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M-PERT and Lean Construction Integration on Steel Construction Works of Warehouse Buildings

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Abstract*: The growth of the manufacturing industry is quite high, The manufacturing industry is growing rapidly demanding more availability of factory buildings. The trend of using steel structures at this time is reasonable considering that WF steel can be a reliable support for the structure. The annual steel construction growth is predicted to reach reaches 5.5%, until 2025. Unfortunately, the number of lateness of steel construction projects reached 20-30% and it's waste reached 9.6%. Based on the delay problems mentioned above, the researchers implemented M-PERT to reduce the amount of delay and at the same time providing accurate scheduling that has an accuracy of up to 99%, while applying Lean Construction application could reduce waste down to 8%. The results of statistical analysis using SPSS obtained twelve influential factors, namely: building planning, scheduling, preparation, delivery methods, location optimization, work methods, activity duration distribution, network time determination, managing uncertainty supply, merging project activities, network similarities, timely scheduling. As a general illustration, the Lean Construction application could reduce the waste down to 7.78%. As for scheduling in steel construction, the application of M-PERT produced an accuracy of 98.89% or an error of 1.1%, interesting amount to be further study.

***Index Terms*: Steel construction, Lean construction, M-PERT, Accurate schedule, Reduce Waste**

I. INTRODUCTION

The progress of a nation can be seen from the progress of its industry. The more advanced the manufacturing industry, the demand for the supply of factory buildings, especially warehouses, will be even higher. Along with the rapid growth of the industry, the land used has become increasingly limited. Nonetheless, the demand for a room that is large enough is a must. Therefore, a popular warehouse design is a gable frame, because there is no middle support of the warehouse building.

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This type of warehouse construction type is sometimes referred to as clear span, as seen in figure 1. For example: if it is called clear span 23, clear span 30, or clear span 50, then we can immediately assume a building with a stretch of 23 m, without support in the middle of the building. If it is called clear span 30, it means the building with a span of 30 m without support in the middle. When large clear-span areas are required for special industrial and commercial projects, the gable frame type is typically the economical choice special in industrial building [1].

The reasons are quite strong in Indonesia for using steel as the mainframe, in this case, the factory building is:

1) Indonesia is known as the Ring of Fire [2]. In addition to the hazards posed by the numerous volcanoes that resulted in the ‘Ring of Fire’ appellation, communities situated around the Pacific Rim also have to contend with earthquakes, tsunami, storms, cyclones/typhoons, flood and bushfire [3], so that the strength of the building becomes very important. Because at any time an earthquake can occur. If the main building framework is not strong enough to support the allowance, it is feared that the building can collapse.

2) Structural steel market volume was estimated at nearly 125 million tons in 2015 and projected to grow at a CAGR of over 4,0% from 2016 to 2015 according to International Conference of Steel Structural. One country that has good growth (about 4%) according to structural steel international conferences is Indonesia. As industrial production increases, it will spur the industrial sector to increase factory expansion in order to increase production capacity [4], it is easy to repair. Compared to concrete, which is very difficult to repress. The tendency was dismantled in the damaged part and rebuilt. And, The concrete structural-frame construction has more associated energy use, CO_2, CO, NO_2, particulate matter, SO_2, and hydrocarbon emissions due to more formwork used, larger transportation impacts due to a larger mass of materials, and longer equipment use due to the longer installation process [5]. It’s must be carefully considered.

1) The Indonesian government, in this case, PUPR has the want to make steel construction a "mother of industry". This is in accordance with the potential that exists in Indonesia, that steel construction practitioners, that steel construction practitioners in Indonesia are very familiar with steel structures, whether fabrication and erection.

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2) Pull strength and compressive strength of steel have. almost the same value. If compared to concrete, the concrete is strongly pressed but it is not strong enough to resist the pull.

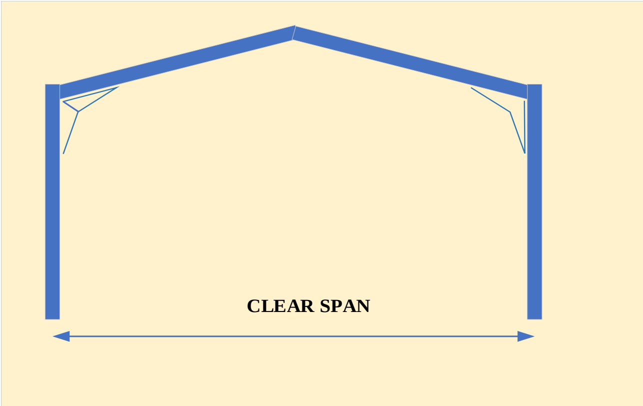

Figure 1. Clearspan

II. M-PERT AND LEAN CONSTRUCTION

A. Objectives and Theory

The objectives of this research are to study how optimizing the time and accuracy of scheduling with M-PERT, and how efficient the application of Lean Construction is on the Steel Construction project in factory buildings.

B. Program Evaluation Review Technique (PERT)

PERT Theory (Project Evaluation and Review Technique). It was noted in 1957 that the US Navy launched a Polaris type of missile project, to ensure the project was on time PERT. The scope was to develop and deploy fleet submarines carrying intercontinental nuclear missiles as fast as possible. The project was huge, extremely complex, and had to be executed under harsh time pressure. However, when the first missile was successfully launched in 1960 – several years ahead of the original schedule – it became regarded as an outstanding success [5]. By applying the PERT method can optimize project time to 4.85% from the time the original plan [6].

C. Critical Path Methode (CPM)

The classic Critical Path Method (CPM) has been widely used for network analysis and project planning in industry and in academe ever since its invention in 1950 [7]. The total duration of construction projects can be estimated by using deterministic Critical Path Method (CPM) or Probabilistic Evaluation and Review Technique (PERT)] scheduling techniques [8]. Although PERT and CPM differ to some extent in terminology and in the construction of the network, their objectives are the same [9].

D. Manual Program Evaluation Review Technique (M-PERT)

The theory of M- PERT (Manual PERT), this method is a development of PERT. Not done computerized, but manually as stated by the inventor of this theory. M-PERT allows manual calculation through a recursive merging procedure that downsizes the network until the last standing activity represents the whole project duration [10].

E. Lean Construction

Lean construction is a method used to design a product that minimizes waste, shortens its duration, and attempts to reach the maximum values. Lean construction refers to the application of lean production principles to construction [11]. In fact, the current conditions, waste in the construction sector is still higher than waste in the manufacturing sector.

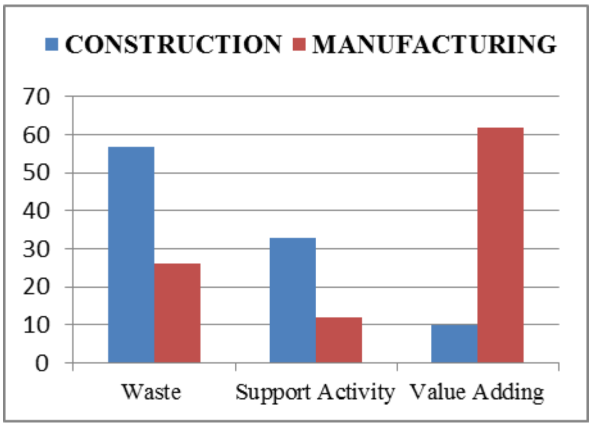

Figure 2. Waste Comparison
(Source: John Willey and Sons, 2009)

This is seen in the graph above, that's figure 2. Seen in figure 2 that the construction waste sector is far greater than the manufacturing sector. but the value adding of the construction sector has not been as expected. And for the support activity in the sector construction greater than the manufacturing sector. This is not as expected by construction practitioners. The calculation of waste simply is:

$$\textbf{\% Waste} = \frac{\text{buy volume} - \text{installed volume}}{\text{buy volume}} \quad \ldots\ldots\ldots \quad (1)$$

From equation (1), it can be seen, if fewer installed volumes, the percentage of waste increases. That is to say, the more material installed means the waste is smaller conversely if the less material installed means the more waste.

III. DATA PROCESSING AND METHOD

This research begins by starting some literature study. And Then go through the steps as illustrated in the flowchart below figure 3. This flowchart is a standard guideline for the author to facilitate checks and progress to be achieved.

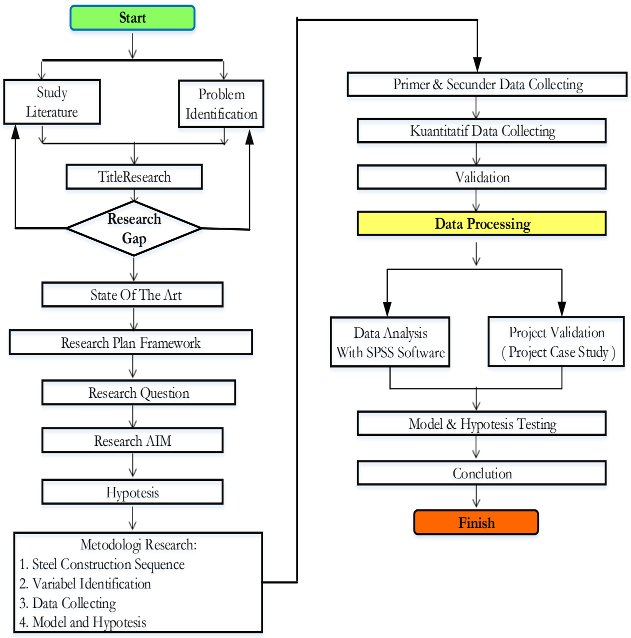

Figure 3. Research Flowchart

IV. DATA PROCESSING

The planning stage for office space construction is reflected in the organization structure and working technique that has to be determined from the early design phases [12]. SPSS is a powerful program which provides many ways to rapidly examine data and test scientific hunches. The SPSS implementation flowchart is as follows in Figure 4. From the processing of SPSS data, Cronbach's Alpha data was obtained between Steel Construction (X1), PERT / M-PERT (X2), Lean Construction (X3), Cost (Y1) and Time (Y2). Generally, Cronbach's alpha or also known as coefficient alpha is the main requirement in the reliability test. the tested data meets the requirements. Cronbach's alpha reliability coefficient normally ranges between 0 and 1. Cronbach's Alpha above 0.6 means all variables are declared consistent shown at Tables 1 to 5 that alpha coefficients close to 1.

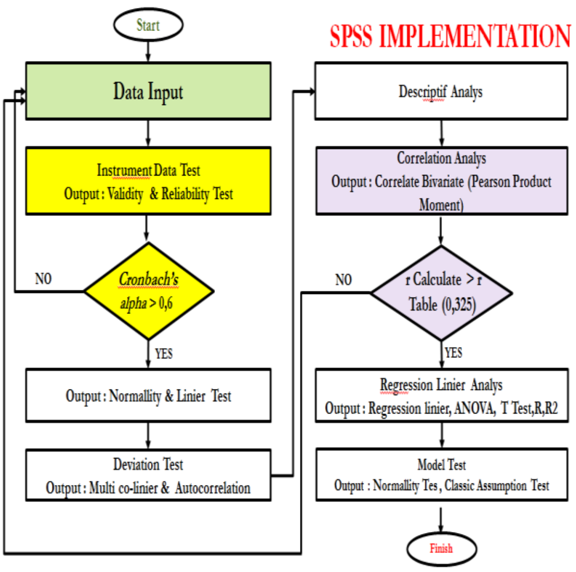

Figure -3. SPSS Implementation flowchart.

Table 1. Cronbach's Alpha X_1

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.987	0.987	14

Table 2. Cronbach's Alpha X_2

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.985	0.985	15

Table 3. Cronbach's Alpha X_3

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.959	0.959	7

Table 4. Cronbach's Alpha Y_1

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.969	0.969	4

Table 5. Cronbach's Alpha Y_2

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.977	0.977	7

The coefficients between independent and dependent variables can be seen as table 6 below.

Table 6. Coefisien X_1, X_2, X_3, Y_1

Coefficients[a]					
	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
(Constant)	0.212	0.489		0.435	0.666
X_1	0.279	0.048	0.978	5.846	0.000
X_2	0.136	0.065	0.489	2.087	0.044
X_3	-0.297	0.136	-0.495	-2.186	0.035
Dependent Variable : Y_1					

Lines of regression: There are two lines of regression first Y on X and second X on Y. The line of regression of Y on X is given by $Y = \alpha + \beta X$ where α and β are unknown constants known as intercept and slope of the equation [13]. That is used most often is the Pearson product – moment correlation coefficient, hereafter referred to as correlation in this article.

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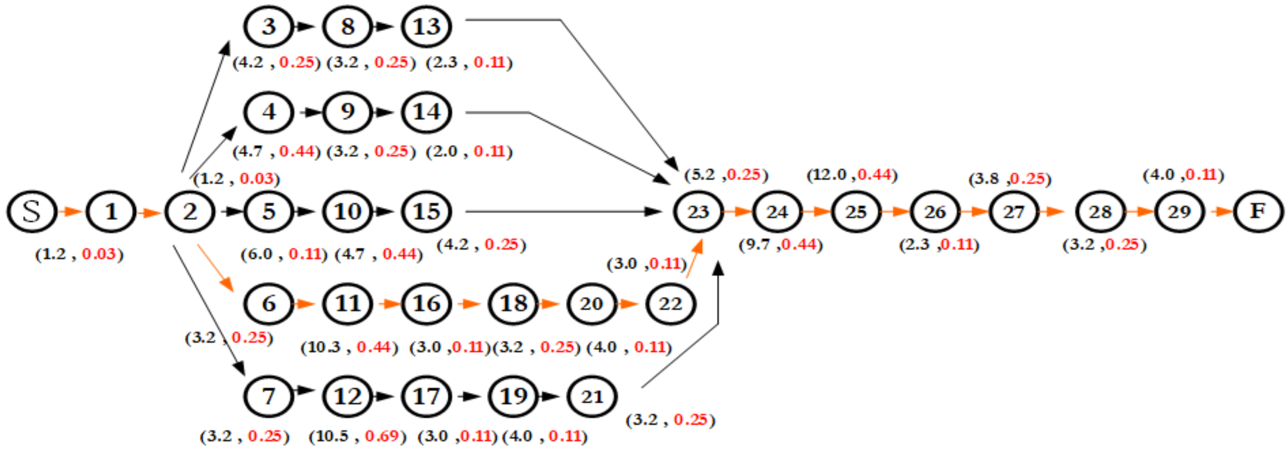
This statistic describes the size and direction of the linear relationship between two continuous variables (generically represented by X and Y), and ranges in value from –1.0 (perfect negative relationship) to +1.0 (perfect positive relationship); if no relationship exists between the two variables, the value of the correlation is zero [14]. From table 6 above, we can get a clue that X3 (lean construction) has a close relationship with Y1 (cost), although it is in the opposite direction. That is, if X3 is increasingly optimized, Y1 will drop. Conversely, if X3 is not optimal then Y1 will rise. The regression model formed is as :



Legend : 1)Survey 2)Marking 3)Tirod & Bracing fabrication, 4)Canopy fabrication 5)Purlin Fabrication 6)Base plate fabrication 7)Rafter haunch fabrication 8)Tirod & bracing blasting 9)Canopy blasting 10)Purlin blasting 11)Column fabrication 12)Rafter & beam fabrication 13)Tirod & bracing coating 14)Canopy coating 15)Purlin coating 16)Column haunch fabrication 17)Bracing & bracket fabrication 18)Side wall frame fabrication 19)Rafter & beam blasting 20)Column Blasting 21)Rafter & beam coating 22)Column coating 23)Delivery 24)Column erection 25)Rafter & beam erection 26)Bracing Erection 27)Purlin Erection 28)Tirod erection 29)Canopy erection S = Start F = Finish

Figure 5. Critical Path

Based on the application of the two equations, the following results are obtained (table 9):

To calculate the duration the following equation is used :

$$\mu p = \Sigma \mu i \quad \text{.............................} (4)$$

To calculate the variance the following equation is used

$$\sigma p = \sqrt{\Sigma v} \quad \text{..............................} (5)$$

Table 8. Duration & variance line 1,2,3,4 & 5

	Side	DURATION AND VARIANCE							TOTAL
Duration μ	Left	1.2	1.2	0	0	0	0	0	2.4
Variance σ		0.03	0.03	0	0	0	0	0	0.042426
Duration μ	Right	5.2	9.7	12	2.3	3.8	3.2	4	40.2
Variance σ		0.25	0.44	0.44	0.11	0.25	0.25	0.11	0.773886

$\mathbf{Y_1}$ = 0.212 + 0.279 X_1 + 0.136 X_2 - 0.297 X_3 .... (2)

Y2 = -0.221 + 0.320 X1 + 0.350 X2 - 0.406 X3 .... (3)

Table 7. Coefisien X_1, X_2, X_3, Y_2

Coefficients[a]

Model	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
(Constant)	-0.211	0.744		-0.284	0.778
X_1	0.320	0.073	0.647	4.404	0.000
X_2	0.350	0.099	0.727	3.532	0.001
X_3	-0.406	0.207	-0.390	-1.963	0.057

Dependent Variable: Y_2

I. MPERT CALCULATION

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Table 9. Duration & variance (left & right)

	LINE	DURATION AND VARIANCE							TOTAL
Duration μ	1	4.2	3.2	2.3	0	0	0	0	9.7
Variance σ		0.25	0.25	0.11	0	0	0	0	0.37027
Duration μ	2	4.7	3.2	2	0	0	0	0	9.9
Variance σ		0.44	0.25	0.11	0	0	0	0	0.51788
Duration μ	3	6	4.7	4.2	0	0	0	0	14.9
Variance σ		0.11	0.44	0.25	0	0	0	0	0.51788
Duration μ	4	3.2	10.3	3	3.2	4	3	0	26.7
Variance σ		0.25	0.44	0.11	0.25	0.11	0.11	0	0.595735
Duration μ	5	3.2	10.5	3	4	3.2	0	0	23.9
Variance σ		0.25	0.69	0.11	0.11	0.25	0	0	0.790759

Furthermore, for parallel mergers, the equation is used

$$\mu_k = \mu_i\phi(\delta) + \mu_j(1-\phi(\delta)) + \theta\phi(\delta) \quad \text{................} \ (6)$$

$$\sigma_k^2 = (\sigma_i^2+\mu_i^2)\phi(\delta) + (\sigma_j^2+\mu_j^2)(1-\phi(\delta)) + (\mu_i+\mu_j)\theta\phi(\delta) - \mu_k^2 \quad \text{....................} \ (7)$$

A. Merger Step

Based on table 9 and table 10, the next step is to do a serial merger as shown below :

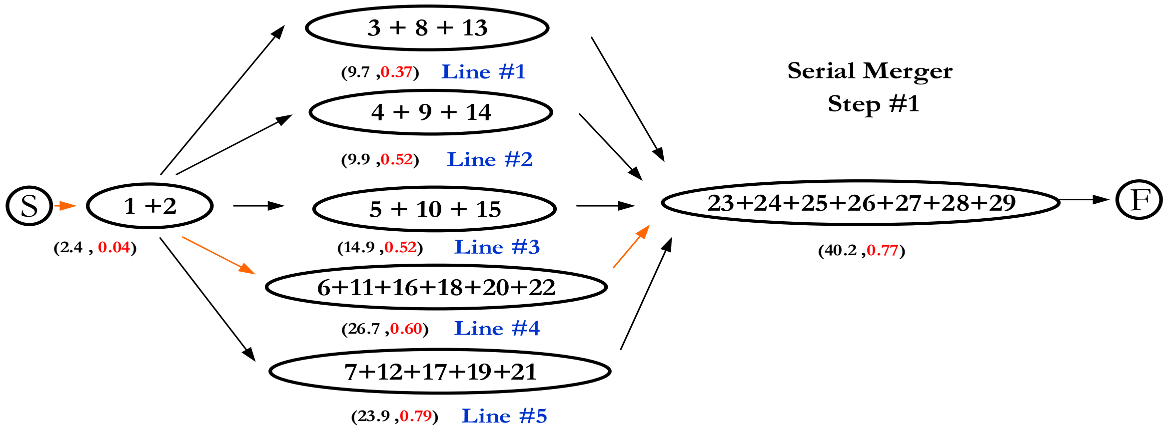

Figure 6. Step #1 Serial Merger

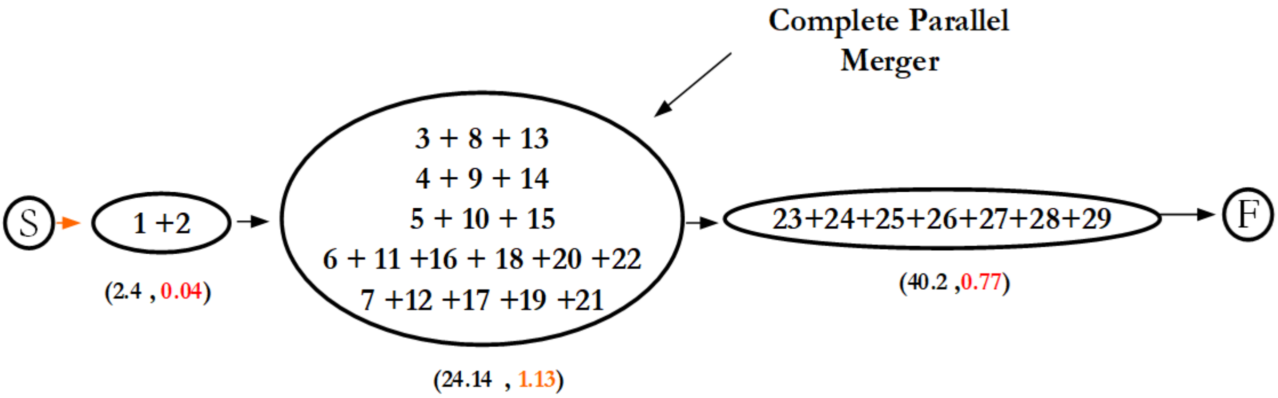

Figure 7. Complete Parallel Merger

Based on figure 7 above and using equations 4 and 5, new duration and variance are (66.74, 1.37)

Table 10. Accuration PERT & M-PERT

		On Site		PERT
Time (days)	63	66	69.3	66.74
Accuration			95.24%	98.89%

B. Lean Construction Implementation

Referring to table 6, that between lean construction and costs has a close relationship, but is inversely proportional. The benefits of lean and sustainability have been considered by many authors mainly on improvement of environmental quality, reduction in waste and the health and safety [15].

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To calculate the duration the following equation is used :

$$\mu p = \Sigma \mu i \quad (4)$$

To calculate the variance the following equation is used

$$\sigma p = \sqrt{\Sigma v} \quad (5)$$

Based on the application of the two equations, the following results are obtained (table 9) :

Step by step parallel merger is:

1. Merger line #1 with line #2
2. Merger line #1, #2 with line #3
3. Merger line #1, #2, #3 with line #4
4. Merger line #1, #2, #3,#4 with line#5

Waste minimization is a process that avoids, eliminates, or reduces waste at its source, enabling the reuse/recycling of waste to begin purposes [16]. Toyota production system, identified seven activities that failed to create value, as follows [17].

B. Over Production

Create a simple table that can give understanding to the operator how much waste is due to overproduction and how much profit, as could be seen in table 11.

Table -11. Control table sample for overproduction

Order	Production	Waste	Profit
7	7	7 - 7	7 - 0
5	6	6 - 5	5 - 1
6	8	8 - 6	6 - 2
3	6	6 - 3	3 - 3

C. Over Inventory

The cause of over inventory is fear of material shortages. So that the stock is carried out efficiently. Even though it's not needed. To overcome this problem, material data must be accurately collected.

With the support of sophisticated IT Technology today, good inventory dick is very possible

D. Waiting Time

Waiting time is caused by material or machinery or tools that are not ready for production. So the operator has no activity. To overcome this, good planning and communication are needed

E. Transportation

The main cause of waste in transportation is distance. It's Can distance between departments in a workshop plant. Or it could be because of the distance between the workshop and the supplier. Next, the distance of our workshop with the site. To overcome this, a minimum distance must be sought. The longer the ring delivery, the greater the waste transportation. Furthermore, research suggests that improved logistics will reduce the costs incurred in the system by low productivity, and save on indirect costs associated with the transportation and handling of construction materials [18].

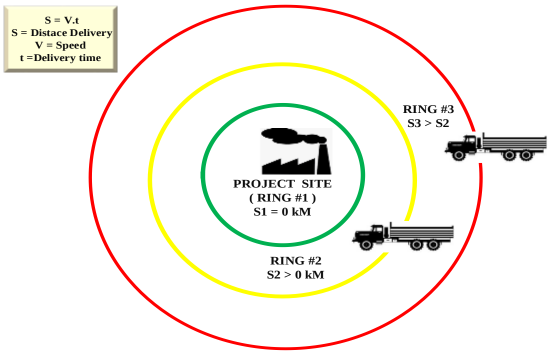

Fig.8. Ring of delivery

G. Over Processing

Over-processing occurs due to waiting time, for example, a blasting operator that should have finished the blasting process, but because the next material has not arrived. So he keeps on doing the blasting process continuously

H. Over Motion

The cause of waste because of the many motion or activities is the design of the production process that is not right, the absence of work standards, poor layout, and unorganized.

I. Defect

Definition of the defect is producing goods not according to order or designation. This can happen including: due to poor equipment, inappropriate material, weak quality control. From lean construction implementation our case study and compare with study literature about waste in steel construction obtained results:

Table -12. Material price for warehouse steel structural

No.	Description	Quantity		Unit Price (IDR)	Total Price (IDR)
1	WF 250 x 125 x 6 x9	49,641.00	Kg	16,000	794,256,000
2	WF 200 x 100 x 5,5x8	4,652.00	Kg	16,000	74,432,000
3	WF150 x 75 x 5 x 7 (1)	4,992.12	Kg	16,000	79,873,920
4	WF150 x 75 x 5 x 7 (2)	30,950.60	Kg	16,000	495,269,602
5	CNP 150 x 50 x 20 x 3,2	1,914.41	Kg	16,000	30,630,560
6	L 50 x 60 x 6	901.45	Kg	16,000	14,423,200
7	L 50 x50 x 5 & Plate Strip	118.47	Kg	16,000	1,895,520
8	All plate t=20, 12, 10, 5 mm	13,497.3	Kg	16,000	215,956,800
9	Bolt M 12, M 16, M 19	943.50	Kg	16,000	15,096,000
10	Tie rod 10 mm	1,176.00	Kg	16,000	18,816.000
11	Bracket	122.00	Kg	16,000	1,952,000
12	Fabrication & Erection	109,041.21	Kg	8,000	872,329,680
13	Coating Primer & finish	109,041.21	Kg	6,000	654,247,260
				TOTAL	3,269,118,540.00

Table 13. Before & after lean construction implementation

NO	DESCRIPTION	BEFORE		AFTER	
		Kg	IDR	Kg	IDR
1	WF 250 x 125 x 6 x9	4,765.54	76,248,576	4,418.05	70,688,784
2	WF 200 x 100 x 5,5x8	437.29	6,996,608	405.65	6,490,470
3	WF150 x 75 x 5 x 7 (1)	464.27	7,428,275	424.33	6,789,283
4	WF150 x 75 x 5 x 7 (2)	2,909.36	46,549,702	2,636.99	42,191,858
5	CNP 150 x 50 x 20 x 3,2	170.38	2,726,120	152.96	2,447,382
6	L 50 x 60 x 6	90.15	1,442,320	83.74	1,339,915
7	L 50 x50 x 5 & Plate Strip	11.73	187,656	187,656.48	175,336
8	All plate t=20, 12, 10, 5 mm	1,268.75	20,299,939	1,171.57	18,745,050
9	Bolt M 12, M 16, M 19	87.75	1,403,928	81.05	1,296,746
10	Trestang 10 mm	112.9	1,806,336	110.00	1,668,979
11	Bracket	11.47	183,488	10.66	170,605
12	Fabrication & Erection	9,050.42	72,403,363	8,319.84	66,558,754
13	Coating Primer & finish	10,795.08	64,770,479	10,064.50	60,387,022
		Total (before)	302,446,790	Total (After)	278,950,185

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Table 14. Lean Construction performance

Waste (%) Before	Waste (%) Before	Lean Construction Performance
Lean Implementation	Lean Implementation	(%)
9.25	8.53	7.78

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I. CONCLUSION

1. Lean Construction can effectively reduce waste, with a lean performance of 7.78 %.

3) The steel construction project in the case study 63 days of project planning time. Calculated with PERT or a critical path of 69.3 days. And Actual length of work 66 days. It means a difference of 3.3 days compared to the actual time on site or has accurate 95,24%. Calculations based on MPERT 66.74 days. It means a difference of 0.74 days compared to the actual time on site or has accurate 98.89%. So using M-PERT is more accurate.

3) Integration Lean Construction and M-PERT successfully to reduce waste and make scheduling more accurate like point 1 & 2 above

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