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Project Schedule Optimization for Villa Development Using the Critical Path Method (CPM) and Line of Balance (LOB): A Case Study of the Indie Villa Development Project in Kuta

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Abstract— Project scheduling is a critical factor in ensuring timely completion, efficient resource utilization, and effective control of construction projects. Villa construction projects often involve repetitive activities, where conventional scheduling methods may not adequately address workflow continuity and resource coordination. This study aims to optimize the construction schedule of the Indie Villa Project by integrating the Critical Path Method (CPM) and the Line of Balance (LOB). A quantitative descriptive approach was applied using primary data collected through interviews with the project manager, site engineer, and field supervisor, supported by secondary data including project schedules, work breakdown structures, and progress reports. CPM was employed to identify critical activities and determine the project critical path, while LOB was applied to analyze repetitive activities and optimize crew movement among villa units. Schedule optimization was achieved through activity overlapping, resource leveling, and selective crashing. The results show that the original project duration of 526 days was successfully reduced to 345 days, saving 181 days or 34.41% without changing the project scope. The integrated CPM–LOB approach improved workflow continuity, reduced idle time, optimized resource utilization, and enhanced schedule control, demonstrating its effectiveness for repetitive villa construction projects.

Keywords: Critical Path Method, Line of Balance, schedule optimization, villa construction.

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1. Introduction

Villa development, as part of the property construction sector, has experienced significant growth in recent years, particularly in Kuta, Pujut District, Central Lombok Regency, Indonesia, in line with the increasing demand for exclusive residences and tourism accommodation. The rapid development of the Mandalika Special Economic Zone (SEZ), together with the increasing number of international tourism events, has accelerated investment in tourism infrastructure and accommodation facilities. According to Statistics Indonesia (BPS), Central Lombok Regency recorded 200 accommodation establishments in 2023, consisting of 12 star-rated hotels and 188 non-star accommodation establishments [1]. The continuous expansion of tourism infrastructure around the Mandalika SEZ has also stimulated the development of villa projects to accommodate the growing demand for private tourist accommodation. Consequently, villa construction projects have become increasingly complex, requiring effective project planning, scheduling, and resource management to ensure successful project delivery.

Project scheduling plays a crucial role in ensuring that construction projects are completed on time, within budget, and in accordance with the required quality standards. Effective scheduling enables project managers to optimize resource allocation, coordinate construction activities, minimize delays, and balance the trade-offs among time, cost, and quality, thereby improving overall project performance [2]. However, despite advances in construction management practices, achieving timely project completion remains a major challenge for construction projects worldwide.

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One of the primary challenges in villa construction project management is optimizing resource allocation and project duration to minimize delays. Schedule overruns frequently result in increased project costs, reduced productivity, inefficient resource utilization, and lower client satisfaction. Therefore, effective planning, resource coordination, and schedule control are essential for improving project performance and ensuring successful project delivery [3]. These challenges become more pronounced in repetitive construction projects, where delays are often caused by inadequate synchronization among repetitive activities, schedule conflicts, discontinuity of work crews, and inefficient resource allocation. Such conditions disrupt workflow continuity, reduce productivity, and ultimately contribute to project time and cost overruns [4].

Villa construction projects generally consist of multiple units with similar construction sequences, making them representative of repetitive construction projects. In projects with repetitive work characteristics—such as residential developments, villa complexes, apartment buildings, and linear infrastructure—conventional scheduling methods often fail to optimize production flow because they do not explicitly account for repetitive work units, crew continuity, or uniform workflow [5]. As a result, resource interruptions, idle time, and scheduling conflicts frequently occur during project execution. These limitations indicate the need for scheduling approaches capable of simultaneously optimizing activity sequencing, workflow continuity, and resource utilization.

Among various scheduling techniques, the Critical Path Method (CPM) remains one of the most widely adopted methods for identifying critical activities that determine project completion time. CPM enables project managers to establish logical activity sequences, estimate project duration, calculate activity float, and prioritize monitoring of activities with zero float [6]. Nevertheless, CPM was originally developed for non-repetitive construction projects and does not explicitly consider crew continuity, varying production rates, or continuous workflow across repetitive work units. Consequently, when applied to repetitive construction projects, CPM may result in inefficient resource utilization, crew interruptions, and schedule conflicts that reduce overall project efficiency [6].

To overcome these limitations, the Line of Balance (LOB) method has been widely recognized as an effective scheduling technique for repetitive construction projects, including villa developments, residential housing, apartment buildings, and other repetitive facilities [7], [8]. Unlike conventional scheduling techniques, LOB represents the relationship between time and work progress using linear diagrams, enabling project managers to visualize workflow continuity, identify potential schedule conflicts, detect work overlaps, and determine optimal start times for each repetitive work unit [7]. Furthermore, LOB promotes continuous crew movement, minimizes idle time, and improves resource allocation efficiency, thereby increasing project productivity [8], [9]. Its structured and visual scheduling approach also facilitates project monitoring and allows project schedules to be adjusted efficiently in response to changes in production rates, resource availability, or field conditions. Consequently, LOB contributes to improved workflow coordination, optimized resource utilization, and enhanced project time performance in repetitive construction projects [8], [9].

Numerous studies have demonstrated the effectiveness of LOB in repetitive construction scheduling. Sinaga *et al.* [10] and Efendi *et al.* [11] reported that LOB outperformed conventional scheduling approaches by improving workflow continuity and reducing project duration. Similarly, Ammar [12] demonstrated that LOB significantly improves resource utilization through better crew continuity and reduced idle time. More recent studies have further enhanced LOB by integrating optimization techniques, adaptive scheduling algorithms, and resource-leveling strategies to improve schedule stability and construction productivity [7], [13]. These developments indicate that LOB has evolved from a visual scheduling tool into a comprehensive decision-support approach for repetitive project management.

Despite these advancements, implementing LOB in practical construction projects remains challenging because it requires accurate productivity data, reliable resource planning, and the ability to accommodate changes in project conditions, such as design modifications and fluctuating labor

productivity [14]. Moreover, recent research has increasingly focused on integrating traditional scheduling methods with optimization techniques, metaheuristic algorithms, and automated scheduling models to improve schedule robustness and resource efficiency. Although these studies have demonstrated promising results, most have been conducted on large-scale infrastructure projects, high-rise buildings, or theoretical optimization models.

A review of previous studies reveals a significant research gap. Existing studies have predominantly examined CPM and LOB as independent scheduling methods or have emphasized advanced optimization algorithms without considering their practical integration in small- and medium-scale repetitive construction projects. Furthermore, limited research has investigated the combined application of CPM and LOB in villa construction projects, particularly within the Indonesian construction industry, where labor productivity, resource availability, and project management practices differ from those reported in previous studies. Consequently, empirical evidence regarding the effectiveness of integrating CPM and LOB for improving project completion time, workflow continuity, and resource utilization in repetitive villa construction remains limited.

To address this gap, this study proposes an integrated scheduling approach combining the Critical Path Method (CPM) and the Line of Balance (LOB) to optimize the construction schedule of the Indie Villa Project in Kuta, Central Lombok. Unlike previous studies that applied CPM or LOB separately, this research integrates both methods through critical path analysis, activity overlapping, resource leveling, and selective crashing to improve schedule efficiency. The findings are expected to provide both theoretical and practical contributions by demonstrating the effectiveness of the integrated CPM–LOB approach in reducing project duration, improving workflow continuity, optimizing resource utilization, and supporting decision-making in repetitive villa construction projects.

2. Method

This study uses a quantitative approach to describe the results of project scheduling optimization by integrating the critical path method and line of balance against the target project completion time compared to the existing schedule. The data used consists of primary data—obtained through interviews with project managers, site engineers, and foreman—and secondary data in the form of project documents such as time schedules, progress reports, work plans, and project networks. The research location is in Merendeng Hamlet, Kuta Village, Pujut District, Central Lombok, on the Indie villa development project, as shown in Figure 1, which has preparatory, structural, architectural, mechanical-electrical, and finishing work activities.



Figure 1. The Research Location

The research object data was obtained from the project manager in the form of a time schedule and working drawings (DED) to be used in the analysis of the two scheduling methods. Data collection techniques include field observations to observe the actual work conditions and activity sequences, structured interviews to verify the duration and relationship of the work, documentation of schedule documents and project reports, and literature studies related to CPM, LOB, and scheduling

optimization theories. Data analysis is conducted through three main stages: (1) CPM analysis to determine activity dependency relationships, calculate ES–EF–LS–LF–float, and identify the critical path; (2) LOB analysis for repetitive work by calculating production speed and constructing LOB diagrams as a basis for evaluating work continuity; and (3) integration of CPM and LOB to formulate an optimization schedule through overlapping activities, resource leveling, and crashing. Next, time efficiency calculations are carried out by comparing the initial duration and optimization results. The research procedure includes preparation stages (literature studies and initial data collection), field data collection and documentation, preparation of work sequence logic, CPM and LOB analysis, combined schedule optimization, and evaluation of results to produce recommendations for improving project scheduling.

3. Result and Discussion

The first stage of the research was to evaluate the project implementation schedule used by the contractor. Based on the time schedule data on the table 1, the project was completed in 526 days, with the work sequenced according to the Work Breakdown Structure (WBS). The following table 1 shows the duration of each work item, taken from the planned time schedule.

Table 1. Time Schedule

CODE	ACTIVITY	DURATION (Day)	PREDECESSOR
A	PRELIMINARY WORK	7	-
B	EARTH WORK	7	A
C	POOL GROUND WORK	7	B
D	FOUNDATION WORK	21	C
E	POOL FOUNDATION WORK	7	D
F	1ST-FLOOR STRUCTURAL WORK	91	E
G	POOL STRUCTURAL WORK	35	E
H	POOL PLUMBING WORK	10	E
I	POOL ELECTRICAL WIRING WORK	7	E
J	2ND-FLOOR STRUCTURAL WORK	56	F,G,H,I
K	1ST-FLOOR WALL WORK	14	J
L	2ND-FLOOR WALL WORK	21	K
M	PLUMBING WORK	28	K
N	1ST-FLOOR CEILING WORK	7	L,M
O	2ND-FLOOR CEILING WORK	7	N
P	ELECTRICAL WIRING WORK	14	O
Q	FLOOR WORK	42	P
R	POOL FLOOR & WALL WORK	14	P
S	FINISHING WORK	35	Q,R
T	DOORS AND WINDOWS WORK	7	S
U	PLUMBING ACCESSORIES WORK	10	T
V	ELECTRICITY ACCESSORIES WORK	9	U

From Table 1, the researchers then compiled it into a flowchart, which is then presented in Figure 2, a Critical Path Method (CPM) diagram. From this diagram, we can see the planned work sequence, interdependencies between tasks, and the optimal duration of the planned tasks.

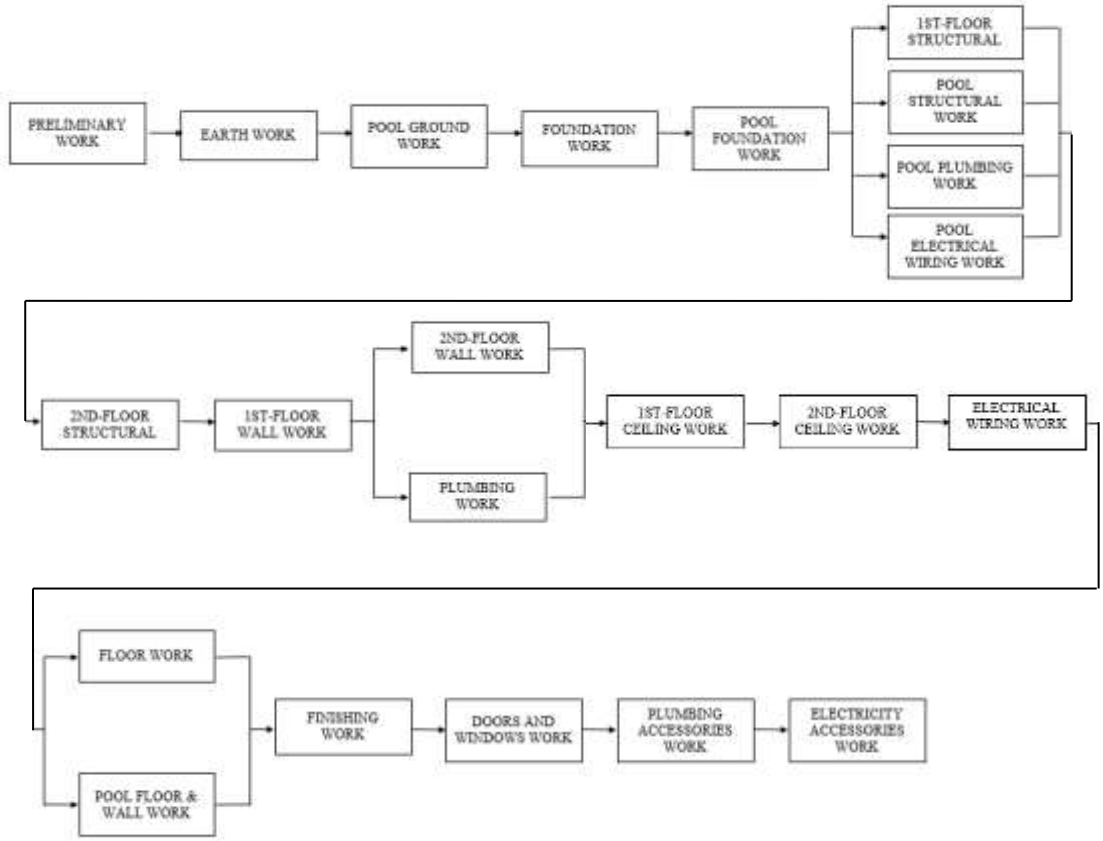


Figure 2. Flowchart Time Schedule

Based on the flowchart above (figure 2), the researcher then conducted a Critical Path Method (CPM) analysis using the planned schedule data owned by the contractor in accordance with Figure 3, namely the critical path method table.

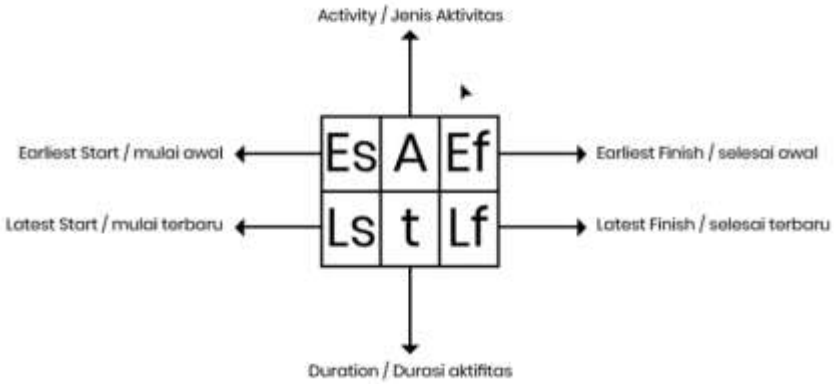


Figure 3. Critical Path Method (CPM) table

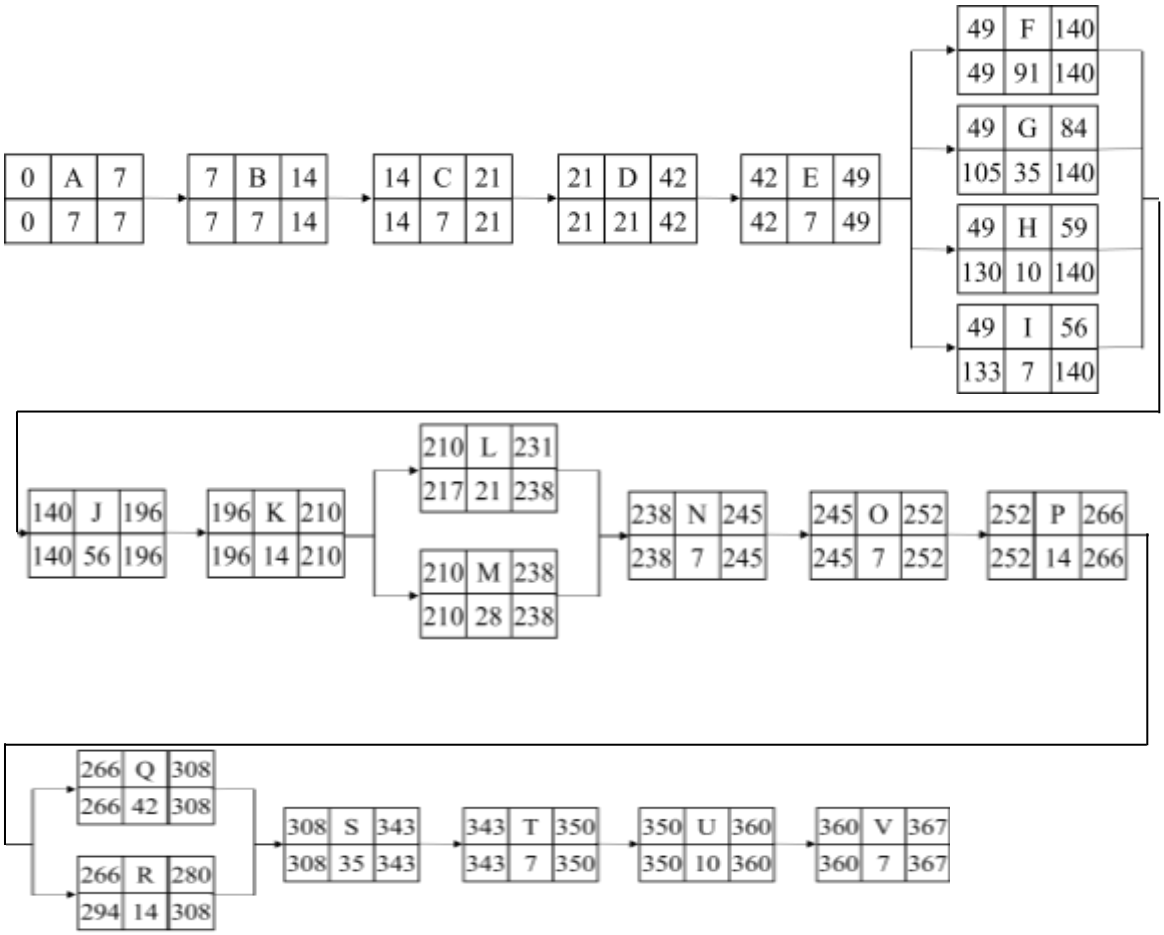


Figure 4. Critical Path Method (CPM) Calculation

Figure 4 explains the calculation of the duration of each work item analyzed using the critical path method, which consists of two calculation methods, namely forward and backward calculations. From figure 4, the critical path can be determined as follows.

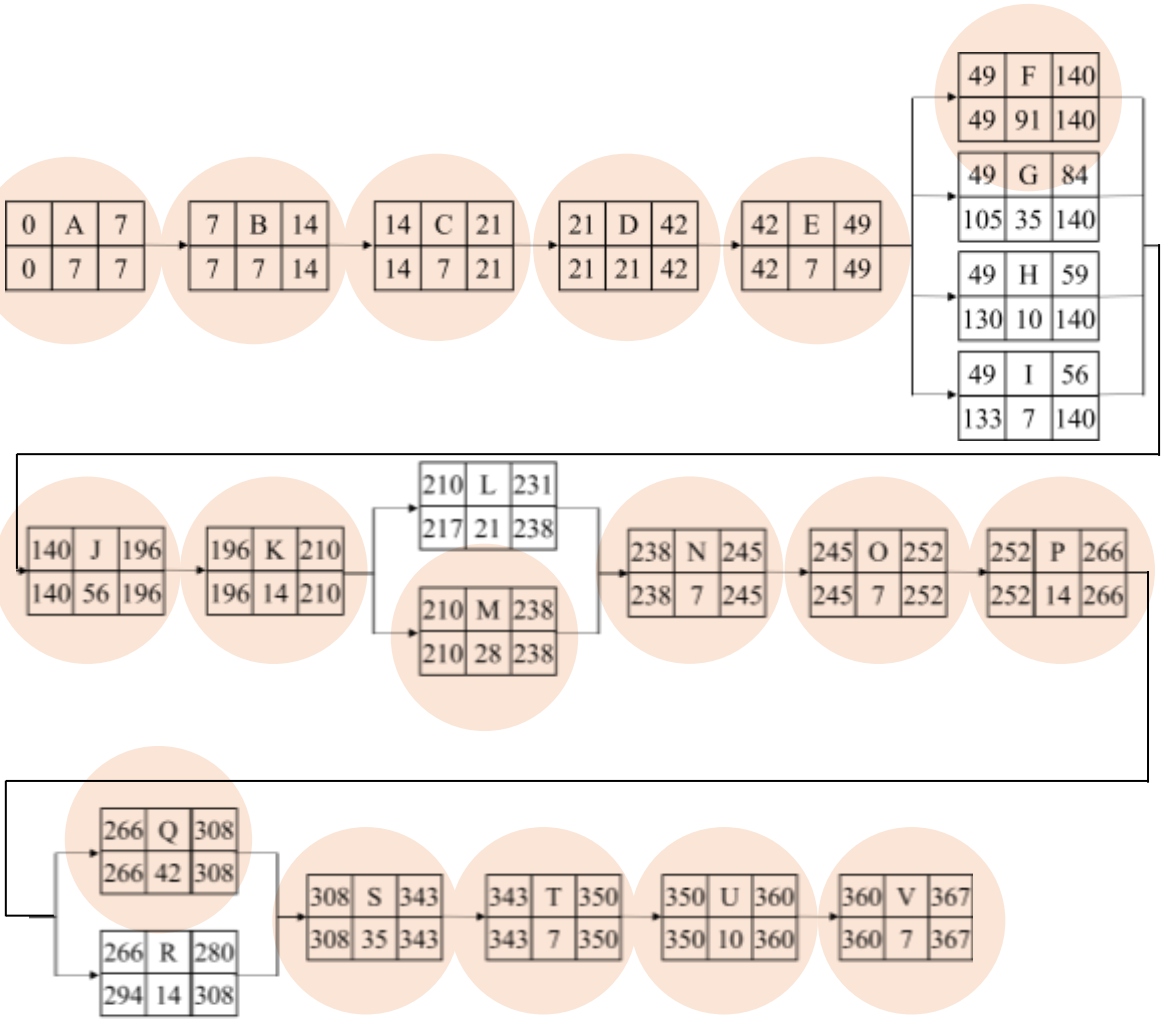


Figure 5. Critical Path Method (CPM) Analysis

Based on figure 5, the critical path is obtained after calculating the early start (ES) and early finish (EF) in a forward calculation. Then, after calculating the backward calculation to obtain the latest start (LS) and latest finish (LF) values. If the numbers for the early start (ES) and latest start (LS) are the same, and the early finish (EF) and latest finish (LF) are the same, then this work item is categorized as critical work, or on the critical path. The results obtained are as follows.

A – B – C – D – E – F – J – K – M – N – O – P – Q – S – T – U – V

After identifying the critical path and the planned work duration, the next step was to calculate the work duration for the two villas using the line of balance method to determine continuity between the tasks. The following is the calculation of the total duration for the two villas.

Table 2. Line of Balance Method

CODE	ACTIVITY	DURATION (Day)	TOTAL DURATION (Day)	START	FINISH
A	PRELIMINARY WORK	7	14	0	14
B	EARTH WORK	7	14	7	21
C	POOL GROUND WORK	7	14	14	28
D	FOUNDATION WORK	21	42	21	63

E	POOL FOUNDATION WORK	7	14	56	70
F	1ST-FLOOR STRUCTURAL WORK	91	182	63	245
G	POOL STRUCTURAL WORK	35	70	63	133
H	POOL PLUMBING WORK	10	20	63	83
I	POOL ELECTRICAL WIRING WORK	7	14	63	77
J	2ND-FLOOR STRUCTURAL WORK	56	112	189	301
K	1ST-FLOOR WALL WORK	14	28	287	315
L	2ND-FLOOR WALL WORK	21	42	301	343
M	PLUMBING WORK	28	56	301	357
N	1ST-FLOOR CEILING WORK	7	14	350	364
O	2ND-FLOOR CEILING WORK	7	14	357	371
P	ELECTRICAL WIRING WORK	14	28	364	392
Q	FLOOR WORK	42	84	378	462
R	POOL FLOOR & WALL WORK	14	28	378	406
S	FINISHING WORK	35	70	427	497
T	DOORS AND WINDOWS WORK	7	14	490	504
U	PLUMBING ACCESSORIES WORK	10	20	497	517
V	ELECTRICITY ACCESSORIES WORK	9	18	508	526

Look at Table 2. Before getting the balance line graph, we first need to find the start and finish times for each work item. Before doing this, we need to know the total project duration. Then, we will find the start and finish times for each work item. The successor referred to here is the previous work item. For example, if we are looking for the duration of work B, then the successor to work B is work A. Keep in mind that the calculation of the start and finish times for each work item refers to the logic diagram above (Figure 2).

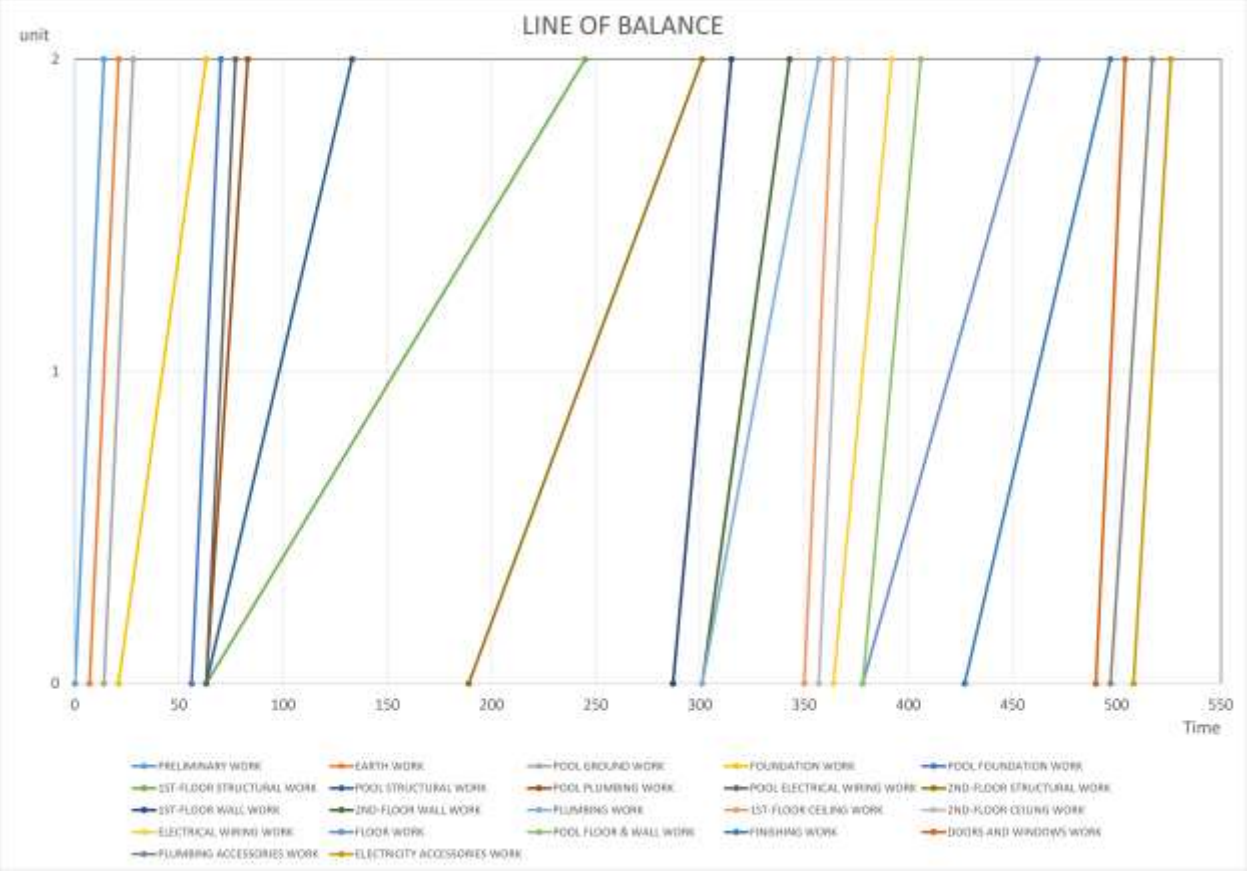


Figure 6. Metode Line of Balance

Based on the analysis using the two aforementioned methods, the Indie Villa project is projected to be completed within 526 days. Following the CPM analysis, the Line of Balance (LOB) method was applied to further evaluate the project duration. The results indicate that the project requires a relatively long completion time, as illustrated in Figure 6. An examination of each work sequence in Figure 6 reveals that individual activities have relatively long durations, considerable idle time occurs before subsequent activities can commence, and opportunities for parallel activities remain limited. Therefore, the researchers conducted further analysis to rearrange the sequence of work items and optimize resource allocation, particularly labor and time, across several work activities.

Based on the interviews, the researchers then created a Work Breakdown Structure (WBS) based on the implementer's data. The following is the WBS, or list of activities, after optimization.

Table 3. List of Activity

CODE	ACTIVITY	DURATION (Day)	PREDECESSOR
A	PRELIMINARY WORK	7	-
B	EARTH WORK	8	A
C	POOL GROUND WORK	7	A
D	FOUNDATION FORMWORK	2	B,C
E	FOUNDATION REINFORCEMENT	3	D
F	PEDESTAL COLUMN REINFORCEMENT	9	E
G	FOUNDATION CONCRETE WORK	2	F
H	PEDESTAL COLUMN FORMWORK	4	G
I	PEDESTAL COLUMN CONCRETE	2	H
J	STONE FOUNDATION WORK	7	I
K	POOL STRUCTURAL WORK	7	I
L	POOL WALL FORMWORK	8	K
M	TIE BEAM REINFORCEMENT	9	J
N	TIE BEAM FORMWORK	4	L,M
O	1ST-FLOOR REINFORCEMENT	4	L,M
P	TIE BEAM CONCRETE	4	N,O
Q	1ST-FLOOR DIRTY WATER	3	N,O
R	1ST-FLOOR CONCRETE	4	P,Q
S	1ST-FLOOR COLUMN REINFORCEMENT	9	R
T	1ST-FLOOR COLUMN FORMWORK	7	S
U	1ST-FLOOR COLUMN CONCRETE	2	T
V	2ND-FLOOR BEAM FORMWORK	6	U
W	2ND-FLOOR FORMWORK	7	U
X	2ND-FLOOR BEAM REINFORCEMENT	9	V,W
Y	2ND-FLOOR REINFORCEMENT	7	X
Z	CONCRETE OF BEAM & FLOOR	1	Y
AA	2ND-FLOOR COLUMN REINFORCEMENT	8	Z
AB	2ND-FLOOR COLUMN FORMWORK	6	AA
AC	2ND-FLOOR COLUMN CONCRETE	2	AB
AD	ROOF BEAM FORMWORK	5	AC
AE	ROOF PLATE FORMWORK	7	AC
AF	ROOF BEAM REINFORCEMENT	7	AD,AE
AG	ROOF PLATE REINFORCEMENT	6	AF
AH	CONCRETE OF BEAM & ROOF PLATE	1	AG
AI	1ST-FLOOR WALL WORK	5	AH
AJ	2ND-FLOOR WALL WORK	7	AI
AK	2ND-FLOOR DIRTY WATER	5	AI
AL	1ST-FLOOR CLEAN WATER	5	AI
AM	1ST-FLOOR ELECTRICAL	5	AI
AN	1ST-FLOOR PLASTER WORK	9	AJ,AK,AL,AM
AO	2ND-FLOOR CLEAN WATER	7	AJ,AK,AL,AM

AP	2ND-FLOOR ELECTRICAL	7	AJ,AK,AL,AM
AQ	2ND-FLOOR PLASTER WORK	16	AN,AO,AP
AR	1ST-FLOOR CEMENT WALL	6	AQ
AS	2ND-FLOOR CEMENT WALL	7	AR
AT	CEILING WORK	6	AS
AU	FLOOR & WALL WORK	28	AT
AV	FINISHING WORK	12	AU
AW	DOORS AND WINDOWS WORK	7	AV
AX	POOL FLOOR & WALL WORK	7	AV
AY	PLUMBING ACCESSORIES WORK	7	AW
AZ	ELECTRICITY ACCESSORIES WORK	5	AX,AY

Based on Table 3, it is explained that after all project activities have been identified and organized into a Work Breakdown Structure (WBS), the next step is to organize the dependencies between activities in the form of a network diagram. This network is then analyzed using the Critical Path Method (CPM) to determine the critical path and calculate the start and finish times for each activity. The following is a flowchart generated after interviews with project implementers.

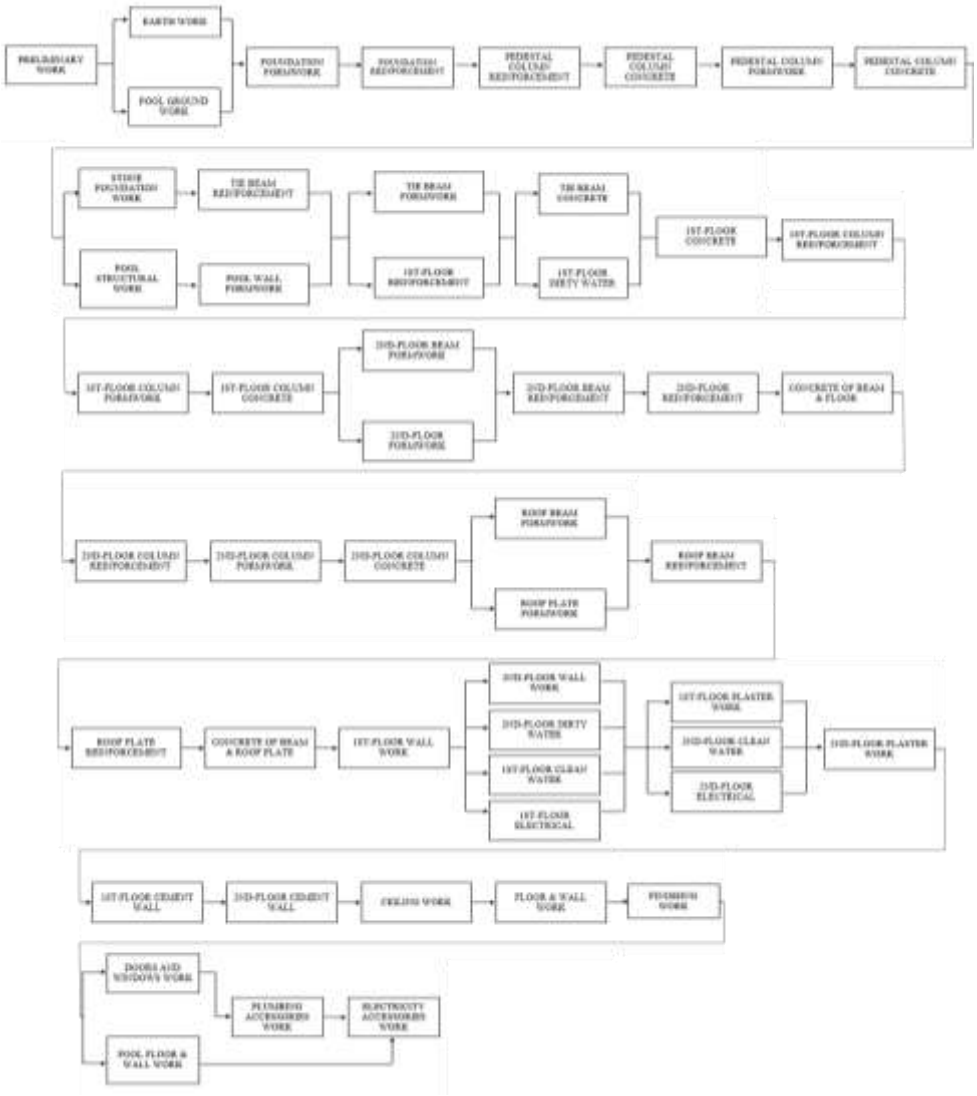


Figure 7. Flowchart of analysis results

In Figure 7, it explains the project work flow based on field data. Next, an analysis was carried out using the CPM method.

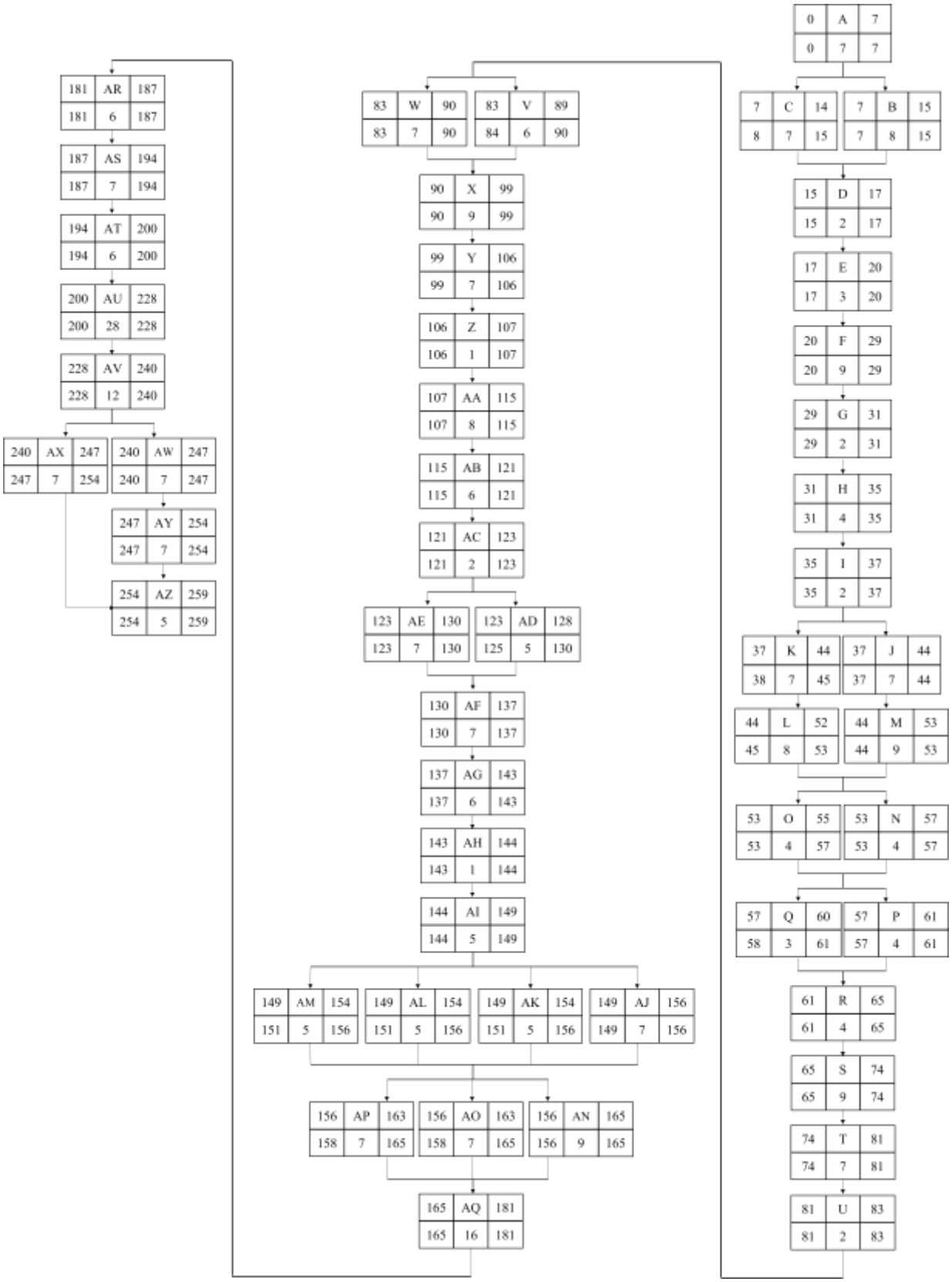


Figure 8. Contractor data CPM calculation

In Figure 8, the results of the CPM calculation on the data obtained in the field are explained. Then the critical path is obtained according to Figure 9.

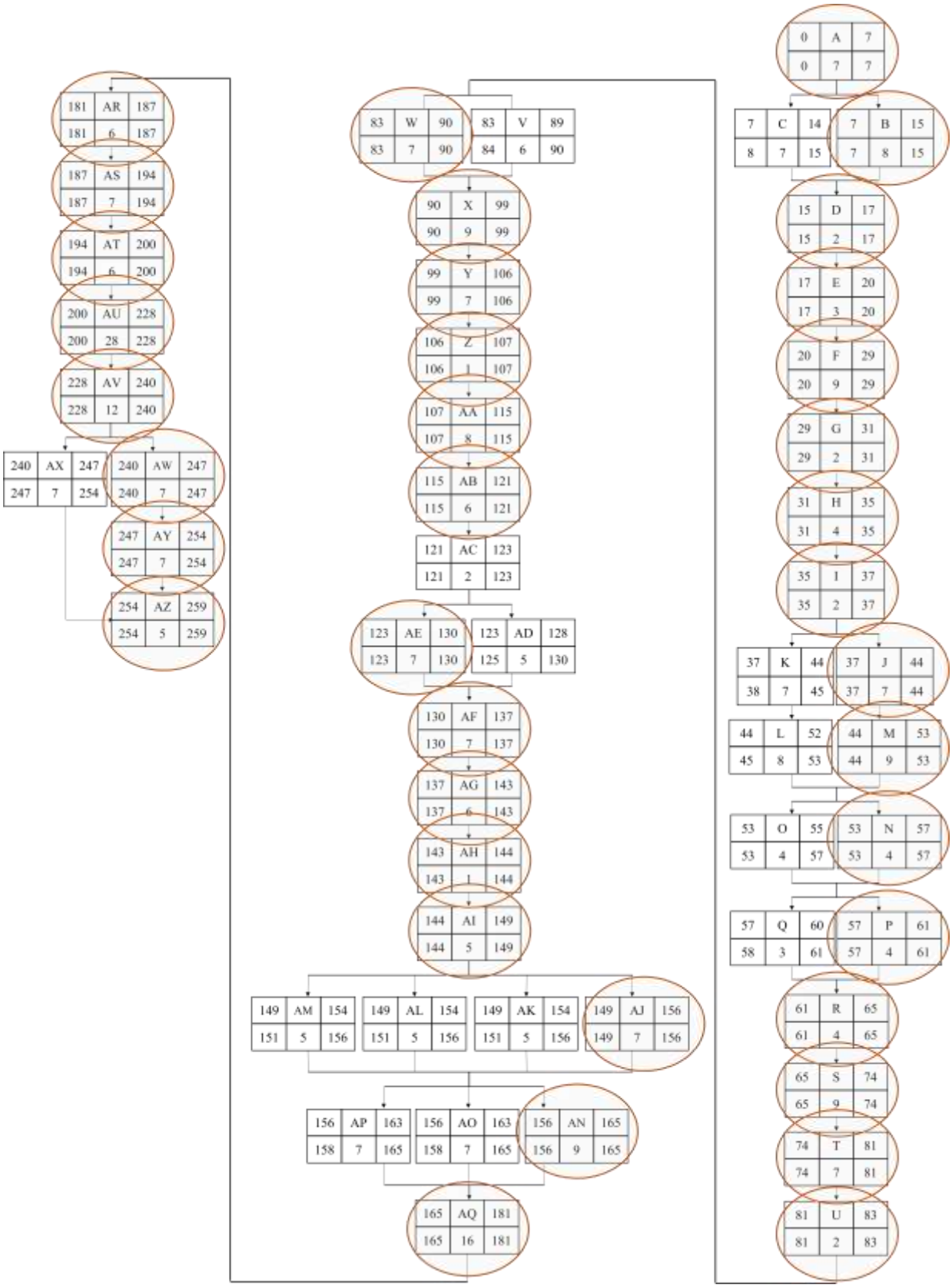


Figure 9. CPM analysis of contractor data

The following is the critical path according to Figure 9.

A - B - D - E - F - G - H - I - J - M - N - P - R - S - T - U - W - X - Y - Z - AA - AB - AC - AE - AF - AG - AH - AI - AJ - AN - AQ - AR - AS - AT - AU - AV - AW - AY – AZ

The critical path is obtained after calculating the early start (ES) and early finish (EF) in a forward calculation. Then, after calculating the backward calculation to obtain the latest start (LS) and latest finish (LF) values. If the numbers for the early start (ES) and latest start (LS) are the same, and the early finish (EF) and latest finish (LF) are the same, then this work item is categorized as critical work, or on the critical path.

Next, a Line of Balance (LOB) analysis was conducted. After all project activities were identified through the Work Breakdown Structure (WBS) and organized into a List of Activities, the next step was to calculate the duration of each activity in both villa units. This calculation aimed to determine the completion time for each task in each unit, allowing for an efficient implementation sequence. In this study, each activity was analyzed based on the duration obtained from the contractor. These durations were then used as the basis for determining the start and finish times for each activity in Units 1 and 2. The results of these calculations formed the basis for constructing the Line of Balance (LOB) graph.

Duration calculation using the Line of Balance method based on table 4.

Table 4. Duration with Line of Balance Method

CODE	ACTIVITY	DURATION (Day)	TOTAL DURATION (Day)	START	FINISH
A	PRELIMINARY WORK	7	14	0	14
B	EARTH WORK	8	16	7	23
C	POOL GROUND WORK	7	14	7	21
D	FOUNDATION FORMWORK	2	4	21	25
E	FOUNDATION REINFORCEMENT	3	6	23	29
F	PEDESTAL COLUMN REINFORCEMENT	9	18	26	44
G	FOUNDATION CONCRETE WORK	2	4	42	46
H	PEDESTAL COLUMN FORMWORK	4	8	44	52
I	PEDESTAL COLUMN CONCRETE	2	4	50	54
J	STONE FOUNDATION WORK	7	14	52	66
K	POOL STRUCTURAL WORK	7	14	52	66
L	POOL WALL FORMWORK	8	16	59	75
M	TIE BEAM REINFORCEMENT	9	18	59	77
N	TIE BEAM FORMWORK	4	8	73	81
O	1ST-FLOOR REINFORCEMENT	4	8	77	81
P	TIE BEAM CONCRETE	3	6	78	84
Q	1ST-FLOOR DIRTY WATER	3	6	78	84
R	1ST-FLOOR CONCRETE	4	8	81	89
S	1ST-FLOOR COLUMN REINFORCEMENT	9	18	85	103
T	1ST-FLOOR COLUMN FORMWORK	7	14	96	110
U	1ST-FLOOR COLUMN CONCRETE	2	4	108	112
V	2ND-FLOOR BEAM FORMWORK	6	12	110	122
W	2ND-FLOOR FORMWORK	7	14	110	124
X	2ND-FLOOR BEAM REINFORCEMENT	9	18	117	135
Y	2ND-FLOOR REINFORCEMENT	7	14	128	142
Z	CONCRETE OF BEAM & FLOOR	1	2	141	143
AA	2ND-FLOOR COLUMN REINFORCEMENT	8	16	142	158
AB	2ND-FLOOR COLUMN FORMWORK	6	12	152	164
AC	2ND-FLOOR COLUMN CONCRETE	2	4	162	166
AD	ROOF BEAM FORMWORK	5	10	164	174
AE	ROOF PLATE FORMWORK	7	14	164	178
AF	ROOF BEAM REINFORCEMENT	7	14	171	185
AG	ROOF PLATE REINFORCEMENT	6	12	179	191
AH	CONCRETE OF BEAM & ROOF PLATE	1	2	190	192
AI	1ST-FLOOR WALL WORK	5	10	191	201
AJ	2ND-FLOOR WALL WORK	7	14	196	210
AK	2ND-FLOOR DIRTY WATER	5	10	196	206
AL	1ST-FLOOR CLEAN WATER	5	10	196	206
AM	1ST-FLOOR ELECTRICAL	5	10	196	206

AN	1ST-FLOOR PLASTER WORK	9	18	203	221
AO	2ND-FLOOR CLEAN WATER	7	14	203	217
AP	2ND-FLOOR ELECTRICAL	7	14	203	217
AQ	2ND-FLOOR PLASTER WORK	16	32	212	244
AR	1ST-FLOOR CEMENT WALL	6	12	238	250
AS	2ND-FLOOR CEMENT WALL	7	14	244	258
AT	CEILING WORK	6	12	252	264
AU	FLOOR & WALL WORK	28	56	258	314
AV	FINISHING WORK	12	24	302	326
AW	DOORS AND WINDOWS WORK	7	14	319	333
AX	POOL FLOOR & WALL WORK	7	14	319	333
AY	PLUMBING ACCESSORIES WORK	7	14	326	340
AZ	ELECTRICITY ACCESSORIES WORK	5	10	335	345

Look at table 4, before obtaining the line of balance graph, we first need to find the start and finish times for each work item. Before doing this, we need to know the total duration of the project. Then, we'll find the start and finish times for each work item. The successors referred to here are the previous work items. For example, if we're looking for the duration of work B, then work B's successor is work A. Keep in mind that calculating the start and finish times for each work item refers to the logic diagram above (Figure 7). The following is a balance line graph obtained from table 4.

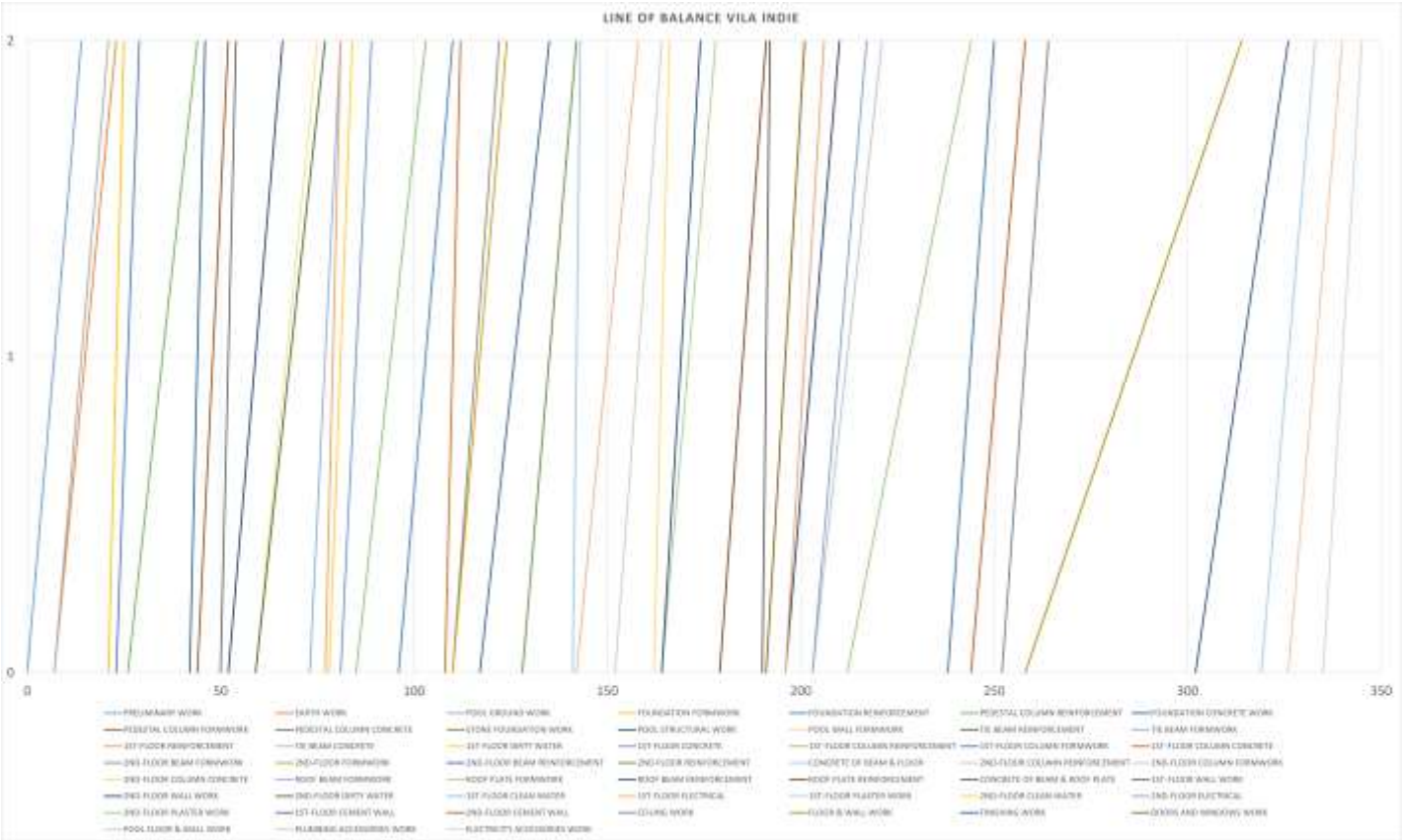


Figure 10. LOB graph of contractor data

The CPM analysis yielded an effective work sequence and optimal duration for each work item. This was followed by a LOB calculation, where each work item was executed more continuously, resulting in 345 work days. This figure was obtained after resource leveling and overlapping several work items. Therefore, each line in Figure 10 has an optimal work duration, with no downtime before the next task, and several tasks are executed in parallel.

After analyzing the two methods above, the optimal duration for completing the villa project was obtained. The following are the results.

Table 5. Time Efficiency Evaluation

Information	Existing	Optimization
Total Duration	526 days	345 days
Duration Reduction	-	181 days

$$time\ efficiency(\%) = \frac{D_{start} - D_{optimization}}{D_{start}} \times 100\%$$

$$time\ efficiency(\%) = \frac{526 - 345}{526} \times 100\%$$

$$time\ efficiency(\%) = 34{,}41\%$$

The reduction in duration is primarily due to:

- eliminating waiting time,
- increasing parallel activities,
- rearranging the work sequence,
- accelerating critical activities.

This allows for faster project completion without changing the scope of work.

The optimization results demonstrate that integrating the Critical Path Method (CPM) and the Line of Balance (LOB) provides a more efficient scheduling strategy than the conventional S-curve schedule used by the contractor. The existing schedule required 526 days, whereas the optimized schedule reduced the project duration to 345 days, representing a reduction of 181 days (34.41%). This improvement was achieved without modifying the project scope, but rather by reorganizing activity sequences, increasing parallel execution, and improving resource continuity.

The CPM analysis successfully identified the activities located on the critical path, indicating that these activities possess zero float and therefore directly determine the overall project duration. Identifying the critical path enables project managers to prioritize monitoring and control efforts on activities that have the greatest influence on project completion. This finding is consistent with [16], who stated that CPM provides an effective framework for identifying schedule-sensitive activities and supporting managerial decision-making in construction projects. Likewise, [17] emphasized that concentrating project control on critical activities significantly reduces the risk of schedule overruns.

Unlike CPM, which primarily focuses on activity dependencies, the LOB method emphasizes production continuity in repetitive construction. The Indie Villa project consists of two villa units with identical construction sequences, making it well suited for LOB implementation. The LOB diagram clearly illustrates the movement of work crews from Unit 1 to Unit 2 while maintaining continuous workflow and minimizing interruptions. Consequently, idle time between successive activities can be substantially reduced. This result supports previous studies by [10], who reported that LOB improves labor utilization through continuous crew movement, and by [13], who demonstrated that LOB enhances resource balancing and minimizes productivity losses in repetitive construction projects.

One important finding of this research is that schedule optimization was not achieved solely through CPM or LOB individually, but through their integration. CPM identified the sequence of critical activities, whereas LOB determined the most appropriate production flow for repetitive work. Based on interviews with the Project Manager, Site Supervisor, and Foreman, several construction activities were rescheduled using activity overlapping, including earthwork, swimming pool structural work, plumbing installation, electrical wiring, floor slab formwork, roof slab formwork, and clean water piping. These activities were technically feasible to perform simultaneously because they were executed by different work crews and did not create physical conflicts during construction.

The implementation of overlapping activities was further supported by resource leveling and selective crashing. Resource leveling minimized fluctuations in workforce allocation between

successive activities, while crashing accelerated several critical activities by increasing work intensity without changing the construction scope. According to the [18], these optimization techniques are among the most effective approaches for improving schedule performance while maintaining project quality and controlling additional costs.

4. Conclusion

Based on the research results, it can be concluded that optimizing the scheduling of the Indie Villa construction project through the integration of the Critical Path Method (CPM) and Line of Balance (LOB) can significantly increase the efficiency of project implementation. The CPM analysis successfully identified critical activities that determine the duration of project completion, while the LOB method provides a better picture of the continuity of work on repetitive projects and helps reduce waiting time between activities. Through the application of activity overlapping, resource leveling, and crashing on possible activities, the project duration was successfully shortened from 526 days to 345 days or an acceleration of 181 days (34.41%) without changing the scope of work. Thus, the integration of CPM and LOB has proven effective in optimizing the scheduling of the villa construction project through more efficient work sequencing, more optimal resource utilization, and increased effectiveness of schedule control compared to conventional S-Curve-based scheduling methods.

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