Research Article

Scheduling Analysis with Monte Carlo Simulation and Statistic Method on a Building Construction Project

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Abstract.
In the construction of an office building in Indonesia, a delay occurred in the first-floor concrete work. The project was planned to be completed in 161 days but it took 168 days to complete. This study analyzed the issues that arose by doing a scheduling analysis and by comparing the Monte Carlo Simulation and the Statistic method. A comparison between these methods was carried out to determine the project duration scheduling probability level from each method. The data included in the study were the project's Time Schedule and the interview data from respondents who were directly related to the office building construction project. Monte Carlo Simulation analysis showed that to get a 100% probability level, the duration can only be accelerated by two days, from 168 days to 166 days, while the Statistical method analysis showed that to get a 99.99% probability level the duration can only be accelerated by 4,2 days, from 168 days to 163.8 days. From the results above, it can be concluded that the Monte Carlo Simulation has a more accurate calculation than the Statistic Method because the result from the Monte Carlo Simulation was 166 days with a 100% probability level. It is close to the project realization duration which was 168 days.

Keywords: construction delay analysis, monte carlo simulation, statistic method comparison

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1. Introduction

In construction projects, scheduling is the key that holds the success of a project. The scheduling of a construction project should be planned carefully and optimally to avoid delays in project time. The deadline is in every general project, which means that the project must be completed before or on time. But in reality, a project duration doesn't always match the schedule that has been made. In construction projects, there are several types of scheduling methods that are commonly used for both small and large-scale projects.

Previous studies indicate that if a project is delayed, it can be rescheduled. Bustamin M. O., [1] research whose analysis uses the Monte Carlo Simulation shows that the shortest acceleration duration is 90 days with a 5% probability level, and the longest acceleration duration is 99 days with a 100% probability level. Pratama Y. A. [2] research whose analysis uses the PERT and Z Distribution Statistic Method shows that the shortest acceleration duration is 163 days which is faster than the planning (191 days) and realization (231 days). However, schedule completion with 163 days duration only gave a 57,1% probability level.

Based on the previous studies above, the Project Evaluation and Review Technique (PERT), Monte Carlo Simulation, and Z Distribution Statistic Method can be used to reschedule a project. Analysis of the project's scheduling method with the application of the PERT, Monte Carlo Simulation, and Z Distribution Statistic Method will be implemented in the construction of an office building in Indonesia, a delay occurred in the first-floor concrete work, and the project was planned to be completed in 161 days but in reality, it took 168 days to complete [3].

Both of Monte Carlo Simulation and Statistic Method analysis will provide a duration probability level. These methods will then be compared to see which method is the most accurate. The results of the comparative analysis from these methods are expected to help project workers to be able to plan project schedules with a high duration probability level [4].

2. Methods

The object of this study is an office building project in Indonesia that was delayed for seven days. This research was conducted by analyzing several methods, namely the Project Evaluation and Review Technique (PERT), Monte Carlo Simulation, and Z Distribution Statistic Method. The PERT method required the project's Time Schedule and interview data from respondents who are directly related to the office building construction project such as the Project Manager, Site Engineer, Engineer, etc. who had a minimum of five years of working experience. Obtained data then will be analyzed using these steps: 1) calculating the duration of each activity based on the results of the a, m, and b duration, 2) rescheduling each activity using the TE duration, 3) identifying the duration and determining the relationship between activities, 4) building a network diagram, 5) calculating the ES, EF, LS, LF, and TF value.

After the calculation of the PERT Method is done, the next step is to analyze it with Monte Carlo Simulation and Statistic Method. Monte Carlo Simulation is analyzed by determining the number of Iiteration that is needed for the simulation. Z Distribution Statistic Method will be analyzed by determining each activity's standard deviation and variance and then analyze the probability level. Both of these methods will provide a duration probability level, a comparison is made to see which method is the most accurate.

3. Result and Discussion

3.1. Project evaluation and review technique

Data for calculations in this study were obtained from interviews, data obtained from the respondents are optimistic duration (a), most likely duration (m), and pessimistic duration (b). Respondents who were interviewed are people that are directly related to the office building construction project such as Project Manager, Site Engineer, Engineer, etc. who had a minimum of five years of working experience. The results from the interviews were then averaged based on the a, m, and b, for each activity [5].

3.1.1. Expected duration analysis

After determining the estimated numbers for a, m, and b, the next step is to analyze the relationship between the three numbers into one expected duration number (TE). For example, the calculation for activity A would look as follow:

$$\frac{17 + (4\ x\ 19) + 22}{6} = 19 \tag{1}$$

Calculations for the expected duration (TE) can be seen in Table 1.

After obtaining the TE duration, a network diagram needed to be made to get the total duration of the building construction work in this study.

3.1.2. Building a network diagram

Large-scale projects require careful planning, scheduling, and coordinating various interrelated activities for the project to be successful. Therefore, a procedure was developed based on the use of a network diagram. The type of activity, the relationship between activities, and the duration of each activity are used as a reference in making the network. An example of a network diagram can be seen in Figure 1.

Table 1: Analysis on workplace well-being.

NO	ACTIVITY	AVERAGE DURATION (DAYS)			TE
		(a)	(m)	(b)	
I	PRELIMINARY WORK				
A	Preparatory Work	17	19	22	19
II	FIRST FLOOR				
B	Pile Work	17	19	22	20
C	Earth and Sand Work	17	18	21	19
D	Stone Foundation Work	19	20	22	20
E	Concrete	36	42	48	42
F	Masonry and Plaster	27	29	31	29
G	Floor and Wall Covering	24	28	30	28
H	Ceiling Work	11	14	16	14
I	Door and Window Frames	10	13	14	13
J	Painting	15	18	20	18
K	Ramp	4	6	8	6
L	Sanitary	24	27	29	27
M	Drainage Around the Building	18	20	23	20
III	SECOND FLOOR				
N	Concrete	26	29	32	29
O	Masonry and Plaster	28	29	31	29
P	Floor and Wall Covering	25	28	30	28
Q	Ceiling Work	20	22	25	22
R	Door and Window Frames	18	21	24	21
S	Painting	17	20	22	20
T	Sanitary	18	21	22	20
U	Roof	37	41	43	41
IV	MECHANICAL AND ELECTRICAL				
V	Electrical	45	48	50	48
W	Air Conditioning	18	21	23	21
X	Clean Water Pipe	63	66	72	67
Y	Dirty and Used Water Pipe	5	8	9	8
Z	Sound System	3	5	7	5
AA	CCTV	3	4	6	4
AB	Telephone	2	3	4	3
AC	Fire Alarm	24	27	29	27
AD	Lightning Rod	3	4	6	4
AE	MATV	2	3	6	4
AF	LAN	3	5	6	5
V	YARD AND PARKING LOT				
AG	Paving Block	29	33	35	33

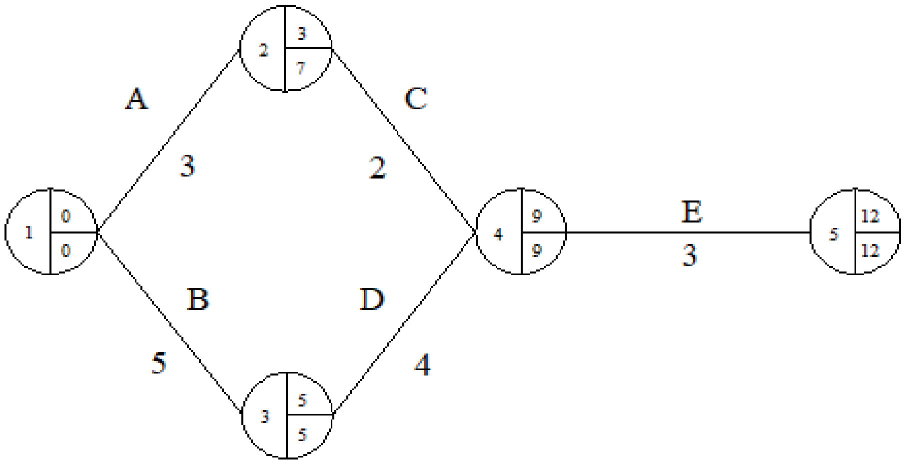

Figure 1: Network diagram.

3.1.3. Earliest start, earliest finish, latest start, and latest finish

After the network diagram has been made, the calculation for ES, EF, LS, and LF can be done. Earliest start (ES) is the fastest time an activity can be started, earliest finish (EF) is the fastest time an activity can be finished, latest start (LS) is the slowest time an activity can be started, and latest finish (LF) is the slowest time an activity can be finished. The calculation of ES, EF, LS, and LF can be seen in Table 2.

After the ES, LS, and EF, LF values are obtained, the Total Float can be calculated.

3.1.4. Total float

Calculation of the total float is implemented on all activities. From the ES, EF, LS, and LF values, the total float can be analyzed. Total float can be analyzed using this formula.

$$TF = LF - -Duration - -ES \tag{2}$$

Calculations of the Total Float can be seen in Table 3.

From the Total Float Calculation, it can be seen that there are some TF with 0 values. This shows that the critical path is in the activities with 0 values TF.

3.1.5. Critical path

The critical path can be seen from activities that have TF with 0 values. Based on the calculations above, the activities that are on the critical path are:

Table 2: ES, EF, LS, and LF.

NO	ACTIVITIES	Predecessor	Duration (Days)	ES	EF	LS	LF
I	PRELIMINARY WORK						
A	Preparation Work	-	19	0	19	0	19
II	FIRST FLOOR						
B	Pile Work	A	20	19	39	19	42
C	Earth and Sand Work	A	19	19	38	19	38
D	Stone Foundation Work	B	20	39	59	42	62
E	Concrete	C	42	38	80	38	80
F	Masonry and Plaster	E	29	80	109	80	109
G	Floor and Wall Covering	F	28	109	137	109	146
H	Ceiling Work	F	14	109	123	109	127
I	Door and Window Frames	E	13	80	137	80	146
J	Painting	N	18	88	106	93	127
K	Ramp	R	6	127	154	148	154
L	Sanitary	H	27	123	154	127	154
M	Drainage Around The Building	P, Q	20	116	136	121	141
III	SECOND FLOOR						
N	Concrete	D	29	59	88	62	93
O	Masonry and Plaster	D	29	59	88	62	100
P	Floor and Wall Covering	N	28	88	116	93	121
Q	Ceiling Work	O	22	88	110	100	126
R	Door and Window Frames	J	21	106	127	127	148
S	Painting	X	20	126	146	127	147
T	Sanitary	Q	20	110	130	126	146
U	Roof	F	41	109	150	109	150
IV	MECHANICAL AND ELECTRICAL						
V	Electrical	D	48	59	137	62	146
W	Air Conditioning	O	21	88	116	100	121
X	Clean Water Pipe	D	67	59	126	62	129
Y	Dirty and Used Water Pipe	M	8	136	144	141	149
Z	Sound System	Y	5	144	154	149	154
AA	CCTV	I, G, V, AC	4	137	141	146	150
AB	Telephone	T	3	130	146	146	149
AC	Fire Alarm	N	27	88	137	93	146
AD	Lightning Rod	U	4	150	154	150	154
AE	MATV	AA	4	141	154	150	154
AF	LAN	S, AB	5	146	154	149	154
V	YARD AND PARKING LOT						
AG	Paving Block	P, W	33	116	154	121	154

Table 3: Total float calculation.

ACTIVITIES	Duration (Days)	ES	LF	Duration (Days)
A	19	0	19	0
B	20	19	42	3
C	19	19	38	0
D	20	39	62	3
E	42	38	80	0
F	29	80	109	0
G	28	109	146	9
H	14	109	127	4
I	13	80	146	53
J	18	88	127	21
K	6	127	154	21
L	27	123	154	4
M	20	116	141	5
N	29	59	93	5
O	29	59	100	12
P	28	88	121	5
Q	22	88	126	16
R	21	106	148	21
S	20	126	147	1
T	20	110	146	16
U	41	109	150	0
V	48	59	146	39
W	21	88	121	12
X	67	59	129	3
Y	8	136	149	5
Z	5	144	154	5
AA	4	137	150	9
AB	3	130	149	16
AC	27	88	146	31
AD	4	150	154	0
AE	4	141	154	9
AF	5	146	154	3
AG	33	116	154	5

1. Activity A: Preparation work.
2. Activity C: Earth and sand work.
3. Activity E: Concrete Work (1st floor).
4. Activity F: Masonry and Plaster (1st floor).

5. Activity U: Roof Work.
6. Activity AD: Lightning Rod Work

The critical path formed from these activities is A-C-E-F-U-AD. The critical path needs to be determined because only activities that are on the critical path have an influence on the acceleration of the total project's duration.

3.2. Monte carlo simulation

The first step in Monte Carlo Simulation is to determine iteration value is by calculating the standard deviation. The maximum and minimum values are 168 and 154 days, and the total population is two. Standard deviation is calculated by using this formula [6].

$$\sigma = \sqrt{\frac{\sum (168 - \ 154)^2}{2}} = 9,89 \tag{3}$$

The second step is to determine the absolute error value which is less than 1%, absolute error is calculated by using this formula:

$$= \frac{154}{\frac{1}{0,01}} = 1,54 \tag{4}$$

The last step is to determine the number of iterations required with less than 2% error, number of iterations is calculated by using this formula:

$$N = (\frac{3\ x\ 9,89}{1,54})^2 = 371,90 = 372 \tag{5}$$

From the calculations above, the number of iterations for the Monte Carlo Simulation is 372 times.

3.2.1. Monte carlo simulation calculation

In this study, Monte Carlo simulation is analyzed by generating a random number using the RAND function in Microsoft Excel. For example, the calculation for activity A would look as follows:

$$= RAND() * (22 - 17) + 17 \tag{6}$$

Monte Carlo simulation calculation is only implemented on activities whose activities are in a critical path. The calculation for the Monte Carlo simulation can be seen in Table 4.

Table 4: Monte carlo calculation.

Activity	Duration	Iteration	Iteration	Iteration	Iteration	Iteration	Iteration	Iteration	Duration
	(a)	(b)	1	2	3	4	5	6	7
A	17	22	19	19	20	22	20	18	20
C	17	21	19	19	20	19	18	20	20
E	36	48	47	43	48	46	42	38	39
F	27	31	28	29	30	29	28	29	31
U	37	43	39	39	40	43	38	39	37
AD	3	6	5	6	4	6	4	6	3
		Total	158	154	162	165	150	151	149
	(a)	**(b)**	**366**	**367**	**368**	**369**	**370**	**371**	**372**
A	17	22	17	20	19	18	22	17	17
C	17	21	17	18	18	20	20	18	17
E	36	48	37	38	45	41	45	40	46
F	27	31	28	29	28	29	29	30	27
U	37	43	39	42	41	42	39	42	38
AD	3	6	5	5	4	4	4	3	4
		Total	145	151	156	153	157	150	150

The calculation results from the table above are then translated into a graph to see the percentage of the probability level duration.

3.2.2. Monte carlo simulation duration probability level graph

Based on Table 4, a frequency distribution and graph combination of Probability Density Function (PDF) and Cumulative Distribution Function (CDF) can be made. PDF is a function that gives a likelihood of a random variable to have a value, CDF is a function that sums the possible values up to a certain event. Table of analysis of simulation results with PDF and CDF values can be seen in Table 5.

The graph of the duration probability level 1% error value, with a combination of PDF and CDF can be seen in Figure 2.

From the table and the graph, it can be seen that the shortest duration is 143 days, but the duration probability level is only 0,27% with a risk of failure 99,73%. To get a 100% probability level with 0% risk of failure, the required duration is 166 days.

Table 5: Monte carlo calculation with PDF and CDF.

Activity	**Duration**		**Iteration**	**Iteration**	**Iteration**	**Iteration**	**Iteration**	**Iteration**	**Iteration**
	(a)	**(b)**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
A	17	22	19	19	20	22	20	18	20
C	17	21	19	19	20	19	18	20	20
E	36	48	47	43	48	46	42	38	39
F	27	31	28	29	30	29	28	29	31
U	37	43	39	39	40	43	38	39	37
AD	3	6	5	6	4	6	4	6	3
		Total	158	154	162	165	150	151	149
Activity	**Duration**		**Iteration**	**Iteration**	**Iteration**	**Iteration**	**Iteration**	**Iteration**	**Iteration**
	(a)	**(b)**	**366**	**367**	**368**	**369**	**370**	**371**	**372**
A	17	22	17	20	19	18	22	17	17
C	17	21	17	18	18	20	20	18	17
E	36	48	37	38	45	41	45	40	46
F	27	31	28	29	28	29	29	30	27
U	37	43	39	42	41	42	39	42	38
AD	3	6	5	5	4	4	4	3	4
		Total	145	151	156	153	157	150	150

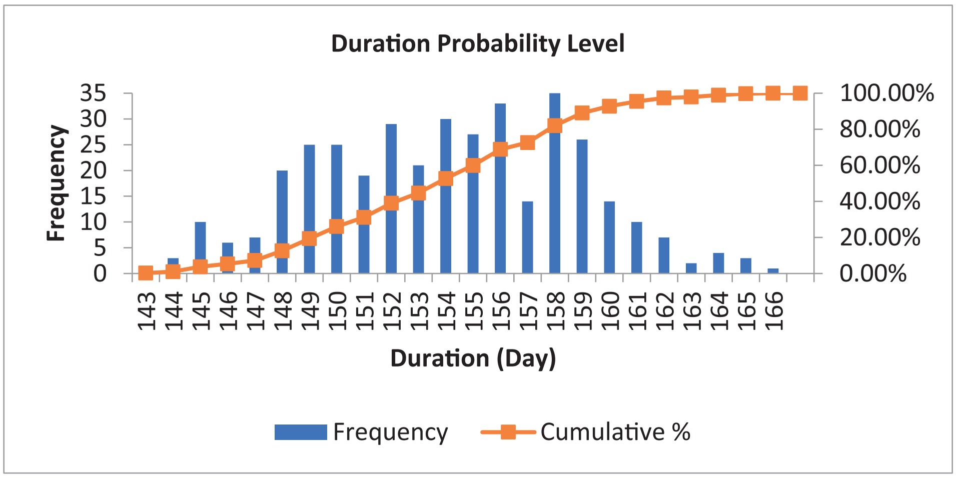

Figure 2: Monte carlo duration probability level.

3.3. Z distribution statistic method

Estimation for the PERT method uses a time span and not a definite period of time. This time span marks the degree of uncertainty. The parameters that describe this problem are known as Standard Deviation and Variance. The smaller the value of the Variance indicates more certain activity can be completed and vice versa.

Standard Deviation and Variance can be calculated using the following formulas:

$$S = \frac{1}{6} x b - a \tag{7}$$

$$V = S^2 \tag{8}$$

Calculations for Standard Deviations and Variances can be seen in Table 6.

From the calculation above, V values that on the critical path is 6,35.

3.3.1. Analysis of scheduling target

According to the network diagram that has been made, the total expected duration (TE) = 154 days, and the total activity variance (V/S^2) = 6,35. The relationship between the expected time (TE) and the target (TD) is stated in z. The probability level of the project being completed on the desired target (TD) = 161 days can be determined by using the following calculation:

$$z = \frac{T(d) - TE}{\sqrt{S}} = \frac{161 - 154}{\sqrt{6,35}} = \frac{7}{2,52} = 2,78 \tag{9}$$

z = 2,78 = 0,9973 (obtained from Z Cumulative Normal Distribution Table)

Probability value = 0,9973 x 100% = 99,73%

To obtain several possibilities from the project duration, several calculations were taken. The results of the sample can be seen in Table 7.

According to the Table, it can be seen that the shortest duration is 145 days, but the duration probability level is only 0,02%. To get a 99,99% probability level, the required duration is 163,8 days.

3.4. Comparative analysis between monte carlo simulation and Z distribution statistic method

Monte Carlo Simulation is analyzed by generating a random number using the RAND function in Microsoft Excel. From the calculation, the number of iterations that needed is 372 times. Based from the iterations, the duration obtained varies from the shortest duration which is 143 days, and the longest duration which is 166 days. From the table and graph, it can be seen that the shortest duration (143 days) probability level is 0,27%, while the longest duration (166 days) probability level is 100%. Z Distribution Statistic Method is analyzed by determining Standard Deviation and Variance from estimated numbers of optimistic duration (a), most likely duration (m), and pessimistic duration (b) [7]. From the calculations it can be seen that the duration obtained varies from the

Table 6: Standard deviations and variances.

NO	ACTIVITY	AVERAGE DURATION (DAYS)			S	S²
		(a)	(m)	(b)		
I	PRELIMINARY WORK					
A	Preparatory Work	17	19	22	0,767	0,588
II	FIRST FLOOR					
B	Pile Work	17	19	22	0,833	0,694
C	Earth and Sand Work	17	18	21	0,633	0,401
D	Stone Foundation Work	19	20	22	0,567	0,321
E	Concrete	36	42	48	1,867	3,484
F	Masonry and Plaster	27	29	31	0,767	0,588
G	Floor and Wall Covering	24	28	30	1,033	1,068
H	Ceiling Work	11	14	16	0,867	0,751
I	Door and Window Frames	10	13	14	0,633	0,401
J	Painting	15	18	20	0,867	0,751
K	Ramp	4	6	8	0,633	0,401
L	Sanitary	24	27	29	0,767	0,588
M	Drainage Around The Building	18	20	23	0,867	0,751
III	SECOND FLOOR					
N	Concrete	26	29	32	0,900	0,810
O	Masonry and Plaster	28	29	31	0,633	0,401
P	Floor and Wall Covering	25	28	30	0,767	0,588
Q	Ceiling Work	20	22	25	0,833	0,694
R	Door and Window Frames	18	21	24	0,933	0,871
S	Painting	17	20	22	0,833	0,694
T	Sanitary	18	21	22	0,733	0,538
U	Roof	37	41	43	1,000	1,000
IV	MECHANICAL AND ELECTRICAL					
V	Electrical	45	48	50	0,800	0,640
W	Air Conditioning	18	21	23	0,767	0,588
X	Clean Water Pipe	63	66	72	1,500	2,250
Y	Dirty and Used Water Pipe	5	8	9	0,667	0,444
Z	Sound System	3	5	7	0,600	0,360
AA	CCTV	3	4	6	0,500	0,250
AB	Telephone	2	3	4	0,433	0,188
AC	Fire Alarm	24	27	29	0,800	0,640
AD	Lightning Rod	3	4	6	0,533	0,284
AE	MATV	2	3	6	0,667	0,444
AF	LAN	3	5	6	0,567	0,321
V	YARD AND PARKING LOT					
AG	Paving Block	29	33	35	1,067	1,138
				V Total	Critical Path	6,35

shortest duration which is 145 days, and the longest duration is 163,8 days. The duration

Table 7: Probability value analysis.

Duration (Days)	Z	Distribution	Probability Level (%)
145	-3,57	0,0002	0,02%
146	-3,17	0,0008	0,08%
147	-2,78	0,0027	0,27%
148	-2,38	0,0087	0,87%
149	-1,98	0,0239	2,39%
150	-1,59	0,0559	5,59%
151	-1,19	0,1170	11,70%
152	-0,79	0,2148	21,48%
153	-0,40	0,3446	34,46%
154	0,00	0,5000	50,00%
155	0,40	0,6554	65,54%
156	0,79	0,7852	78,52%
157	1,19	0,8830	88,30%
158	1,59	0,9441	94,41%
159	1,98	0,9761	97,61%
160	2,38	0,9913	99,13%
161	2,78	0,9973	99,73%
162	3,17	0,9992	99,92%
163	3,57	0,9998	99,98%
163,8	3,89	0,9999	99,99%

probability level for the shortest (145 days) is 0,02% and the duration probability level for the longest duration (163,8 days) is 99,99%.

4. Conclusion

Based on the discussion and analysis that has been described previously, several conclusions are obtained:

1. Monte Carlo Simulation analysis shows that the shortest duration of 143 days only has a 0,27% probability level, whereas the 166 days duration has an 100% probability level, which is only two days different from the realization duration (168 days).

2. Analysis using the Statistic Method shows that the shortest duration of 145 days but with a probability level of only 0,02%. To get a 99,99% duration probability level, the building construction work must be done in 163,8 days, which 4,2 days different from the realization duration (168 days)

3. Analysis using the Monte Carlo Simulation has a more accurate calculation than using the Statistic Method because the Monte Carlo Simulation analysis obtained result is 166 days with an 100% probability level, close to the project realization duration which is 168 days. While the Statistic Method obtained a duration which is 163,8 days with a probability level 99,99%, which 4,2 days different from the realization duration (168 days).

References

[1] Bustamin MO. Study of Acceleration Scheduling of Landing Craft Utility (LCU) with Monte Carlo Simulation Method, 2015. Thesis of Institute of Technology Sepuluh November.

[2] Pratama YA. Project Scheduling Analysis Using PERT Method, 2020. Thesis: The State Islamic University.

[3] Widiasanti I, and Lenggogeni. *Management Construction*, Rosda Bandung; 2013.

[4] Husen A. Management Project. Andi Yogyakarta; 2010.

[5] Soeharto I. Management Project from Conceptual to Operational. Airlangga Jakarta; 1999.

[6] Ersahin T, McCabe B, Mark D. Monte Carlo Simulation Analysis at Lester B Pearson International Development Project. ASCE; 2003. https://doi.org/10.1061/40671(2003)107.

[7] Pang CK, Mohd-Lair NA, Chua YS. Using PERT to Optimise the Completion Time of Air-Conditioning and Mechanical Ventilation (ACMV) Project. Trans Tech Publications Ltd Switzerland; 2019. https://doi.org/10.4028/www.scientific.net/AMM.892.266.