Scheduling design of Jakarta-Cikampek II elevated toll road project (P.186 – P.187)

Abdul Khalim¹*, Harun Usman Ghifarsyam², Nikko Rozy³, Faqih Ma’arif⁴

¹Department of Civil Engineering, Beijing Jiaotong University, Beijing, China
²Department of Computer Science, Beijing Jiaotong University, Beijing, China
³Swadaya Gunungjati University, Cirebon, Indonesia
⁴Department of Civil Engineering, Beihang University, Beijing, China

*E-mail: abdoel553@outlook.com

* corresponding author

ABSTRACT

The key to achieving effective and efficient development goals is by increasing the quality of construction management by collecting up-to-date data about the project's resources, mainly about productivity. In this research space, productivity will be discussed, including human resources and their management. The case study is the project of Jakarta-Cikampek II Elevated Toll Road. This project was a developing project to improve the capacity of the existing Jakarta-Cikampek toll road. This elevated structure will be built right in the area (median and side edge) of the existing toll road, making it interesting to discuss how the construction is carried out. Scheduling analysis in this study was carried out at points P.186 to P.187 of the construction project. The analysis includes identifying the productivity index of labor resources and equipment that has a major role in shaping the scheduling concept. The concept will be performed by determining a network diagram that will use the Critical Path Method (CPM) rule. The data used in this analysis are construction drawing, s-curve plan, worker data, weekly job plan, work method, and some interviews with worker and field project manager. These results obtained the large productivity of workers and equipment, and the duration required to complete the construction starting from point P.186 to P.187 is 248 working days.

This is an open-access article under the CC–BY-SA license

ARTICLE INFO

Article history
Received: 7 October 2020
Revised: 26 November 2020
Accepted: 20 January 2021

Keywords
Wemos
Drivethru market
Internet of things
Android application

1. Introduction

The Project of Jakarta-Cikampek II Elevated Toll Road will be built right in the median area and on the side of the existing toll road. This project's duration will greatly affect the conduciveness of traffic, especially in the Jakarta-Cikampek toll road area. It needs an effective and efficient construction management plan to be done and completed properly.

Management is coordinating work activities so that the work is completed efficiently and effectively and through other researchers [1], [2]. The research aims to plan a construction
management concept within the scope of effective and efficient scheduling to minimize disruption to the currently active toll road. The research method must include productivity analysis of human resources and tools. The data must be as accurate as possible because it will be used to determine the work duration and compile it into a network diagram using the CPM (Critical Path Method) method.

In this study, the information on workers in the form of numbers and their productivity during working at a certain time will determine the productivity index of a worker in a particular job. The tools used and which play an important role in the completion of a job will also be identified for their number, specifications, and productivity. The productivity will eventually be used to determine how long it takes for tools and workers to complete their work. The optimal duration will be obtained, which will be used to compile a network diagram and analyze it using the Critical Path Method (CPM).

2. Method

The productivity of equipment are as follows:

2.1. Excavator

| (1) Bucket Capacity (m3) | V |
|--------------------------|---|
| (2) Bucket Factor        | Fb|
| (3) Equipment efficiency factor | Fa |
| (4) Conversion factor, Depth <40% | Fv |
| (5) Time cycle           | Tc |
| (6) Digging (minute)     | T1 |
| (7) Swing and Dump (minute) | T2 |
| (8) Setting Position (minute) | T3 |
| (9) Disruption (minute)  | T4 |
| (10) Time cycle (minute) (T1+T2+T3+T4) x Fv | Tc |
| (11) Prod./Hour (m3/hour) | Q_{\text{Excavator}} |

**Table 1.** The bucket fill factor of an excavator (Fa) from Regulation of the Minister of Public Works No. 28 2016 [3]

| Operating condition | Field condition                              | Bucket factor (Fb) |
|---------------------|----------------------------------------------|--------------------|
| Easy                | Common ground, clayey soil, soft soil        | 1.1 – 1.2          |
| Average             | Sandy soil, dry soil                         | 1.0 – 1.1          |
| Rather difficult    | Sandy soil with gravel                       | 1.0 – 0.9          |
| Difficult           | Blasted rock                                 | 0.9 – 0.8          |

**Table 2.** The efficiency factor of an excavator (Fa) from Regulation of the Minister of Public Works No. 28 2016

| Operating condition | Efficiency Factor (Fa) |
|---------------------|------------------------|
| Good                | 1.1 – 1.2              |
| Average             | 1.0 – 1.1              |
| Rather poor         | 1.0 – 0.9              |
| Poor                | 0.9 – 0.8              |
### Table 3. Conversion factor (Fv) from Regulation of the Minister of Public Works No. 28 2016 [3]

| Digging Condition | Easy | Normal | Rather difficult | Difficult |
|-------------------|------|--------|-----------------|-----------|
| ≤ 40%             | 0.7  | 0.9    | 1.1             | 1.4       |
| (40 – 75) %       | 0.8  | 1.0    | 1.3             | 1.6       |
| > 75 %            | 0.9  | 1.1    | 1.5             | 1.8       |

\[ Q_{\text{excavator}} = \frac{V \times F_b \times F_a \times 60}{T_c} \]  \hspace{1cm} (1)

#### 2.2. Wheel Loader

1. Average speed (km/h) \( v \)
2. Number of passes (passes) \( n \)
3. Efficiency factor (good = 0.83) \( F_e \)
4. Compaction width effectivity \( b_e \)
5. Compaction thickness (m) \( t \)
6. Productivity/hour (m³/h) \( Q_{\text{vibraroller}} \)

\[ Q_{\text{vibraroller}} = \frac{(b_e \times v \times 1000) \times t \times F_e}{n} \]  \hspace{1cm} (2)

#### 2.3. Dump Truck

1. Bed Capacity (m³) \( V \)
2. Loaded average speed (km/h) \( v_1 \)
3. Empty average speed (km/h) \( v_2 \)
4. Time cycle \( T_c \)
5. Loading \( (V / Q_1) \times 60 \) \( T_1 \)
6. Loaded travel time \( (L / V_1) \times 60 \) \( T_2 \)
7. Empty travel time \( (L / V_2) \times 60 \) \( T_3 \)
8. Time cycle \( (\sum T) \) \( T_c \)
9. Productivity/hour (m³/h) \( Q_{\text{dump truck}} \)

### Table 4. Job Efficiency (Fe) from Regulation of the Minister of Public Works No. 28 2016 [3]

| Work condition  | Job efficiency (Fe) |
|-----------------|---------------------|
| Good            | 0.83                |
| Average         | 0.80                |
| Rather poor     | 0.75                |
| Poor            | 0.70                |
### Table 5. Average speed (F)<sub>a</sub>

| Field condition | Loading condition | Speed / v (km/h) |
|-----------------|------------------|-----------------|
| Flat            | Loaded           | 40              |
|                 | Unloaded         | 60              |
| Uphill          | Loaded           | 20              |
|                 | Unloaded         | 40              |
| Downhill        | Loaded           | 20              |
|                 | Unloaded         | 40              |

\[
Q_{\text{dumptruck}} = \frac{V \times F_e \times 60}{D \times F_k \times T_c} \quad (3)
\]

#### 2.4. Flatbed Truck

1. Bed Capacity (unit of RCP) \( V \)
2. Efficiency factor \( F_e \)
3. Loaded average speed \( v_1 \)
4. Empty average speed \( v_2 \)
5. Time Cycle \( \sum T_{1,2,3,4} \)
6. Loaded travel time \((L/v_1) \times 60\) \( T_1 \)
7. Empty travel time \((L/v_2) \times 60\) \( T_2 \)
8. Loading \( T_3 \)
9. RCP erection \( T_4 \)
10. Productivity/hour \((m'/hour)\) \( Q_{\text{flatbed}} \)

\[
Q_{\text{flatbed}} = \frac{V \times F_e \times 60}{T_c} \quad (4)
\]

#### 2.5. Drill Machine SR60

1. Production Capacity \((m'/hour)\) \( Q_1 \)
2. Production Capacity \((m^3/hour)\) \( Q_1' \)

\[
Q_1' = 0.25\pi \times D_2 \times Q_1 \quad (5)
\]

#### 2.6. Water Tank Truck

1. Bucket Capacity \((m^3)\) \( V \)
2. Bucket Factor \( F_b \)
3. Efficiency factor \((\text{good} = 0.83)\) \( F_e \)
4. Conversion factor, Depth <40% \( F_v \)
5. Time cycle \( T_c \)
6. Digging \((V / Q_1') \times 60\) (minute) \( T_1 \)
7. Swing and Dump (minute) \( T_2 \)
8. Disruption (minute) \( T_4 \)
9. Time cycle \((T_1+T_2+T_3+T_4) \times F_v\) \( T_c \)
10. Prod./Hour \((m^3/hour)\) \( Q_{\text{Watertruck}} \)
\[ Q_{\text{watertank}} = \frac{V \times F_b \times F_e \times 60}{T_c} \] (6)

(11) Capacity (m³) \( V \)
(12) Efficiency factor (good = 0.83) \( F_e \)
(13) Loaded average speed \( V_1 \)
(14) Empty average speed \( V_2 \)
(15) Time cycle \( T_c \)
(16) Filling \((V : Q_1) \times 60\) \( T_1 \)
(17) Transport \((L : V_1) \times 60\) \( T_2 \)
(18) Reverse \((L : V_2) \times 60\) \( T_3 \)
(19) Setting, idling, pouring \( T_4 \)
(20) Productivity/hour (m³/hour) \( Q_{\text{truckmixer}} \)

\[ Q_{\text{truckmixer}} = \frac{V \times F_e \times 60}{T_c} \] (7)

2.6. Crawler Crane

(1) Lifting Capacity (ton) \( V \)
(2) Efficiency factor (good = 0.83) \( F_e \)
(3) Time cycle \( T_{c3} \)
(4) Binding \( T_1 \)
(5) Lifting \( T_2 \)
(6) Swing \( T_3 \)
(7) Setting, Holding & Uninstall Pipe \( T_4 \)
(8) Productivity/hour (ton/hour) \( Q_{\text{tremiepipe}} \)

\[ Q_{\text{tremiepipe}} = \frac{V \times F_e \times 60}{T_c} \] (8)

2.7. Wheel Loader

(1) Bucket Capacity \( V \)
(2) Bucket factor \( F_b \)
(3) Equipment efficiency factor \( F_e \)
(4) Forward average speed \( V_f \)
(5) Reverse average speed \( V_r \)
(6) Time cycle (mnt) \( T_c \)
(7) Loading to Bin (mnt) \( T_1 \)
(8) Reverse to Stock Bin (mnt) \( T_2 \)
(9) Disruption (mnt) \( T_3 \)
(10) Productivity/ hour (m²/h) \( Q_1 \)
Table 6. Bucket factor of wheel loader (Fa) from Regulation of the Minister of Public Works No. 28 2016 [3]

| Pouring condition  | Bucket factor   |
|-------------------|-----------------|
| Easy              | 1.0 – 1.1       |
| Average           | 0.85 – 0.95     |
| Rather difficult  | 0.80 – 0.85     |
| Difficult         | 0.75 – 0.80     |

\[ Q_{\text{wheel loader}} = \frac{V \times F_b \times F_e \times 60 \times W_s}{T_c} \] (9)

2.8. Pneumatic Tire Roller

(1) Average speed (km/hr) \( V \)
(2) Effective width compaction (m) \( b \)
(3) Number of passes (passes) \( n \)
(4) Number of line \( N \)
(5) Equipment efficiency factor \( F_e \)
(6) Overlap width (m) \( b_0 \)
(7) Productivity/hour (ton/hour) \( Q_{\text{tireroller}} \)

\[ Q_{\text{tireroller}} = \frac{(V \times 1000) \times (N(b - b_0) + b_0) \times t \times F_e \times D_1}{n} \] (10)

2.9. Productivity of Manpower

Manpower productivity is identified by comparing the output and the time required for a job [4].

Productivity/day: \( Q_t = T_w \times Q_1 \) (11)

(1) Time working/day \( T_w \)
(2) Digging Productivity/Day \( Q_t \)

\[ Q_t = T_w \times Q_1 \] (12)

Manpower:
(1) Worker \( w \)
(2) Foreman \( f \)

Manpower Coefficient/M3:
(1) Worker \( = \frac{(T_w \times w)}{Q_t} \)
(2) Foreman \( = \frac{(T_w \times f)}{Q_t} \)

The management function approach shows apparent effectiveness or obligation when coordinating others efficiently and effectively—the four essential functions of management [1]: planning,
organizing, lead, controlling. In the analysis of the network, there are two concepts, namely events and activity.

1. **Events**: is the beginning or end of an activity.
2. **Activity**: is a job or task where the completion requires a certain period, costs, and facilities.

To design a project network, three important elements must be known [5], [6].

1. **Inventory of activity**
2. The process of inventory of these activities is the breakdown of a project into several major components of the project
3. **Dependency Logic**
4. Solving the project into work packages should consider the sequence of work to be performed
5. **Estimated Time**
6. This time estimate is the period required to complete each activity

Several factors determine the length of activity, job volume, labor, weather, project location, time estimating procedure. The terms used in the network diagram are as follows [7], [8]:

1. Earliest Start Time (ES) is the earliest time an activity can start, taking into account the expected activity time and the sequence requirements of the exhortation.
2. Latest Start Time (LS) is the slowest time to be able to start an activity without delaying the entire project.
3. Earliest Finish Time (EF) is the earliest time an activity can be completed
4. Latest Finish Time (LF) at the latest to be able to complete an activity without delaying the completion of the overall project.
5. **Duration (D)** is the period of activity.

---

**Fig. 1. Activity on Arrow (AOA)**

Activity on arrow or often referred to as CPM (Critical Path Method) consists of:

1. \( i,j \) = Case number
2. \( X \) = Activity name
3. \( EET \) = Earliest Event Time
4. \( LET \) = Latest Event Time
5. \( Y \) = Activity Duration
6. \( ES \) = Earliest Start Time
7. \( EF \) = Earliest Finish Time
8. \( LS \) = Latest Start Time
(9) LF = Latest Finish Time

Calculation:
Forward pass:
(1) Early Start = Maximum (or Highest) EF value from immediate predecessor(s)
(2) Early Finish = ES + Duration
Backward pass:
(1) Late Start = LF – Duration
(2) Late Finish = Minimum (or Lowest) LS value from immediate Successor(s)
Float:
(1) Total Float = LS – ES (it is also calculated by LF – EF)
(2) Free Float = Lowest ES of successors – EF

Critical Path method has the following characteristics:
(1) Network A network diagram is created using arrows to illustrate the activities, and the node describes an event. At the beginning of the arrow, the node is determined as I-Node, while at the end of the arrow is specified as J-Node.
(2) Use advanced calculations to obtain the earliest start time (EETi) on the earliest I-Node and start time (EET) on the J-Node of all activities by taking its maximum value. Here it is understood that the earliest time of event occurs = 0. The calculation is EETj = EETi + duration X.
(3) Use the countdown to obtain the slowest completion time (LETi) on the I-Node and the slowest completion time (LETj) on the J-Node of all activities by taking the minimum value. The calculation is LETi = LETj - X duration. LETi = LETj - X duration.
(4) Between two events, there is a CPM (Critical Path Method), where a deterministic approach uses only one type of duration on its activities. Total Float (TF) = 0.
(5) Float: the tolerance limit for the delay in an activity that can be used for time optimization and resource allocation.

Fig. 2. Float variation of an activity
3. Results and Discussion

Productivity identification of tools that had a vital role in developing construction is presented in Table 7. Labor productivity has differences in each type of work [9]–[11] as Fig. 3 shows different labor productivity in several jobs based on the duration of the number of workers according to conditions in the field [12].

| Equipment                                      | Job section                  | Prod.      |
|------------------------------------------------|------------------------------|------------|
| Excavator Komatsu PC128US-2                   |                              | 59.94 m3/hr|
| Dump Truck Hino FM 260 JD                     | Work Platform and compaction | 16.48 m3/hr|
| Vibrator Roller CatCB54B                      |                              | 136 m3/hr  |
| Excavator Komatsu PC128US-2                   |                              | 20.54 m3/hr|
| Dump Truck Hino FM 260 JD                     | Drainage                     | 7.53 m3/hr |
| Flatbed Truck Tata LPS 4018 TC EX             |                              | 7.45 m³/hr |
| Drill Machine SR60                            |                              | 11.03 m³/hr|
| Watertank Truck Henghe HHR5160GSS4EQ           | Drilling Bored Pile          | 9.91 m3/hr |
| Dump Truck Hino FM 260 JD                     |                              | 1.28 m3/hr |
| Service Crane (Crawler)                       |                              |            |
| Concrete Mixer Hino FM 260 JM                 | Bored Pile Concrete Casting  | M3/hr      |
| Crawler crane                                 |                              |            |
| Excavator Vibro mounted YZM                   | Driving Steel Sheet Pile     | 7 sheet/hr |
| Excavator Kobelco SK-200                      | Pile cap                     | 29.88 m³/hr|
| Dump Truck Hino FM 260 JD                     |                              | 9.03 m³/hr |
| Bar Cutter & Bender                           | Reinforcement                | 199.20 kg/hr|
| Bar Roller                                    |                              | 420 kg/hr  |
| Concrete Mixer Hino FM 260 JM                 | Concrete Casting, Pile Cap,  | 6.23 m³/hr |
| Concrete Pump                                 | Pier, Slab                   |            |
| Concrete Vibrator REDFOX                      |                              | 21.86 m³/hr|
| Wheel Loader CDM816                           |                              | 3.00 m³/hr |
| Dump Truck Hino FM 260 JD                     |                              | 47.52 m²/hr|
| Asphalt finisher Sumitomo HB45W               |                              | 3.37 m³/hr |
| Tandem roller Sakai SW350                     |                              | 48.11 ton/hr|
| AC-WC                                         |                              | 21.99 ton/hr|
| Pneumatic Tire Roller Sakai TS7409            |                              | 51.26 ton/hr|
| Thermoplastic Machine Jili Jlcrj              |                              | 9.34 m²/hr |
| Air Compressor                                | Street Marking               | 8.305 m²/hr|
### Rebar Installation

| Volume | Duration (Specification) | Labor | Productivity Kg/Day |
|--------|--------------------------|-------|---------------------|
| V 18157.9 Kg | D 5 Day | W 11 | $\frac{V}{D}Q = 3631.59$ Kg/Day |

**Coefficient of Manpower**

- Labor: $6 \text{ Man} : 6 : Q \rightarrow 0.00165$ MD
- Skilled labor: $2 \text{ Man} : 2 : Q \rightarrow 0.00055$ MD
- Skilled labor: $1 \text{ Man} : 1 : Q \rightarrow 0.00055$ MD
- Foreman: $1 \text{ Man} : 1 : Q \rightarrow 0.00055$ MD

### Rebar Pier Installation

| Volume | Duration (Specification) | Labor | Productivity Kg/Day |
|--------|--------------------------|-------|---------------------|
| V 4815.27 Kg | D 1 Day | W 6 | $\frac{V}{D}Q = 4815.27$ Kg/Day |

**Coefficient of Manpower**

- Labor: $2 \text{ Man} : 2 : Q \rightarrow 0.00042$ MD
- Skilled labor: $2 \text{ Man} : 2 : Q \rightarrow 0.00042$ MD
- Skilled labor: $1 \text{ Man} : 1 : Q \rightarrow 0.00042$ MD
- Foreman: $1 \text{ Man} : 1 : Q \rightarrow 0.00042$ MD

### Rebar Pier Head Installation

| Volume | Duration (Specification) | Labor | Productivity Kg/Day |
|--------|--------------------------|-------|---------------------|
| V 14936.7 Kg | D 7 Day | W 10 | $\frac{V}{D}Q = 2133.81$ Kg/Day |

**Coefficient of Manpower**

- Labor: $6 \text{ Man} : 6 : Q \rightarrow 0.00281$ MD
- Skilled labor: $6 \text{ Man} : 6 : Q \rightarrow 0.00094$ MD
- Skilled labor: $1 \text{ Man} : 1 : Q \rightarrow 0.00094$ MD
- Foreman: $1 \text{ Man} : 1 : Q \rightarrow 0.00094$ MD

### Rebar Slab & Barrier Installation

| Volume | Duration (Specification) | Labor | Productivity Kg/Day |
|--------|--------------------------|-------|---------------------|
| V 196941 Kg | D 20 Day | W 22 | $\frac{V}{D}Q = 9847.05$ Kg/Day |

**Coefficient of Manpower**

- Labor: $14 \text{ Man} : 14 : Q \rightarrow 0.00142$ MD
- Skilled labor: $6 \text{ Man} : 6 : Q \rightarrow 0.00062$ MD
- Skilled labor: $1 \text{ Man} : 1 : Q \rightarrow 0.00062$ MD
- Foreman: $1 \text{ Man} : 1 : Q \rightarrow 0.00062$ MD

### Pile Demolition

| Volume | Duration (Specification) | Labor | Productivity Kg/Day |
|--------|--------------------------|-------|---------------------|
| V 8 Point | D 3 Day | W 8 | $\frac{V}{D}Q = 2,667$ Point/Day |

**Coefficient of Manpower**

- Labor: $6 \text{ Man} : 6 : Q \rightarrow 1.5$ MD
- Skilled labor: $2 \text{ Man} : 2 : Q \rightarrow 0.75$ MD
- Skilled labor: $1 \text{ Man} : 1 : Q \rightarrow 0.75$ MD
- Foreman: $1 \text{ Man} : 1 : Q \rightarrow 0.75$ MD

---

**Fig. 3.** The productivity of each labor/worker.
### 3.1. Network Diagram Using Critical Path Method (CPM)

#### Table 8. CPM deterministic and critical path identification

| No | Description                      | Node | Immediate Predecessor | Duration | Critical Path | LS | ES | EF | LF | Slack Time |
|----|----------------------------------|------|-----------------------|----------|---------------|----|----|----|----|------------|
| 1  | General Work                     |      |                       |          |               |    |    |    |    |            |
| 2  | Traffic Protection and Treatment |      |                       |          |               |    |    |    |    |            |
| 3  | Bored Pile Foundation            |      |                       |          |               |    |    |    |    |            |
| 4  | Drilling                         |      |                       |          |               |    |    |    |    |            |
| 5  | Bored Pile Foundation            |      |                       |          |               |    |    |    |    |            |
| 6  | Pier Head                        |      |                       |          |               |    |    |    |    |            |
| 7  | Pier Head                        |      |                       |          |               |    |    |    |    |            |
| 8  | Steel Box Girder                 |      |                       |          |               |    |    |    |    |            |
| 9  | Slab                             |      |                       |          |               |    |    |    |    |            |
| 10 | Reinforcement Work               |      |                       |          |               |    |    |    |    |            |
| 11 | S-Form Installation              |      |                       |          |               |    |    |    |    |            |
| 12 | Deck Drain                       |      |                       |          |               |    |    |    |    |            |
| 13 | Concrete Structure               |      |                       |          |               |    |    |    |    |            |
| 14 | Moving S-Form                    |      |                       |          |               |    |    |    |    |            |
| 15 | Barrier Structure                |      |                       |          |               |    |    |    |    |            |
| 16 | Drainage                         |      |                       |          |               |    |    |    |    |            |
| 17 | Excavation 0-2 M                 |      |                       |          |               |    |    |    |    |            |
| 18 | Finishing                        |      |                       |          |               |    |    |    |    |            |
| 19 | Scheduling design of Jakarta     |      |                       |          |               |    |    |    |    |            |
| 20 | Cikampek II elevated toll road   |      |                       |          |               |    |    |    |    |            |

*Notes:*(P.186 – P.187)
Fig. 4. Network diagram using critical path method (CPM)
General work activities could begin one week before all activities are carried out and become routine activities every day, supporting other activities [13] so that the total project duration will increase by six days. The results of network diagram analysis using the Critical Path Network (CPM) are formed into a Gantt Chart. This Gantt Chart is linked by calendar and weekly blocks (in a week has six working days) [14]. This scheduling concept fundamentally depends on the development methodology, which technically determines the schedule's effectiveness and efficiency. The activity which is the main concern for determining the work method is the pier head section [15]. This section is demanded the optimal duration, but the location of the work in an active toll road area is a serious challenge [16] so that to carry out the development in this section, the Sosrobahu method is chosen, it is aimed at avoiding the direct influence on traffic consumption.
4. Conclusion

The research found that the productivity of equipment and manpower resources affects each other. The optimization of both will provide acceleration and improvement in the quality of work. This productivity data is the fundamental data needed to create an effective and efficient scheduling concept. Through analysis using the Critical Path Method (CPM), the project is known to be planned for completion in 248 working days + 6 days = 254 days, 43 weeks.

References

[1] S. P. Robbins, Management. Denver: Pearson Prentice Hall, 2007.

[2] R. Wirahadikusumah, Safitri, B. Susanti, and B. Soemardi, “Risk Inclusion in the Reserve Price Estimation for Toll Road Concession Award,” J. Traffic Logist. Eng., vol. 2, no. 1, pp. 34–39, 2014, [Online]. Available: http://www.jtle.net.

[3] the Minister of Public Works, Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat: Pedoman Analisis Harga Satuan Bidang Pekerjaan Umum. 2016.
[4] P. F. Marzuki, H. Permadi, and I. Sunaryo, “Factors Affecting Job Satisfaction of Workers in Indonesian Construction Companies,” *J. Civ. Eng. Manag.*, vol. 18, no. 3, pp. 299–309, 2012, DOI: 10.3846/13923730.2012.698889.

[5] Moder et al., *Project Management with CPM, PERT and Precedence Diagraming*, 3rd ed. New York: Van Nostrand Reinhold Company, 1983.

[6] P. D. Galloway, “Survey of the construction industry relative to the use of CPM scheduling for construction projects,” *J. Constr. Eng. Manag.*, vol. 132, no. 7, pp. 697–711, 2006.

[7] Trihendradic, *Microsoft Project 2007 Langkah Cerdas Merencanakan, Menjadwalkan dan Mengontrol Proyek*. Yogyakarta: Andi, 2008.

[8] D. Trietsch and K. R. Baker, “PERT 21: Fitting PERT/CPM for use in the 21st century,” *Int. J. Proj. Manag.*, vol. 30, pp. 490–502, 2012, [Online]. Available: www.sciencedirect.com.

[9] M. S. Nashwan, “Construction labour productivity: review of factors identified,” *Int. J. Constr. Manag.*, pp. 1–13, 2019, DOI: 10.1080/15623599.2019.1627503.

[10] Amaliah, “Penerapan Manajemen Proyek dengan Metode CPM (Critical Path Method) Pada Proyek Pembangunan SPBE,” *J. Pengabdi. Kpd. Masy.*, vol. 3, no. May, 2019.

[11] M. Htike and Thein, "Critical path analysis programming method without network diagram,” 2018, DOI: doi.org/10.1051/matecconf/201819201027.

[12] A. Freidi, “Determinants of the best practices for successful project management,” *Int. J. u-e-Serv. Sci. Technol.*, vol. 7, no. 3, pp. 173–186, 2014, DOI: http://dx.doi.org/10.14257/ijunesst.2014.7.3.15.

[13] P. Ivan and S. Andi, “Monitoring and Analysis Project Schedule,” 2017.

[14] R. Susanti and L. Lukman, “Studi Eksporasi Metode Penjadwalan Pada Proyek Konstruksi (Studi Kasus: Proyek Pembangunan Jalan Tol Semarang-Solo Ruas Ruas Ungaran – BAWEN PAKET V),” *J. Proy. Tek. Sipil*, vol. 2, no. 1, pp. 1–3, 2019, DOI: https://doi.org/10.14710/potensi.2019.3607.

[15] M. F. A. Arifin, "Cost analysis for heavy equipment in earthfill work – An optimization of heavy equipment fleet (Case study: Jabung ring dike project)," 2017, DOI: 10.1063/1.4976869.

[16] M. Lu, J. Liu, and W. Ji, “Formalizing a path-float-based approach to determine and interpret total float in project scheduling analysis,” *Int. J. Constr. Manag.*, vol. 17, no. 4, pp. 251–263, 2017, DOI: 10.1080/15623599.2016.1207366.