

Scheduling Analysis using CPM, PERT, and LoB Method

Milinda Nur Indah Puspita*, I Nyoman Dita Pahang Putra

Universitas Pembangunan Nasional "Veteran" Jawa Timur

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*Correspondence: Milinda Nur Indah

Puspita

Email: melindanurindah@gmail.com

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Abstract: Project delays frequently occur in construction projects and often result from the inability to accurately identify critical activities within the project network, leading to ineffective time control. Therefore, it is necessary to apply scheduling methods that are appropriate to the characteristics of the project in order to improve time control effectiveness and minimize the risk of delays. The aim of this research is to analyze scheduling results using the Critical Path Method, Program Evaluation and Review Technique, and Line Of Balance method. Also, to determine the difference in project completion duration using the PERT, CPM and LoB Methods. This research employs a quantitative method with a comparative approach, using secondary data that was obtained from a supervisory consultant. The data includes the durations and the work list. The analysis data is obtained to determine the critical path using PERT, CPM and LoB methods. The PERT method calculates three estimation times: optimistic duration, most likely duration, and pessimistic duration to determine the critical path. The results show the CPM and LoB method predicts the completion project in 159 days, and the PERT method predicts the completion project in 164 days. The difference in completing the project using the CMP and PERT methods is 5 days. The difference in project completion duration between LOB and PERT is 5 days. In contrast, no difference is observed between the CPM and LOB methods, as both yield an identical project completion time of 159 days.

Keywords: CPM, Duration, LoB, PERT, Scheduling

Introduction

Nowadays, the construction sector in Indonesia continues to grow to meet the community's needs and is expected can bring a positive impact for Indonesia's economic growth (Abma, 2016). Especially in road development, which has a crucial role in Indonesia's economy and regional connectivity. The efficient and high-quality road development is a top priority in various regions, including Surabaya City. Project delays became a problem that appears frequently, which then has an impact on all work in that project (Perdana & Rahman, 2019). Delays that are not immediately addressed cause serious problems, so that is necessary to handle them, namely by carrying out project management (Ramadhan & Sugiyono, 2019). Pramuja et al. (2025) emphasized that one of the causes of project delays is the inability to accurately identify the activities that are truly critical within the project network, resulting in ineffective time control. Project delays that are not

addressed promptly can lead to serious issues, thereby necessitating the implementation of proper project management (Kharina & Sambowo, 2019).

Project management is the planning, implementation, control, and coordination of a project from beginning to end to get the optimal, effective, and efficient result in terms of time, budget, and project quality (Erviyanto, 2023). Effective project management can predict budget and time scheduling needs to minimize the loss due to delays during the project (Alawiyah et al., 2022). This is consistent with the findings of Nanda et al. (2023), who stated that project schedule reliability can be significantly enhanced when scheduling methods account for uncertainties and dynamic conditions in the field. Arianie and Puspitasari (2017) state four functions of project management: there is a planning function, to decision-making function that manages selected data and information to be carried out in the future.

Organizing function to unite a collection of human activities, which have their own activity are interconnected (Yusna, 2025). Actuating function to align all members of the organizations involved in carrying out activities. The controlling function measures the performance quality, analyzes, and evaluates activities (Fadila et al., 2024). From several aspects that add value to project management, scheduling is an important aspect in project planning. Scheduling can give information about the timeline, project progress related to resources, like budget, manpower, tools, and materials, also time and progress estimation to finish the project (Megawati, 2021). Scheduling is an available time allocation process to implement every work to finish a project until the optimal result, considering existing obstacles (Fazis & Tugiah, 2022).

The Road X development project is experiencing delays. This causes problems in the sustainability project to finish due to the planned schedule. The scheduling method used in this project is the Bar Chart method. While the Bar Chart provides a clear representation of the execution time for each activity, it has notable limitations, particularly in illustrating the sequence of tasks and the interdependencies among project activities (Susanti & Lukman, 2019). This research proposes the use of the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) for scheduling the project.

CPM is a method used to analyze and make a work sequence in the project by analyzing the most complicated or the longest duration. CPM is used to predict a project's minimum duration, represented by the critical path (Pamungkas et al., 2024). CPM can also determine schedule flexibility or total float. Several recent studies have emphasized the importance of accurate scheduling methods. Badriyah et al. (2025) stated that the Critical Path Method (CPM) can accurately identify the critical path, thereby facilitating the control of activities that may cause delays. CPM has also been shown to enhance the accuracy of duration estimates in infrastructure projects such as road construction.

Otherwise, the PERT method is used to evaluate a project, minimizing delays, conflicts, or disruptions, and to coordinate and synchronize all project activities, thereby facilitating acceleration to complete the project (Oktafiana & Baroroh, 2022). The PERT method is used to address uncertainty in the duration of an activity. PERT uses an approach that assumes activity durations depend on numerous factors and variations (Hadicara et al., 2023). Therefore, the PERT method utilizes three estimates to create a project schedule: the optimistic duration time, the most likely time, and the pessimistic duration time (Soeharto,

1999). This method also includes other parameters for quantitatively measuring uncertainty, namely standard deviation and variance. Yus et al. (2023) also emphasized that PERT is more effective than CPM in analyzing time-related risks in project conditions characterized by a high level of uncertainty.

According to Wicaksono and Putra (2024), scheduling methods that are capable of accurately identifying the critical path, such as the Critical Path Method (CPM), have proven to be more effective than simple visual approaches, such as the S-Curve, particularly in projects with complex and interdependent activity structures. The results of their study indicate that CPM produces a more optimal project duration as well as improved cost efficiency. The CPM results in 9 days shorter than the S-Curve.

Farhan et al. (2024) do research using the CPM and PERT methods to analyze the schedule for the KONI building development project in Centar Jakarta. They conclude that CPM results in a shorter duration than the PERT method. Otherwise, Lubis et al. (2021) do research using the same method to optimize scheduling toll road Becakayu section 1bc development project. They conduct the PERT method results 2 days shorter than the CPM method. Based on the previous research, the CPM and PERT methods both have advantages, depending on several aspects like project type, number, and complexity of activity, as well as uncertainty about the timing of each activity. This research aims to determine the results of identifying project completion duration using the CPM and PERT methods. Also, to determine the difference in project completion duration using the CPM and PERT Methods.

Methodology

This research employs a quantitative method with a comparative approach. Quantitative research method is a method us to solve problems that uses numerical data and statistical programs (Fauzah et al., 2024). This research uses analysis and calculation to schedule duration as a comparison between the two methods.

This research uses secondary data. Secondary data is data that is not obtained directly, or data that is obtained and collected from previous literature studies related to research. The data used in this research are the schedule, the s-curve, work list in the project that was obtained from the supervisory consultant. The work used to calculate the scheduling duration starts from the initial work until the end of the project is completed. The work list used is: preliminary work, earth work, channel and masonry work, road work, road paving work, other work, and electrical power connection and licensing work.

The steps for analyzing the completion schedule of a project using CPM are as follows: Identify activities, create the network diagram, calculate the forward pass, and then calculate the backward pass. Then calculate the total float and determine the critical path (Putra & Sekarsari, 2020). Otherwise, the steps for analyzing using PERT methods are: identify activities, determine three estimation times, then calculate expected time, standard deviations, also variances. Next, create a network diagram to identify the critical path (Sinurat & Misdalena, 2024).

Result and Discussion

The Road X development project is one of the strategic steps to improve connectivity and comfort for transportation in the West Surabaya Region. The assignee on the project is the Department of Water Resources and Highways. The total length of this road project is 350 meters, with a project duration of 159 days. In this project, the scheduling is using the bar-chart method (S-Curve).

Project Scheduling Using the Program (PERT) Method

PERT method using three-time estimation, namely optimistic time (a), pessimistic time (b), and realistic time (m). In this project, optimistic and pessimistic times were obtained from interviews with two of the project participants. The values used are the averages of the results from these interviews, as shown in Table 1. Otherwise, the realistic time is based on the analysis of the project implementation schedule data. After obtaining time implementation using three estimations, they can obtain the expected time (te), standard deviation (s), also variance (v). The following calculation details.

- a. Determine the expected time (te)

$$\begin{aligned} \text{te A1 work} &= \frac{a+4m+b}{6} \\ &= \frac{19+4 \times 21+23,5}{6} = 21 \end{aligned}$$

- b. Determine Standar Deviasi (s)

$$\begin{aligned} S \text{ A1 work} &= \frac{b-a}{6} \\ &= \frac{23,5-19}{6} = 0,75 \end{aligned}$$

- c. Determine Variance (v) activity

$$\begin{aligned} v(\text{te}) \text{ Pekerjaan A} &= s^2 = \left(\frac{b-a}{6}\right)^2 \\ &= 0,667^2 = 0,563 \end{aligned}$$

The results of other work calculations are displayed in Table 1.

Table 1. Time Estimation Project and Calculation of te, s, and v(te)

NO	JOB DESCRIPTION	CODE	PREDECESSOR	DURATION			te	te	S	V(te)
				a (days)	m (days)	b (days)	$\frac{a+4m+b}{6}$	Integration (days)	$\frac{b-a}{6}$	$\left(\frac{b-a}{6}\right)^2$
I PRELIMINARY WORK										
1	Preparation and Hire of Directors Keet	A1	A4	19	21	23,5	21	22	0,750	0,563
2	Making Project Nameplates	A2	A1	7	7	7,5	7	8	0,083	0,007
3	Preparation (Mobilization & Demobilization)	A3	A4	7	7	8	7,17	8	0,167	0,028
4	Uitzet With WaterPass / Theodolite	A4	X	7	7	7,5	7,08	8	0,083	0,007
5	Test Hole	A5	A3	7	7	8	7	7	0,167	0,028
6	Making Bouwplank	A6	A5	7	7	8	7,17	8	0,167	0,028
II EARTHWORKS										

NO	JOB DESCRIPTION	CODE	PREDECESSOR	DURATION			te	te	S	V(te)
				a (days)	m (days)	b (days)	$\frac{a+4m+b}{6}$	Integration (days)	$\frac{b-a}{6}$	$\left(\frac{b-a}{6}\right)^2$
1	Soil Excavation	B1	A6	84	91	97	91	91	2,167	4,694
2	Landfilling Back	B2	B1	52	56	61	56,17	57	1,500	2,250
3	Sirtu (Solid) Backfilling	B3	B1	57,5	63	67	62,75	63	1,583	2,507
4	Transportation of Soil Out of Project	B4	B1	85,5	91	97,5	91	92	2,000	4,000
III DUCT AND PAIR WORK										
1	Procurement of Corrugated Concrete Sheet Pile W 400 Type B	C1	A6	38	42	46,5	42	43	1,417	2,007
2	Installation/Penetration of Corrugated Concrete Sheet Pile W 400 Type B	C2	C1	32	35	38,5	35	36	1,083	1,174
3	Corrugated Concrete Sheet Pile Cutting	C3	C2	32	35	38,5	35	36	1,083	1,174
4	Procurement and Installation of Precast U-Decker	C4	B2	39	42	46	42,17	43	1,167	1,361
5	Procurement and Installation of Bottom Cover	C5	C4	39	42	46	42,17	43	1,167	1,361
6	Procurement and Installation of Top Cover	C6	C5	39	42	46	42,17	43	1,167	1,361
7	Procurement and Installation of U-Ditch + Precast U-Ditch Cover	C7	B2	39	42	46	42,17	43	1,167	1,361
8	Polythene Layer	C8	C7	58,5	63	68	63	64	1,583	2,507
9	Split River Stone Pair	C9	C7	61,5	63	69	64	64	1,250	1,563
10	Wiremesh Reinforced Concrete Work M6-150 FC 20 Mpa	C10	C8	58,5	63	68	63	64	1,583	2,507
11	Reinforced Concrete Casting Work (Fc 30 Mpa) Concrete Caping	C11	C17	46	35	52,5	40	40	1,083	1,174
12	Reinforced Concrete Casting Work for Safety Pegs (FC 30 Mpa)	C12	C11	26	28	30,5	28	29	0,750	0,563
13	FC 20 Mpa Concrete Sloof Work for Manhole	C13	C10	57,5	63	68	63	63	1,750	3,063
14	Procurement and Installation of Precast Water Channel U-Gutters	C14	C7, C5	38	42	46,5	42	43	1,417	2,007
15	Round Color Manhole Grill (Cover & Frame) Precast	C15	C13	26	28	31	28	29	0,833	0,694
16	Crossing Grill	C16	F4	13	14	16	14	15	0,500	0,250
17	Reinforcement Work with Concrete Iron (Plain/Threaded)	C17	C3	45	49	54	49	50	1,500	2,250
IV PEDESTRIAN FLOORING WORKS AND ITS COMPLETENESS										
1	Installation of Black Andesite Stone	D1	C10	32	35	38,5	35	36	1,083	1,174

NO	JOB DESCRIPTION	CODE	PREDECESSOR	DURATION			te	te	S	V(te)
				a (days)	m (days)	b (days)	$\frac{a+4m+b}{6}$	Integration (days)	$\frac{b-a}{6}$	$\left(\frac{b-a}{6}\right)^2$
2	Yellow Stopper Granite Tactile Installation	D2	D1	32	35	38,5	35	36	1,083	1,174
3	Procurement and Installation of Road Safety Stakes (Bollards), natural stone motif finishing.	D3	D2	12,5	14	15,5	14	14	0,500	0,250
4	Concrete Sloof Work for FC 20 Mpa Park	D4	C13	57,5	63	68	63	63	1,750	3,063
5	Planting Pink & White Tabebuaya trees	D5	D8	13	14	16	14	15	0,500	0,250
6	Red Brick Pair	D6	D4	32	35	38,5	35	36	1,083	1,174
7	Smooth Plastering	D7	D6	26	28	30,5	28,08	29	0,750	0,563
8	Acian	D8	D7	19	21	24	21,17	22	0,833	0,694
V STREET LIGHTING WORK										
1	PJU LED Light Installation Ready to Turn on	E1	E4	12,5	14	15,5	14	14	0,500	0,250
2	Strauss Foundation for Underground Cable Street Lighting	E2	B1	13	14	16	14	15	0,500	0,250
3	Installing / Withdrawing NFGBY Cables (for PJU Poles)	E3	E2	13	14	16	14,17	15	0,500	0,250
4	Installation/Pulling of NYFGBY Cables (buried cables)	E4	E2	13	14	16	14,17	15	0,500	0,250
5	Procurement and Installation of 7700 VA 1 Phase Street Light Panels	E5	E4	12,5	14	15,5	14,00	14	0,500	0,250
6	Procurement of Grounding Installation for Meter Panel	E6	E5	5	5	6	5,17	6	0,500	0,250
VI ROAD WORKS										
1	Curb / Curbing pair type B UK. 20x30x50 FC 30 Mpa	F1	C14	51,5	56	61	56,08	57	1,583	2,507
2	Specification 1 PC 2 Ps T=3cm	F2	F1	51,5	56	61	56,08	57	1,583	2,507
3	Class B Subbase Layer Aggregate (Using Tools)	F3	F7	19	21	23,5	21,08	22	0,750	0,563
4	Class A Top Base Layer Aggregate (LPA) Using Tools	F4	F3	12,5	14	16	14,08	15	0,583	0,340
5	Manufacturing and Spreading of Wear-Layer Concrete (AC-WC) Thickness 4 cm	F5	F6	5	5	6	5,17	6	0,167	0,028
6	Fabrication and Spreading of Wear-Layer Concrete (AC-BC) Thickness 6 cm	F6	F4	7	7	8	7,17	8	0,167	0,028
7	Installation of Woven Geotextile Layer Type UW 250	F7	B3	13	14	15,5	14	15	0,417	0,174

Based on Table 1 expected time (te) values can be used as durations for each work in the Network Planning Diagram to determine the duration of completion project and the critical path. The Network Planning Diagram is displayed in Figure 1.

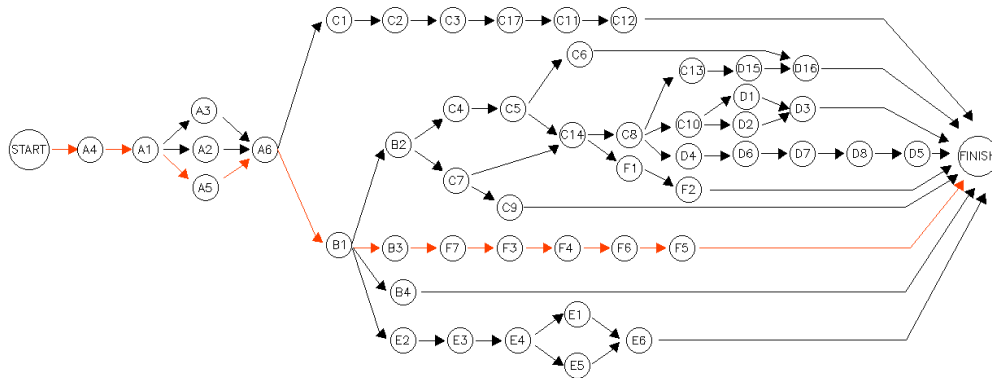


Figure 1. Diagram Network Planning

Next is the calculation for ES, EF, LS, and LF. The aim is to make sure the project duration at and identify more accurately which activities are included in the critical path. The following calculation for ES, EF, LS, LF, and TF example.

- ES Calculation
 $ES_{A4 \text{ Work}} = EF_i$
 $= 0$
- EF Calculation
 $EF_{A4 \text{ Work}} = ES + D$
 $= 0 + 7 = 7$
- LF Calculation
 $LF_{A4 \text{ Work}} = LS_{\text{Pekerjaan B1}}$
 $= 14 - 7 = 7$
- LS Calculation
 $LS_{A4 \text{ Work}} = LF - D$
 $= 7 - 7 = 0$
- TF Calculation
 $TF_{A4 \text{ Work}} = LF - EF$
 $= 7 - 7 = 0$

The results of the calculations for the next work until the end are displayed in Table 2.

Table 2. Calculation of ES, EF, LS, LF, and TF values

NO	JOB DESCRIPTION	KODE	PREDECESSOR	Duration	ES	EF	LS	LF	TF	
				(days)						
I PRELIMINARY WORK										
1	Preparation and Hire of Directors Keet	A1	A4	A4 FS	21	7	28	138	159	131
2	Making Project Nameplates	A2	A3	A3 FS	8	22	30	151	159	129
3	Preparation (Mobilization & Demobilization)	A3	A4	A4 FS + 7	8	14	22	14	22	0
4	Uitzet With WaterPass / Theodolite	A4	-	-	7	0	7	0	7	0
5	Test Hole	A5	A3	A3 FS	7	22	29	22	29	0
6	Making Bouwplank	A6	A5	A5 FS	8	29	37	29	37	0

NO	JOB DESCRIPTION	KODE	PREDECESSOR	Duration		ES	EF	LS	LF	TF
					(days)					
II EARTHWORKS										
1	Soil Excavation	B1	A6	A6 FS	91	37	128	37	128	0
2	Landfilling Back	B2	B1	B1 SS + 14	57	51	108	56	113	5
3	Sirtu (Solid) Backfilling	B3	B1	B1 SS + 21	63	58	121	58	121	0
4	Transportation of Soil Out of Project	B4	B1	B1 SS	91	37	128	72	163	35
III DUCT AND PAIR WORK										
1	Procurement of Corrugated Concrete Sheet Pile W 400 Type B	C1	A6	A6 FS	43	37	80	79	122	42
2	Installation/Penetration of Corrugated Concrete Sheet Pile W 400 Type B	C2	C1	C1 SS + 14	36	51	87	93	129	42
3	Corrugated Concrete Sheet Pile Cutting	C3	C2	C2 SS + 7	36	58	94	100	136	42
4	Procurement and Installation of Precast U-Decker	C4	B2	B2 SS + 7	43	58	101	63	106	5
5	Procurement and Installation of Bottom Cover	C5	C4	C4 SS	43	58	101	63	106	5
6	Procurement and Installation of Top Cover	C6	C5	C5 SS	43	58	101	63	106	5
7	Procurement and Installation of U-Ditch + Precast U-Ditch Cover	C7	B2	B2 SS + 7	43	58	101	63	106	5
8	Polythene Layer	C8	C7	C7 SS + 14	64	72	136	77	141	5
9	Split River Stone Pair	C9	C7	C7 SS + 14	64	72	136	99	163	27
10	Wiremesh Reinforced Concrete Work M6-150 FC 20 Mpa	C10	C8	C8 SS	64	72	136	77	141	5
11	Reinforced Concrete Casting Work (Fc 30 Mpa) Concrete Caping	C11	C17	C17 SS + 21	35	86	121	128	163	42
12	Reinforced Concrete Casting Work for Safety Pegs (FC 30 Mpa)	C12	C11	C11 SS + 7	28	93	121	135	163	42
13	FC 20 Mpa Concrete Sloof Work for Manhole	C13	C10	C10 SS	63	72	135	77	140	5
14	Procurement and Installation of Precast Water Channel U-Gutters	C14	C7, C5	C7, C5 SS	43	58	101	64	107	6
15	Round Color Manhole Grill (Cover & Frame) Precast	C15	C13	C13 FS - 14	29	121	150	134	163	13
16	Crossing Grill	C16	F4	F4 SS	15	142	157	147	162	5
17	Reinforcement Work with Concrete Iron (Plain/Threaded)	C17	C3	C3 SS + 7	50	65	115	107	157	42
IV PEDESTRIAN FLOORING WORKS AND ITS COMPLETENESS										
1	Installation of Black Andesite Stone	D1	C10	C10 SS + 35	36	107	143	120	156	13
2	Yellow Stopper Granite Tactile Installation	D2	D1	D1 SS	36	107	143	120	156	13
3	Procurement and Installation of Road Safety Stakes (Bollards), natural stone motif finishing.	D3	D2	D2 FS - 7	14	136	150	149	163	13
4	Concrete Sloof Work for FC 20 Mpa Park	D4	C13	C13 SS	63	72	135	77	140	5
5	Planting Pink & White Tabebuaya trees	D5	D8	D8 FS - 7	15	143	158	148	163	5
6	Red Brick Pair	D6	D4	D4 SS + 28	36	100	136	105	141	5
7	Smooth Plastering	D7	D6	D6 SS + 14	29	114	143	119	148	5
8	Acian	D8	D7	D7 SS + 14	22	128	150	133	155	5
V STREET LIGHTING WORK										
1	PJU LED Light Installation Ready to Turn on	E1	E4	E4 SS	13	150	163	150	163	0
2	Strauss Foundation for Underground Cable Street Lighting	E2	B1	B1 FS	15	128	143	128	143	0
3	Installing / Withdrawing NFGBY Cables (for PJU Poles)	E3	E2	E2 FS	15	143	158	143	158	0
4	Installation/Pulling of NYFGBY Cables (buried cables)	E4	E2	E3 SS	15	143	158	143	158	0

NO	JOB DESCRIPTION	KODE	PREDECESSOR	Duration		ES	EF	LS	LF	TF
					(days)					
5	Procurement and Installation of 7700 VA 1 Phase Street Light Panels	E5	E4	E4 SS + 7	13	150	163	150	163	0
6	Procurement of Grounding Installation for Meter Panel	E6	E5	E5 SS + 7	6	157	163	157	163	0
VI ROAD WORKS										
1	Curb / Curbing pair type B UK. 20x30x50 FC 30 Mpa	F1	C14	C14 SS + 7	57	79	136	107	164	28
2	Specification 1 PC 2 Ps T=3cm	F2	F1	F1 SS	57	79	136	107	164	28
3	Class B Subbase Layer Aggregate (Using Tools)	F3	F7	F7 SS + 7	21	128	149	128	149	0
4	Class A Top Base Layer Aggregate (LPA) Using Tools	F4	F3	F3 FS - 7	15	142	157	142	157	0
5	Manufacturing and Spreading of Wear-Layer Concrete (AC-WC) Thickness 4 cm	F5	F6	F6 FS	6	158	164	158	164	0
6	Fabrication and Spreading of Wear-Layer Concrete (AC-BC) Thickness 6 cm	F6	F4	F4 FS - 7	8	150	158	150	158	0
7	Installation of Woven Geotextile Layer Type UW 250	F7	B3	B3 FS	15	121	136	121	136	0

Based on the data in Table 2, it can obtain the total project completion duration for 164 days. The critical path in activity A4, Activity A3, Activity A5, Activity A6, Activity B1, activity B3, Activity F7, Activity F3, Activity F4, Activity F6, Activity F5. Then can obtain the planning probability using the following calculation.

a. Varian in the critical path

Variations in the critical path obtained from adding the total activity variance value, which in the critical path or namely critical activity. The following calculation for the variances in the critical path is displayed in Table 3.

Table 3. Calculation of Variance in Critical Path

NO	JOB DESCRIPTION	Kode	v(te)
1	Uitzeit With WaterPass/ Theodolite	A4	0,007
2	Preparation and Hire of Keet Directors	A1	0,563
3	Test Hole	A5	0,028
4	Making Bouwplank	A6	0,028
5	Soil Excavation	B1	4,694
6	Sirtu (Solid) Backfilling	B3	2,507
7	Installation of Woven Geotextile Layer Type UW 250	F7	0,174
8	Class B Subbase Layer Aggregate (Using Tools)	F3	0,563
9	Class A Top Base Layer Aggregate (LPA) Using Tools	F4	0,340
10	Fabrication and Spreading of Wear-Layer Concrete (AC-BC), Thickness 6 cm	F6	0,028
11	Manufacturing and Spreading of Wear-Layer Concrete (AC-WC), Thickness 4 cm	F5	0,028

$$V = \sum v \text{ kegiatan kritis} \quad 8,986$$

b. Standard Deviation

$$S = \sqrt{V}$$

$$= \sqrt{8,986} = 2,998$$

c. Probability

$$z = \frac{T(d) - Te}{S}$$

$$= \frac{159 - 164}{2,998} = -1,67$$

After the Z value is obtained, to determine the time probability of completing the project, the normal distribution table is used. Based on the normal distribution table, the time probability suitable for the planning, the value is 0.0475. This means that the project can be implemented according to the target with a probability of 4,75% with a completion time of 164 days.

Project Scheduling using Critical Path Method (CPM)

The CPM method begins by identifying the activities in the project and the dependency relationships between the activities. For each activity, determine the required duration. Next, a network diagram can be created that illustrates the sequence and relationships between activities so that which activities on the critical path can be known. The relations between works are displayed in Figure 2.

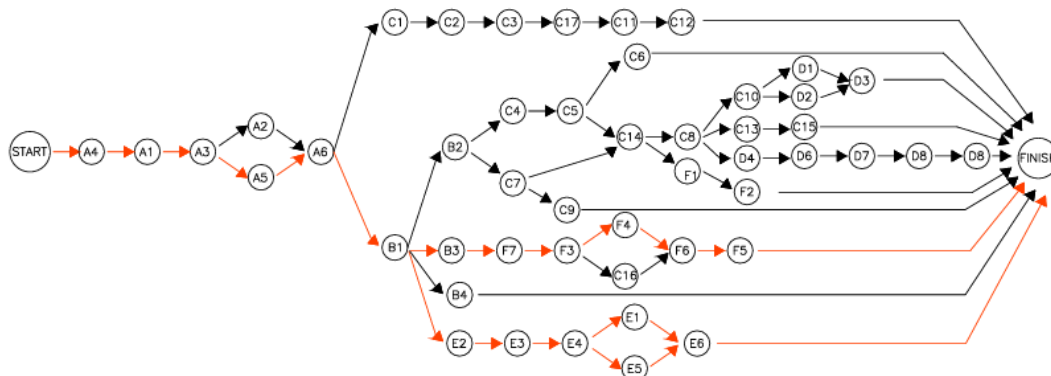


Figure 2. Network Diagram

After that, the Earliest Start Time (ES), Earliest Finish Time (EF), Latest Start Time (LS), and Latest Finish Time (LF) can be calculated. The goal is to better determine the overall project duration and more accurately identify which activities are on the critical path. This way, you can determine which activities have time leeway and which activities must be completed on time to avoid project delays. This is because any delay in an activity along the critical path will inevitably result in delays in subsequent activities (Rahmawati et al., 2022). The following is a calculation of ES, EF, LS, LF, and TF example.

a. ES Calculation

$$\begin{aligned} \text{ES A4 Work} &= \text{EF}_i \\ &= 0 \end{aligned}$$

b. EF Calculation

$$\begin{aligned} \text{EF A4 Work} &= \text{ES} + D \\ &= 0 + 7 = 7 \end{aligned}$$

c. LF Calculation

$$\begin{aligned} \text{LF A4 Work} &= \text{LS B1 Work} \\ &= 14 - 7 = 7 \end{aligned}$$

d. LS Calculation

$$\begin{aligned} \text{LS A4 Work} &= \text{LF} - D \\ &= 7 - 7 = 0 \end{aligned}$$

e. TF Calculation

$$\begin{aligned} \text{TF A4 Work} &= \text{LF-EF} \\ &= 7 - 7 = 0 \end{aligned}$$

The results of the calculations for the next work until the end are displayed in Table 4.

Table 4. Relations Between Works and ES, EF, LS, LF, TF Calculations

No	Job Description	Code	Predecessor	Durati- on (days)	ES	EF	LS	LF	TF	
I PRELIMINARY WORK										
1	Preparation and Hire of Directors Keet	A1	A4	A4 FS	21	7	28	7	28	0
2	Making Project Nameplates	A2	A3	A3 FS	7	21	28	21	28	0
3	Preparation (Mobilization & Demobilization)	A3	A4	A4 FS + 7	7	14	21	14	21	0
4	Uitzet With WaterPass / Theodolite	A4	X	-	7	0	7	0	7	0
5	Test Hole	A5	A3	A3 FS	7	21	28	21	28	0
6	Making Bouwplank	A6	A5	A5 FS	7	28	35	28	35	0
II EARTHWORKS										
1	Soil Excavation	B1	A6	A6 FS	91	35	126	35	126	0
2	Landfilling Back	B2	B1	B1 SS + 14	56	49	105	54	110	5
3	Sirtu (Solid) Backfilling	B3	B1	B1 SS + 21	63	56	119	56	119	0
4	Transportation of Soil Out of Project	B4	B1	B1 SS	91	35	126	68	159	33
III DUCT AND PAIR WORK										
1	Procurement of Corrugated Concrete Sheet Pile W 400 Type B	C1	A6	A6 FS	42	35	77	68	110	33
2	Installation/Penetration of Corrugated Concrete Sheet Pile W 400 Type B	C2	C1	C1 SS + 14	35	49	84	82	117	33
3	Corrugated Concrete Sheet Pile Cutting	C3	C2	C2 SS + 7	35	56	91	89	124	33
4	Procurement and Installation of Precast U-Decker	C4	B2	B2 SS + 7	42	56	98	61	103	5
5	Procurement and Installation of Bottom Cover	C5	C4	C4 SS	42	56	98	61	103	5
6	Procurement and Installation of Top Cover	C6	C5	C5 SS	42	56	98	103	145	47
7	Procurement and Installation of U-Ditch + Precast U-Ditch Cover	C7	B2	B2 SS + 7	42	56	98	61	103	5
8	Polythene Layer	C8	C7	C7 SS + 14	63	70	133	75	138	5
9	Split River Stone Pair	C9	C7	C7 SS + 14	63	70	133	96	159	26
10	Wiremesh Reinforced Concrete Work M6-150 FC 20 Mpa	C10	C8	C8 SS	63	70	133	75	138	5
11	Reinforced Concrete Casting Work (Fc 30 Mpa) Concrete Caping	C11	C1 7	C17 SS + 21	35	84	119	117	152	33
12	Reinforced Concrete Casting Work for Safety Pegs (FC 30 Mpa)	C12	C1 1	C11 SS + 7	28	91	119	131	159	40
13	FC 20 Mpa Concrete Sloof Work for Manhole	C13	C1 0	C10 SS	63	70	133	75	138	5
14	Procurement and Installation of Precast Water Channel U-Gutters	C14	C7, C5	C7, C5 SS	42	56	98	61	103	5
15	Round Color Manhole Grill (Cover & Frame) Precast	C15	C1 3	C13 FS - 14	28	119	147	124	152	5
16	Crossing Grill	C16	F4	F4 SS	14	140	154	145	159	5
17	Reinforcement Work with Concrete Iron (Plain/Threaded)	C17	C3	C3 SS + 7	49	63	112	96	145	33
IV PEDESTRIAN FLOORING WORKS AND ITS COMPLETENESS										
1	Installation of Black Andesite Stone	D1	C1 0	C10 SS + 35	35	105	140	119	154	14

No	Job Description	Code	Predecessor	Durati- on (days)	ES	EF	LS	LF	TF	
2	Yellow Stopper Granite Tactile Installation	D2	D1	D1 SS	35	105	140	119	154	14
3	Procurement and Installation of Road Safety Stakes (Bollards), natural stone motif finishing.	D3	D2	D2 FS - 7	12	133	145	147	159	14
4	Concrete Sloof Work for FC 20 Mpa Park	D4	C1 3	C13 SS	63	70	133	75	138	5
5	Planting Pink & White Tabebuaya trees	D5	D8	D8 FS - 7	14	140	154	145	159	5
6	Red Brick Pair	D6	D4	D4 SS + 28	35	98	133	103	138	5
7	Smooth Plastering	D7	D6	D6 SS + 14	28	112	140	117	145	5
8	Acian	D8	D7	D7 SS + 14	21	126	147	131	152	5
V STREET LIGHTING WORK										
1	PJU LED Light Installation Ready to Turn on	E1	E4	E5 SS	14	140	154	140	154	0
2	Strauss Foundation for Underground Cable Street Lighting	E2	B1	B1 FS	14	119	133	119	133	0
3	Installing / Withdrawing NFGBY Cables (for PJU Poles)	E3	E2	E2 FS	14	133	147	133	147	0
4	Installation/Pulling of NYFGBY Cables (buried cables)	E4	E2	E3 SS	14	133	147	133	147	0
5	Procurement and Installation of 7700 VA 1 Phase Street Light Panels	E5	E4	E4 SS + 7	14	140	154	140	154	0
6	Procurement of Grounding Installation for Meter Panel	E6	E5	E5 SS + 7	5	154	159	154	159	0
VI ROAD WORKS										
1	Curb / Curbing pair type B UK. 20x30x50 FC 30 Mpa	F1	C1 4	C14 SS + 21	56	77	133	96	152	26
2	Specification 1 PC 2 Ps T=3cm	F2	F1	F1 SS	56	77	133	103	159	26
3	Class B Subbase Layer Aggregate (Using Tools)	F3	F7	F7 SS + 7	21	126	147	126	147	0
4	Class A Top Base Layer Aggregate (LPA) Using Tools	F4	F3	F3 FS - 7	14	140	154	140	154	0
5	Manufacturing and Spreading of Wear-Layer Concrete (AC-WC) Thickness 4 cm	F5	F6	F6 FS	5	154	159	154	159	0
6	Fabrication and Spreading of Wear-Layer Concrete (AC-BC), Thickness 6 cm	F6	F4	F4 FS - 7	7	147	154	147	154	0
7	Installation of Woven Geotextile Layer Type UW 250	F7	B3	B3 FS	14	119	133	119	133	0

From Table 2, it can be known duration to finish the project is 159 days. It can also be known that TF values = 0 is the critical path work. So known two critical paths, first critical path at utizet with waterpass/theodolite, test hole work, bouplank making work, land excavation work, PJU ground cable strous foundation work, NFGBY cable installation/pulling work (for PJU poles), NFGBY cable installation/pulling work (buried cables), ready-to-light LED PJU lamp installation work, PJU-1 Phase 7700 VA lamp panel procurement and installation work.

Then the second critical work is the work of utizet with waterpass/theodolite, test hole work, bouplank making work, solid sirtu backfill work, installation of woven geotextile layer type UW 250, Aggregate Work of Lower Foundation Layer (LPB) Class B (using tools), Aggregate Work of Upper Foundation Layer (LPA) Class A (using tools), working of

making and spreading of Wear Layer Laston (AC-BC) thick 6 cm, and work of making and spreading of Wear Layer Laston (AC-WC) thick 4 cm.

Project Scheduling using Line Of Balance (LoB)

Line of Balance (LoB) method provides time-duration information in a graphical form. The LoB chart can indicate potential constraints that may occur, enabling greater attention to be given to activities that are susceptible to disruption. The time durations and interrelationships among activities used in the Line of Balance method are the same as those in the Critical Path Method (CPM). A network diagram can be depicted in Figure 3.

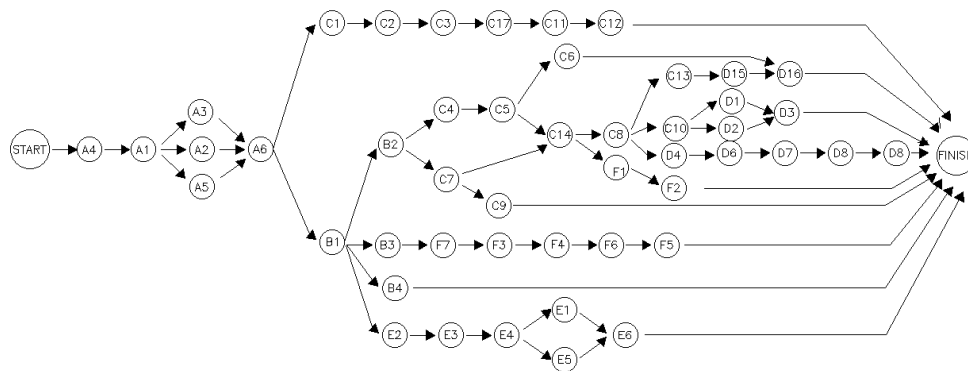


Figure 3. Network Diagram

Once the predecessor relationships are identified, the start and finish times for each activity can be determined. The start and finish times are presented in Table 5.

Table 5. Start and Finish Line Of Balance Method

No	Job Description	Duration (days)	Start	Finish
I PRELIMINARY WORK				
1	Preparation and Hire of Directors Keet	21	7	28
2	Making Project Nameplates	7	21	28
3	Preparation (Mobilization & Demobilization)	7	14	21
4	Uitzet With WaterPass / Theodolite	7	0	7
5	Test Hole	7	21	28
6	Making Bouwplank	7	28	35
II EARTHWORKS				
1	Soil Excavation	91	35	126
2	Landfilling Back	56	54	110
3	Sirtu (Solid) Backfilling	63	63	126
4	Transportation of Soil Out of Project	91	68	159
III DUCT AND PAIR WORK				
1	Procurement of Corrugated Concrete Sheet Pile W 400 Type B	42	68	110
2	Installation/Penetration of Corrugated Concrete Sheet Pile W 400 Type B	35	82	117
3	Corrugated Concrete Sheet Pile Cutting	35	89	124
4	Procurement and Installation of Precast U-Decker	42	61	103
5	Procurement and Installation of Bottom Cover	42	61	103

No	Job Description	Duration (days)	Start	Finish
6	Procurement and Installation of Top Cover	42	103	145
7	Procurement and Installation of U-Ditch + Precast U-Ditch Cover	42	61	103
8	Polythene Layer	63	75	138
9	Split River Stone Pair	63	96	159
10	Wiremesh Reinforced Concrete Work M6-150 FC 20 Mpa	63	75	138
11	Reinforced Concrete Casting Work (Fc 30 Mpa) Concrete Caping	35	117	152
12	Reinforced Concrete Casting Work for Safety Pegs (FC 30 Mpa)	28	131	159
13	FC 20 Mpa Concrete Sloof Work for Manhole	63	75	138
14	Procurement and Installation of Precast Water Channel U-Gutters	42	61	103
15	Round Color Manhole Grill (Cover & Frame) Precast	28	124	152
16	Crossing Grill	14	145	159
17	Reinforcement Work with Concrete Iron (Plain/Threaded)	49	96	145
IV	PEDESTRIAN FLOORING WORKS AND ITS COMPLETENESS			
1	Installation of Black Andesite Stone	35	119	154
2	Yellow Stopper Granite Tactile Installation	35	119	154
3	Procurement and Installation of Road Safety Stakes (Bollards), natural stone motif finishing.	12	147	159
4	Concrete Sloof Work for FC 20 Mpa Park	63	75	138
5	Planting Pink & White Tabebuaya trees	14	145	159
6	Red Brick Pair	35	103	138
7	Smooth Plastering	28	117	145
8	Acian	21	131	152
V	STREET LIGHTING WORK			
1	PJU LED Light Installation Ready to Turn on	14	140	154
2	Strauss Foundation for Underground Cable Street Lighting	14	119	133
3	Installing / Withdrawing NFGBY Cables (for PJU Poles)	14	133	147
4	Installation/Pulling of NYFGBY Cables (buried cables)	14	133	147
5	Procurement and Installation of 7700 VA 1 Phase Street Light Panels	14	140	154
6	Procurement of Grounding Installation for Meter Panel	5	154	159
VI	ROAD WORKS			
1	Curb / Curbing pair type B UK. 20x30x50 FC 30 Mpa	56	96	152
2	Specification 1 PC 2 Ps T=3cm	56	103	159
3	Class B Subbase Layer Aggregate (Using Tools)	21	126	147
4	Class A Top Base Layer Aggregate (LPA) Using Tools	14	140	154
5	Manufacturing and Spreading of Wear-Layer Concrete (AC-WC) Thickness 4 cm	5	154	159
6	Fabrication and Spreading of Wear-Layer Concrete (AC-BC), Thickness 6 cm	7	147	154
7	Installation of Woven Geotextile Layer Type UW 250	14	119	133

The next step is to construct the Line of Balance (LOB) diagram with reference to Table 4.10 above. The LOB diagram consists of a horizontal axis representing duration (days) and a vertical axis indicating units (road length). The Line of Balance diagram can be constructed as shown in Figure 4.

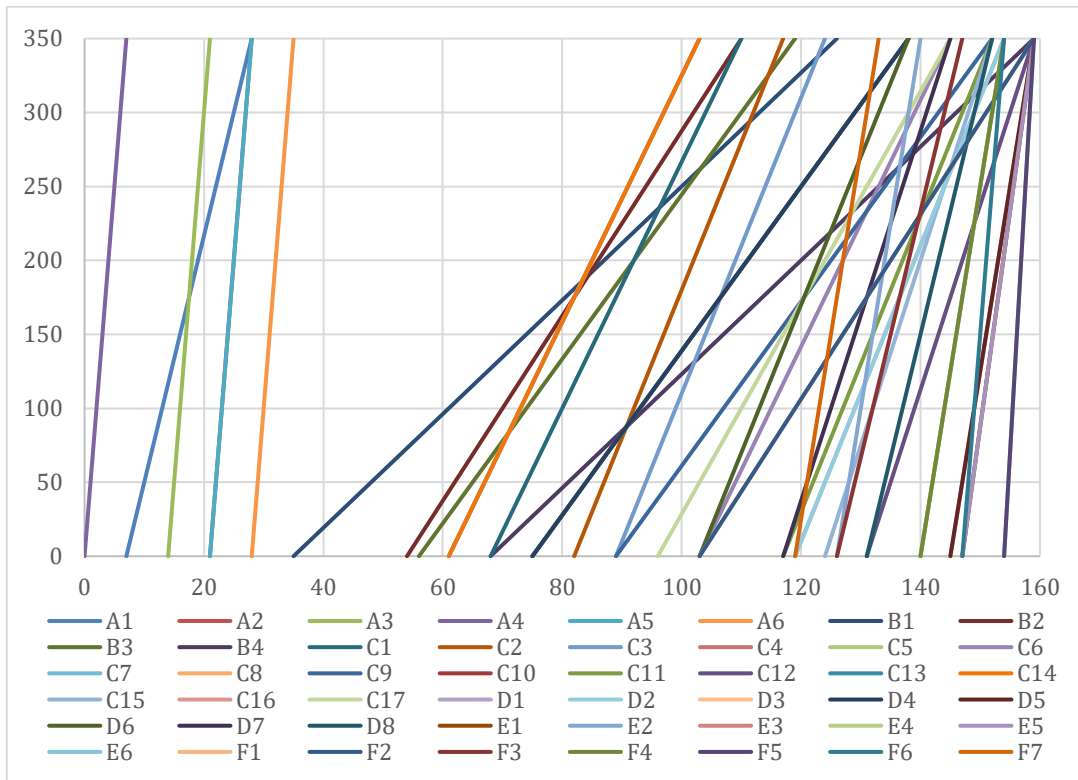


Figure 4. Network Diagram

Based on the LoB diagram presented in Figure 5.3, the total project completion duration is 159 days, and there are still many activities that overlap or potentially interfere with one another. From the Line of Balance diagram above, it can be identified that the project has two critical paths. The critical paths are presented in the form of the following diagram.

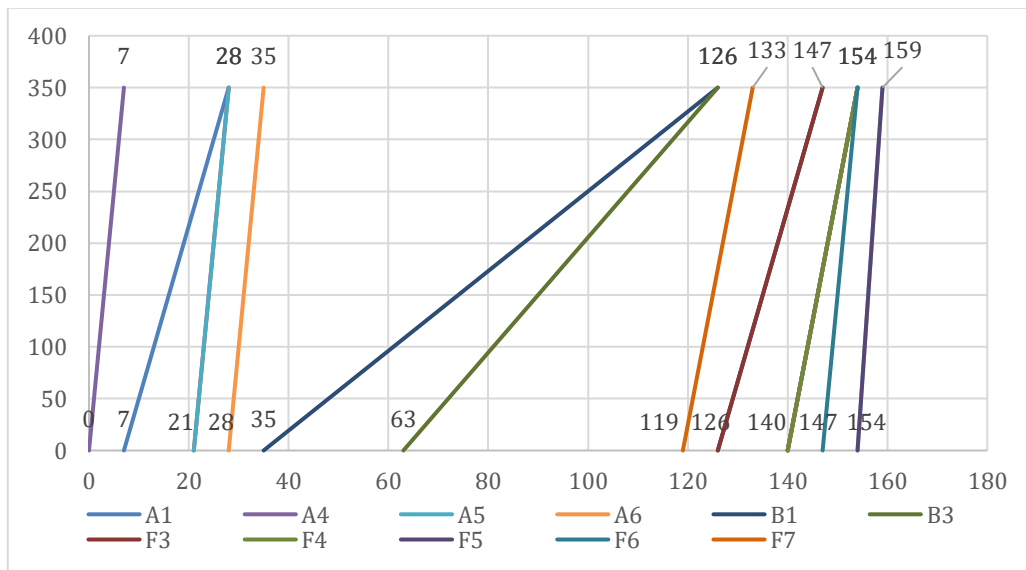


Figure 5. Network Diagram

The figure above illustrates the first critical path of the project is the work of utizet with waterpass/theodolite, test hole work, bouplank making work, solid sirtu backfill work,

installation of woven geotextile layer type UW 250, Aggregate Work of Lower Foundation Layer (LPB) Class B (using tools), Aggregate Work of Upper Foundation Layer (LPA) Class A (using tools), working of making and spreading of Wear Layer Laston (AC-BC) thick 6 cm, and work of making and spreading of Wear Layer Laston (AC-WC) thick 4 cm.

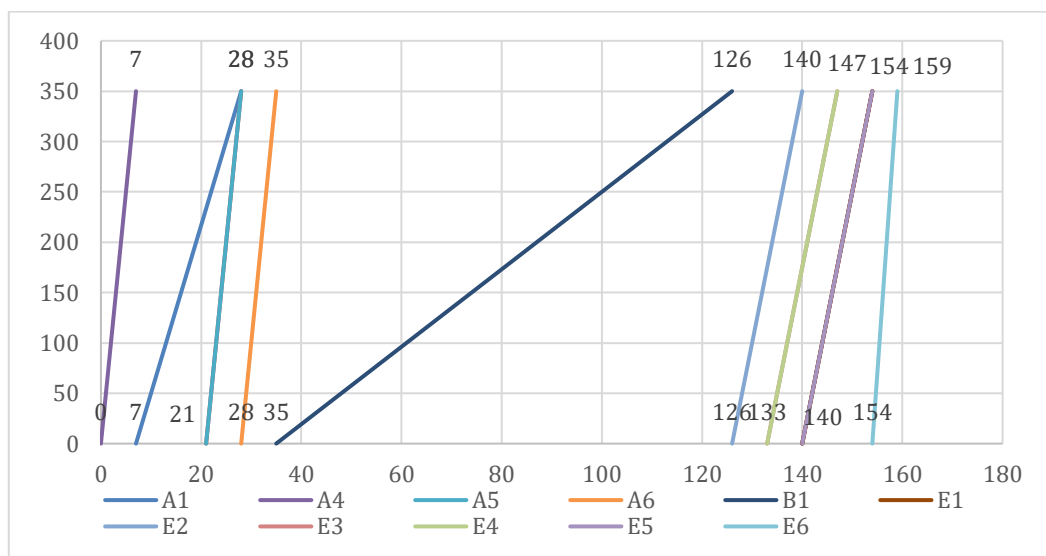


Figure 6. Network Diagram

The figure above represents the second critical path of the project is utilized with waterpass/theodolite, test hole work, bouplank making work, land excavation work, PJU ground cable strous foundation work, NFGBY cable installation/pulling work (for PJU poles), NFGBY cable installation/pulling work (buried cables), ready-to-light LED PJU lamp installation work, PJU-1 Phase 7700 VA lamp panel procurement and installation work.

Conclusion

In the project, which is a case study, we are using the bar chart method for scheduling. Project completion time using CPM and LoB is also 159 days. Meanwhile, the project completion time using PERT is 164 days. It means the duration difference for completing the project using the CPM and PERT methods is 5 days. The difference in project completion duration between LOB and PERT is 5 days. In contrast, no difference is observed between the CPM and LOB methods, as both yield an identical project completion time of 159 days.

Further research is necessary to comprehensively analyze the relationship between project scheduling duration and cost efficiency through the application of the Program Evaluation and Review Technique (PERT), Critical Path Method (CPM), and Line of Balance (LoB). This future research is expected to provide deeper insights into the effectiveness of these scheduling methods in optimizing both project time and cost performance.

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