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# Critical Path Identification and Schedule Rationalization in a Plantation Road Improvement Project: Case Study at PTPN IV, Batanghari

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## *ABSTRACT*

Delays in infrastructure projects particularly in plantation road construction often stem from suboptimal scheduling and resource allocation. This study aims to optimize time and cost in the 2,600meter road improvement project at PTPN IV Regional 4, Batanghari Plantation, using the Critical Path Method (CPM). Primary data were collected through semi-structured interviews with project staff, while secondary data were obtained from official project documents, covering activity durations, costs, and precedence relationships. A network diagram was constructed using the Activity on Arrow (AOA) approach, followed by forward and backward pass analyses to compute earliest/latest start finish times and total float. Results show that the baseline schedule assumed 120 days with a total cost of IDR 1,075,197,832, yet CPM analysis revealed a feasible minimum duration of 117 days, reducing total project cost to IDR 1,069,692.832 a saving of IDR 5,505,000. This reduction is mainly caused by the removal of 3 days of schedule slack, which decreases labor costs (IDR 1,835,000/day × 3 days). The critical path consists of activities A, B, D, E, F, G, H (total slack = 0), while activity C (mobilization/demobilization) shows 2 days of slack and therefore is not critical. This study confirms that CPM not only determines the activities that are crucial for time but also allows measurable time cost efficiency, supporting more responsive project control in the development of plantation infrastructure.
**Keywords: Critical Path Method, Project Scheduling, Time-Cost Optimization, Network Analysis, Construction Management.**

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## 1. INTRODUCTION

Road infrastructure in oil palm plantations plays a crucial role in supporting daily operations. Well-maintained and efficient roads enable the timely transport of Fresh Fruit Bunches (FFB), fertilizers, equipment, and workers, thereby directly influencing productivity, logistics costs, and overall plantation performance (1). Conversely, poor road conditions or delays in road construction can result in longer travel times, increased vehicle maintenance requirements, and missed harvest windows, all of which ultimately reduce profitability (2).

The PTPN IV Regional 4, Batanghari Plantation began a project to upgrade a 2,600meter road to improve internal connections and support long-term work goals.

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However, the project is running late. Although the original plan expected it to take 120 days, observations and discussions with project staff show that progress is slower than expected. Main issues include poor time estimates for tasks, unclear task sequences, and not having enough workers and large machinery. Specifically, tasks happening at the same time, such as testing and preparation work, were not well coordinated, leading to wasted time and inefficient use of resources.

Traditionally, project schedules were managed with basic Gantt charts. Although these charts are easy to understand, they don't clearly display the logical relationships between tasks or measure the amount of delay each task can withstand without impacting the entire project timeline (called float). Because of this, project managers often found it difficult to pinpoint which activities were genuinely critical in terms of timing.

The Critical Path Method (CPM) is a better way to plan projects than older methods. CPM makes a network diagram that shows all the tasks, figures out when they can start and finish, and finds the critical path, which is the longest chain of tasks that depend on each other and sets the shortest project duration (3). There is no float on this path, so if there is a delay, the whole project will be delayed. CPM helps managers focus their resources, see possible delays, and make smart changes by identifying these important tasks. This is especially helpful in places with few resources, like plantations (4) .

Despite its demonstrated benefits, CPM has at least in case studies that have been published, hardly ever been used in infrastructure projects within Indonesia's state-owned plantation sector. This study helps fill that gap by applying CPM to the Batanghari road improvement project. In addition to confirming that the project could be finished in 117 days three days ahead of schedule our analysis also quantifies the cost savings that resulted, showing how network-based scheduling can enhance time and budget control in actual construction projects.

## 2. MATERIAL AND METHODS

### 2.1. Data Types and Sources

The information used in this study came from two main sources primary data and secondary data. Interviews with PTPN IV Regional 4 staff provided primary data about the order and length of each task in building a 2,600meter road in the Batanghari plantation. Company documents, such as budget plans and implementation schedules, were used to get secondary data. The data gathered included the type of project activities, how long each one lasted (in days), the costs of labor and work, and how the activities depended on each other.

### 2.2. Research Methods

The CPM, a network-based scheduling method popular in project management and construction, was used in a quantitative case study. By simulating logical dependencies between tasks and computing time margins (referred to as float) for each task, CPM assists in determining the smallest practical project duration. Unlike simple Gantt charts, CPM explicitly shows which activities are critical (i.e., cannot be delayed without affecting the overall completion time).

### 2.3. Data Analysis Techniques

#### 2.3.1 Critical Path Method

Critical Path Method fundamentally emphasizes the balance between cost and completion time of large projects. By using CPM, the duration required to complete various project stages is assumed to be known, including the relationship between the number of

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resources used and the completion time of each activity. Therefore, CPM can be defined as a network analysis that aims to optimize the total project cost by reducing or accelerating the overall project completion time (5).

The purpose of using the CPM and network planning in project implementation is to complete the project within the specified time according to the provided network diagram. This is not always possible, so implementation can still be delayed. Many types of work have delay limits, but there are also jobs that do not have delay limits, so that delays in completion will affect the duration of the project completion. Activities that do not have delay limits are called critical activities (5).

In an effort to resolve the road construction project in the Batanghari plantation, the CPM was used. The stages of its completion are as follows (3):

1. Identify project activities

   The first step in the problem-solving process for the road improvement construction project at PTPN IV's Batanghari Plantation is identifying project activities. All major construction tasks were listed and coded (A to H) for clarity and computation (see Table 1 and Table 3)

2. Determine Activity Dependencies

   Once For each activity, its immediate predecessor(s) were identified based on field input and standard construction logic. For example:

   a. Activity B (Testing) and C (Mobilization) can only start after A (Survey & Documentation) is finished.
   b. Activity D (Road Profiling) requires both B and C to be completed first.

3. Construct the Network Diagram

   Using the Activity-on-Arrow (AOA) convention, a network diagram was drawn (Figure 2), where:

   a. Nodes (circles) represent events (start/end points)
   b. Arrows represent activities, labeled with codes (A, B, …) and
   c. Durations (e.g., A,4 means Activity A takes 4 days).

**Figure 1**. CPM Network Diagram

Information:

| | |
|---|---|
| *i* and *j* | : Showing node early and node end of activity. |
| ES *(Early Start*) | : Earliest start time. |
| EF (*Early Finish*) | : Earliest finish time. |
| LS (*Late Start*) | : Latest start time |
| LF (*Late Finish*) | : Latest finish time |
| Kegiatan, Durasi | : Written above the arrow to indicate the activity and duration of its execution. |

4. Determining Completion Duration

   In determining project duration there are two calculations, namely forward calculation and backward calculation (4).

   a. Forward Pass (Calculate Earliest Times)

   The forward Pass starts from point 1 (the initial event) and ends at point $n$ (final

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event). The provisions that need to be considered in forward calculations are as follows (6).

1. An activity can only start if its predecessor activity has been completed, except for the initial activity.
2. The starting time for an activity is 0
3. If an activity has only 1 immediate predecessor, then the ES value is the same as the EF value.
4. If an activity has more than 1 immediate predecessor, then the ES value is the maximum value of all the EF values of its predecessors, as formulated in the following equation

$$ES_{(i,j)} = max(EF_{(i,j)}\ prodecessor) \quad (1)$$

5. The earliest finish time (EF) is equal to the earliest start time plus the duration of the activity in question, as formulated in Equation (2).

$$EF_{(i,j)} = ES_{(i,j)} + D_{(i,j)} \quad (2)$$

6. The forward calculation method is said to be complete when all ES and all EF are calculated.

b. Backward Pass (Calculate Latest Times)

The purpose of the countdown is to determine the last time or date at which we can still start and complete an activity without affecting the overall project completion deadline that has been set by the forward countdown. The provisions that need to be considered in the countdown are as follows (5).

1. The countdown starts from the most recent event or in this case the last event.
2. If an activity is the immediate predecessor of an activity, then the latest finish time (LF) of that activity is equal to the latest start time (LS) of the activity that immediately follows it.
3. If an activity is the immediate predecessor of more than 1 activity, the latest finish time (LF) for that activity is the minimum of all the latest start times (LS) of the activities that immediately follow it, as formulated in the following Equation.

$$LF_{(i,j)} = min\ (LS_{(i,j)}\ in\ the\ next\ activity) \quad (3)$$

4. The latest start time (LS) for an activity is determined by subtracting the duration of the activity from the latest finish time (LF). This can be expressed mathematically as:

$$LS_{(i,j)} = LF_{(i,j)} - D_{(i,j)} \quad (4)$$

5. The backward calculation method is considered complete when all LS and LF have been determined.

5. Critical Path Search

The critical path is the path along the network diagram that has the longest time (project duration) and is the path that passes through activities that do not have Float (7). As for Float used, namely, Total Float (TF). TF is the amount of time an activity can be delayed without affecting the overall project completion schedule. If the TF value is 0, this means that the activity cannot be postponed because it will

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cause delays in subsequent activities. Therefore, to determine the TF value, the following equation can be used.

$$TF_{(i,j)} = LF_{(i,j)} - ES_{(i,j)} - D_{(i,j)} \quad (5)$$

6. Time and Cost Efficiency Analysis

Once the critical path and project duration are known, a comparison is made between the project duration and cost before and after the application of CPM, to see the effectiveness of the method in optimizing time and costs. so that it can be formulated as follows.

$$Cost\ Savings = Initial\ Cost - CPM\ Cost \quad (6)$$

## 3. RESULTS AND DISCUSSION

### 3.1. Identify Job Duration and Job Costs

In the Batanghari Oil Palm Plantation road improvement project at PTPN IV, each activity has a different duration and cost depending on the type of work. Details of the duration and cost of each activity can be seen in Table 1.

**Table 1.** Job Duration and Job Cost

| No | Activity | Duration (Days) | Cost (IDR) |
|---|---|---|---|
| 1 | Measurement, Staking and Documentation | 4 | 2,000,000 |
| 2 | Testing (CBR and PLT Test) | 5 | 3,000,000 |
| 3 | Mobilization/Demobilization | 3 | 8,000,000 |
| 4 | Forming the Profile of the Road Body, Road Shoulders and Forming a "V" Ditch with Road Grader | 22 | 38.235,444 |
| 5 | Compaction/Paving of the road body with Vibrator Roller | 15 | 34,289,268 |
| 6 | Road paving with 2,600 meters of gravel | 26 | 720,720,000 |
| 7 | Spreading Material with a Motor Grader | 22 | 25,593,568 |
| 8 | Compaction/Hardening of Material with Vibrator Roller | 23 | 23,159,552 |
| | **Total** | **120** | **854,997,832** |

Based on Table 1, this project consists of 8 main activities with a total duration of 120 days and a total cost of IDR 854,997,832. Each activity has a specific function in the sequence of road construction implementation, starting from the initial work (measurement and testing) to the final stage (material compaction. One of them is the work of measurement, installation of stakes, and documentation which has a duration of 4 days with a total cost of IDR 2,000,000.

**Table 2**. Labor costs

| Type of Work | Amount | Cost per Day (IDR) |
|---|---|---|
| Foreman | 1 | 200,000 |
| Crasfman | 5 | 875,000 |
| Coolie | 7 | 760,000 |
| **Total** | **13** | **1,835,000** |

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Based on Table 2, the project involved 13 workers, consisting of 1 foreman, 5 laborers, and 7 laborers. The total labor cost per day reached IDR 1,835,000, with costs for laborers amounting to IDR 875,000 per day, laborers IDR 760,000 per day, and the foreman IDR 200,000 per day.

### 3.2. Identifying Relationships Between Activities

The sequence of activities in a road construction project is arranged according to the dependencies between the tasks and their predecessors. Details of this sequence of activities can be seen in Table 3.

**Table 3.** Relationship between Activities

| Activity Code | Activity | Duration (Days) | Activity Predecessor |
|---|---|---|---|
| A | Measurement, Staking and Documentation | 4 | - |
| B | Testing (CBR and PLT Test) | 5 | A |
| C | Mobilization/Demobilization | 3 | A |
| D | Forming the Profile of the Road Body, Road Shoulders and Forming a “V” Ditch with Road Grader | 22 | B, C |
| E | Compaction/Paving of the road body with Vibrator Roller | 15 | D |
| F | Road paving with 2,600 meters of gravel | 26 | E |
| G | Spreading Material with a Motor Grader | 22 | F |
| H | Compaction/Hardening of Material with Vibrator Roller | 23 | G |
| | **Total** | **120** | |

Based on Table 3, activity A is the initial work that forms the basis for subsequent activities. After that, activities B and C can begin after A is completed. Then, activity D is carried out after B and C are completed. Next, the work continues sequentially, namely E after D, F after E, G after F, and finally H after G is completed. This can then be depicted through the network diagram in Figure 2.

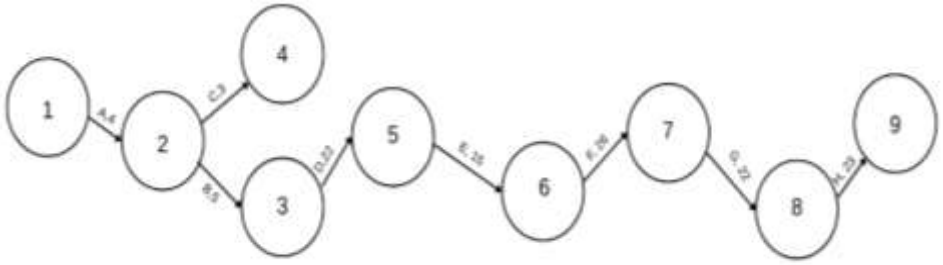


**Figure 2**. Network Diagram

Figure 2 presents The network diagram of the road improvement project in Batanghari Gardens consists of circles (nodes) numbered 1 through 9 that represent events or stages of project activities, also known as events, arrows connect these nodes, indicating the sequence and dependency relationships between activities, each arrow is assigned a letter code (A, B, C, etc.) and a numerical value that indicates the duration of implementation (for example, code A,4 indicates that activity A has a duration of 4 days). The network's detailed activities

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are as follows:

1. Activity A lasts for 4 days, starting at node 1 and ending at node 2. It functions as the project's first activity.
2. Activity B, which lasts for 5 days, links nodes two and three. It is carried out after activity A is finished.
3. Activity C runs for 3 days between nodes two and four. It stands for a different path from node 2.
4. Activity D shifts from node 3 to node 5 over the course of 22 days. It's a continuation of activity B.
5. Activity E lasts for 15 days, starting at node 5 and ending at node 6. It is carried out following the conclusion of activity D.
6. Activity F runs for 26 days between nodes 6 and 7. It is an extension of activity E.
7. Activity G, which lasts for 22 days, links nodes 7 and 8.
8. The project comes to a close when activity H, which lasts for 23 days, moves from node 8 to node 9.

### 3.3. Forward Pass

The next step is to do a forward calculation to find out Earliest Start (ES) and Earliest Finish (EF). The forward count analysis is carried out from the beginning by taking the value 0 and then sorting it to the end. If there are one or more event times, then the largest value is taken. This calculation can be calculated using the formula Equation (2) to obtain the following results:

a) Measurement, stake installation and documentation
This activity starts after A is completed, so:
$ES_{(1,2)} = EF_{(1,2)} = 0$
With a duration of 4 days
$EF_{(1,2)} = ES_{(1,2)} + Durasi_{(1,2)} = 0 + 4 = 4$
Activity A was completed on the 4th day
⋮ ⋮ ⋮
h) Compaction/Hardening of Material with Vibrator Roller
This activity starts after G is finished, so:
$ES_{(8,9)} = EF_{(7,8)} = 94$
With a duration of 23 days
$EF_{(8,9)} = ES_{(8,9)} + Durasi_{(8,9)} = 94 + 23 = 117$
Activity A was completed on the 4th day

Based on the forward calculations that have been carried out, the optimal estimated time for completing the Batanghari Plantation Unit road improvement project is 117 days.

### 3.4. Backward Pass

The next step is to do a backward calculation to find out Latest Start (LS) and Latest Finish (LF). The countdown moves from the final activity to the initial activity of the project. The countdown can be calculated using the formula Equation (4) so that the calculation results are obtained, namely:

a) Final Compaction/Paving with Vibrator Roller
The final activity of the project has a finish time equal to the total duration, so:
$LF_{(8,9)} = LS_{(8,9)} = 117$
With a duration of 23 days

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$LS_{(8,9)} = ES_{(8,9)} - Durasi_{(8,9)} = 117 - 23 = 94$

Activity H must start no later than the 94th day

⋮ ⋮ ⋮

b) Measurement, Stake Installation and Documentation

This activity precedes B and C, so its LF value follows the smallest LS of its two successors::

$LF_{(1,2)} = min(LS_{(2,3)}, LS_{(2,4)}) = 4$

With a duration of 4 days

$LS_{(1,3)} = LF_{(1,2)} - Durasi_{(1,2)} = 4 - 4 = 0$

Activity A starts on day 0 and finishes exactly on day 4

Based on the backward Pass that have been carried out, the optimal estimated time for completing the Batanghari Kebun Unit Road improvement project is 117 days.

### 3.5. Determining the Critical Path

After knowing the value of Earliest Start (IS), Earliest Finish (EC), Latest Start (LS) and Latest Finish (LF) in the activity description, then determine float. This calculation can be calculated using the formula Equation (5) so that the following results are obtained:

a) Measurement, Stake Installation and Documentation

$$TF_{(1,2)} = LF_{(1,2)} - ES_{(1,2)} - Durasi_{(1,2)} = 4 - 0 - 4 = 0$$

b) Testing (CBR and PLT Test)

$$TF_{(2,3)} = LF_{(2,3)} - ES_{(2,3)} - Durasi_{(2,3)} = 9 - 4 - 5 = 0$$

⋮ ⋮ ⋮

c) Compaction/Hardening of Material with Vibrator Roller

$$TF_{(8,9)} = LF_{(8,9)} - ES_{(8,9)} - Durasi_{(8,9)} = 117 - 94 - 23 = 0$$

Regarding the comprehensive results of the total count float, the work process for the Batanghari Oil Palm Plantation Unit Road project is presented in Table 4.

**Table 4.** Total Float

| Genesis | Activity | Preceding Activities | Duration | ES | EF | LS | LF | TF |
|---|---|---|---|---|---|---|---|---|
| 1 | Measurement, stake installation and documentation | - | 4 | 0 | 4 | 0 | 4 | 0 |
| 2 | Testing (CBR and PLT Test) | A | 5 | 4 | 9 | 4 | 9 | 0 |
| 3 | Mobilization/Demobilization | A | 3 | 4 | 7 | 9 | 9 | 2 |
| 4 | Forming the Profile of the Road Body, Road Shoulders and Forming a “V” Ditch with Road Grader | B,C | 22 | 9 | 31 | 9 | 31 | 0 |
| 5 | Compaction/Paving of the road body with Vibrator Roller | D | 15 | 31 | 46 | 31 | 46 | 0 |
| 6 | Road paving with | E | 26 | 46 | 72 | 46 | 72 | 0 |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7 | 2,600 meters of gravel Spreading Material with a Motor Grader | F | 22 | 72 | 94 | 72 | 94 | 0 |
| 8 | Compaction/Hardening of Material with Vibrator Roller | G | 23 | 94 | 117 | 94 | 117 | 0 |

It is clear from the results of the total calculation shown in Table 4 that activities A, B, D, E, F, G, and H have a Total Float (TF) value of zero. Since there is no grace period for delays, this suggests that these seven tasks are on the critical path. On the other hand, activity C has a grace period, which means it cannot be included in the critical path. Thus, Figure 3 shows the project work network.

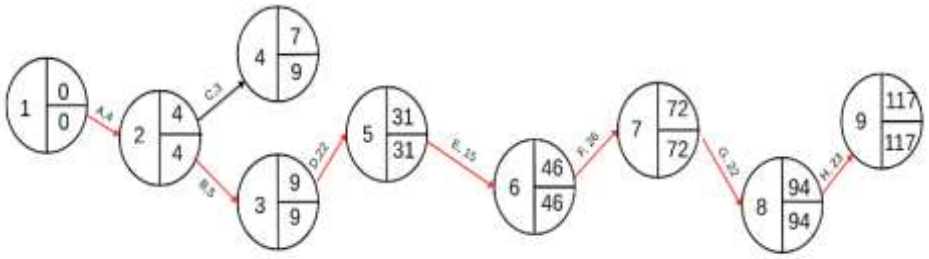


**Figure 3.** Critical Path Network Diagram

### 3.6. Project Cost Analysis and Critical Path Implications

**Table 5**. Comparison of Normal Costs and Using CPM

| Project Requirements | Normal Duration (Days) | Normal Fee (IDR) | CPM Cos (IDR) | CPM Duration (Days) |
|---|---|---|---|---|
| Project Activity Costs | 120 | 1,075,197,832 | 1,069,692,832 | 117 |

By contrasting the initial project conditions with the results following implementation, time and cost efficiency are ascertained. The CPM can be used to determine the cost savings for the Batanghari PTPN IV plantation road improvement construction project. Equation (6) is the formula used in this computation.

$$Cost\ Savings\ Cost\ Savings = \text{IDR } 1{,}075{,}197.832 - \text{IDR } 1{,}069{,}692{,}832$$
$$= \text{IDR } 5{,}505{,}000$$

Following the implementation of the CPM, the project duration decreased from 120 days to 117 days, as shown in Table 5. At the same time, the total cost dropped from IDR 1,075,197,832 to IDR 1,069,692.832. This illustrates how CPM improves project efficiency by accelerating completion times and optimizing cost savings through focused critical path activity control.

## 4. CONCLUSION

This study shows that the 2,600meter road project at PTPN IV Batanghari can be made more accurately scheduled by using the Critical Path Method (CPM). The critical path, as determined by CPM analysis, was A, B, D, E, F, G, and H (TF = 0), whereas activity C had

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two days of float. Not by crashing, but by removing scheduling slack, the minimum feasible duration was 117 days, three days shorter than the initial 120day plan. The overall cost was lowered by IDR 5,505,000 (from IDR 1,075,197,832 to IDR 1,069,692,832) because labor costs IDR 1,835,000 per day. The findings demonstrate that CPM is an effective, low-cost tool for proactive project control in plantation infrastructure. To improve accountability and cut down on delays, we advise incorporating CPM into PTPN IV's regular planning.

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