	RSI	RII	Ranking
X14	48	0.76	0.75	0.57	1
X5	48	0.71	0.69	0.49	2
X17	48	0.72	0.68	0.49	3
X15	48	0.69	0.69	0.48	4
X13	48	0.69	0.69	0.47	5
X24	48	0.57	0.75	0.43	6
X23	48	0.66	0.63	0.42	7
X27	48	0.62	0.64	0.40	8
X6	48	0.57	0.68	0.38	9
X20	48	0.56	0.66	0.37	10
X25	48	0.55	0.66	0.36	11
X21	48	0.53	0.69	0.36	12
X2	48	0.57	0.62	0.35	13
X8	48	0.63	0.54	0.34	14
X26	48	0.55	0.56	0.30	15
X7	48	0.62	0.49	0.30	16
X18	48	0.49	0.53	0.26	17

4. DISCUSSION

4.1. Research Results Discussion

There are seven dominant waste factors identified in the forms of waiting for the needed documents, long and far meetings, waiting for feedback information, waiting for the document approval, producing document with outdated information, error of provided information, and producing dummy document to meet target. The waste factors from waiting category dominated with three factors. Motion, overproduction, defect, and over processing, each has one waste factor.

Waste from waiting category indicates that there is poor planning and inefficient flow of information. The results are similar with [20] and [21] in which waiting is one of the dominant waste factors in construction project. The multivariate correlation test showed that waiting is the strongest correlated waste category to cost overrun. Waiting will result in more waste because there will be a stockpile of information and work in the future [18], delay of schedule [21], and additional resource to access and expedite the needed information [19]. From this argument, it is clear that waiting category will result in different category of waste. Pull-based planning will be useful in these cases to ensure the effective flow of information. The pull-based planning can be adopted and

Manifested in reforms change to streamline information flow and administrative procedure [20]. Moreover, constraints that stop the information should be addressed as soon as possible through informal communication and formal meetings.

From the overproduction category, the waste is producing document using outdated information. This waste will induce rework and poor-quality work in the future [17]. This waste was caused by several conditions such as poor planning, push-based planning, incapability in recognizing the value, and poor-knowledged employee [22]. In order to minimize this type of waste, the project team shall evaluate the information flow in the system using pull-bases planning and ensure the capability of employee in perceiving and processing the information.

The motion category that occurs as the dominant factor are long and far meetings. Meetings will require attention and physical presence of personnel not to mention the emotion that is drained along the way [23]. Meetings are the platform to control, monitor, and clarify all the constraints in the project. Manager shall ensure that meetings convey the valuable information with efficient timing. Moreover, the company can leverage the information system and technology to conduct efficient meetings which can save time to move and gather [19]. The motion waste category showed strong correlation to cost overrun based on multivariate correlation test.

The defects category that occurs as the dominant factor is error of information or deceptive information. This waste causes additional effort and resource to correct the information and unnecessary activities that result from its use [6]. It goes without saying that defects in information product will produce poor document. The processing of error information could be catastrophic and resulting in other forms of waste. Defects will induce rework, poor design, and waiting. Defects category is strongly correlated with cost overrun based on multivariate correlation test. This result is similar with [17] and [3-5]. This waste can be minimized by quality assurance procedure and control tool such as checklist.

The over processing category that occurs as the dominant factor is producing dummy document for unrealistic planning or making do. This happened many times due to progress-oriented mindset but only few realize that there will be many forms of waste occur. In this kind of case, the project team will perform their work based on incomplete preconditions and result in negative effects on quality and productivity [20]. The planning and work allocation shall be effective to cut this waste. The management skill of manager is crucial to map the allocation of work and manpower. In addition, employees are required to notify the manager if any inputs are incomplete. In summary, to manage all these factors successfully, PT. XYZ need to focus on:

- Value adding activities driven.
- Streamlined information flow.
- Pull-based project planning.
- Continuous improvement.
- Human resource improvement.

4.2. Conclusion

The results of this study show the seven dominant waste factors are: (X14) waiting for the needed documents, (X5) long and far meetings, (X17) waiting for feedback information, (X15) waiting for the document approval, (X13) producing document with outdated information, (X24) error of provided information, and (X23) producing dummy document to meet target. The waste categories with strong correlation to cost overrun are motion, waiting, and defects. These results give insights to the engineering manager of EPC project to develop effective strategies and approaches to waste reduction. Waste reduction in engineering phase will be greatly beneficial to the next phases as well. Furthermore, PT.XYZ can utilize lean thinking framework to identify and manage waste in all phases of EPC project. Lean principles should be implemented to gain advantage in completion time, productivity, and profitability of project.

PT. XYZ has several managerial implications based on finding of this research, which are:

- PT. XYZ needs to ensure all parties and teams understand their scope of work and responsibility in executing projects.
- PT. XYZ needs to evaluate the information system used for project. Integrated information system will benefit greatly.
- PT. XYZ needs to initiate pull-based planning instead of conventional push-based planning.
- PT. XYZ needs to gather and codify all knowledge and lesson-learned to ensure the quality of information and employee.
- PT. XYZ needs to put more effort into stimulate the motivation and creativity of employees.

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