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

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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 prom point P.186 to P.187 is 248 working days.

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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)	$Q_{Excavator}$

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 $\left(\frac{\text{Digging condition}}{\text{digging depth}}\right)$	Dumping 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

$$\text{Qexcavator} = \frac{\text{V x Fb x Fa x 60}}{\text{Tc}} \quad (1)$$

2.2. Wheel Loader

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

$$\text{Qvibraroller} = \frac{\text{(be x v x 1000)x t x Fe}}{\text{n}} \quad (2)$$

2.3. Dump Truck

(1)	Bed Capacity (m3)	V
(2)	Loaded average speed (km/h)	v1
(3)	Empty average speed (km/h)	v2
(4)	Time cycle	Tc
(5)	Loading (V / Q1) x 60	T1
(6)	Loaded travel time (L / V1) x 60	T2
(7)	Empty travel time (L / V2) x 60	T3
(8)	Time cycle (∑T)	Tc
(9)	Productivity/hour (m3/h)	$Q_{dump\ truck}$

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 (Fa)

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

$$\text{Qdumptruck} = \frac{\text{V x Fe x 60}}{\text{D x Fk x Tc}} \qquad (3)$$

2.4. Flatbed Truck

(1)	Bed Capacity (unit of RCP)	V
(2)	Efficiency factor	Fe
(3)	Loaded average speed	v1
(4)	Empty average speed	v2
(5)	Time Cycle ($\sum T_{1,2,3,4}$)	Tc
(6)	Loaded travel time (L/v1) x 60	T1
(7)	Empty travel time (L/v2) x 60	T2
(8)	Loading	T3
(9)	RCP erection	T4
(10)	Productivity/hour (m'/hour)	$Q_{flatbed}$

$$\text{Qflatbed} = \frac{\text{V x Fe x 60}}{\text{Tc}} \qquad (4)$$

2.5. Drill Machine SR60

(1)	Production Capacity (m'/hour)	Q1
(2)	Production Capacity (m3/hour)	Q1'

$$Q1' = 0.25\pi \text{ x } D2 \text{ x } Q1 \qquad (5)$$

2.6. Water Tank Truck

(1)	Bucket Capacity (m3)	V
(2)	Bucket Factor	Fb
(3)	Efficiency factor (good = 0.83)	Fe
(4)	Conversion factor, Depth <40%	Fv
(5)	Time cycle	Tc
(6)	Digging (V / Q1') x 60(minute)	T1
(7)	Swing and Dump (minute)	T2
(8)	Disruption (minute)	T4
(9)	Time cycle (T1+T2+T3+T4) x Fv)	Tc
(10)	Prod./Hour (m3/hour)	$Q_{Watertruck}$

$$Qwatertank = \frac{V \text{ x } Fb \text{ x } Fe \text{ x } 60}{Tc} \qquad (6)$$

(11)	Capacity (m3)	V
(12)	Efficiency factor (good = 0.83)	Fe
(13)	Loaded average speed	V1
(14)	Empty average speed	V2
(15)	Time cycle	Tc
(16)	Filling (V : Q1) x 60	T1
(17)	Transport (L : V1) x 60	T2
(18)	Reverse (L : V2) x 60	T3
(19)	Setting, idling, pouring	T4
(20)	Productivity/hour (m3/hour)	$Q_{truckmixer}$

$$Qtruckmixer = \frac{V \text{ x } Fe \text{ x } 60}{Tc} \qquad (7)$$

2.6. Crawler Crane

(1)	Lifting Capacity (ton)	V
(2)	Efficiency factor (good = 0,83)	Fe
(3)	Time cycle	Tc3
(4)	Binding	T1
(5)	Lifting	T2
(6)	Swing	T3
(7)	Setting, Holding & Uninstall Pipe	T4
(8)	Productivity/hour (ton/hour)	$Q_{tremiepipe}$

$$Qcrawlercrane = \frac{V \text{ x } Fe \text{ x } 60}{Tc} \qquad (8)$$

2.7. Wheel Loader

(1)	Bucket Capacity	V
(2)	Bucket factor	Fb
(3)	Equipment efficiency factor	Fe
(4)	Forward average speed	Vf
(5)	Reverse average speed	Vr
(6)	Time cycle (mnt)	Tc
(7)	Loading to Bin (mnt)	T1
(8)	Reverse to Stock Bin (mnt)	T2
(9)	Disruption (mnt)	T3
(10)	Productivity/ hour (m2/h)	Q1

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

$$\text{Qwheelloader} = \frac{\text{V x Fb x Fe x 60 x Ws}}{\text{Tc}} \quad (9)$$

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 Fe
(6) Overlap width (m) bo
(7) Productivity/hour (ton/hour) $Q_{tireroller}$

$$\text{Qtireroller} = \frac{\text{(V x 1000)x (N(b−bo)+bo) t x Fe x D1}}{\text{n}} \quad (10)$$

2.9. Productivity of Manpower

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

Productivity/day: $Q_t = T_w \text{ x } Q_1$ (11)

(1) Time working/day Tw
(2) Digging Productivity/Day Qt

Qt = Tw x Q1 (12)

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

Manpower Coefficient/M3:
(1) Worker = (Tw x w) / Qt
(2) Foreman = (Tw x f) / Qt

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.

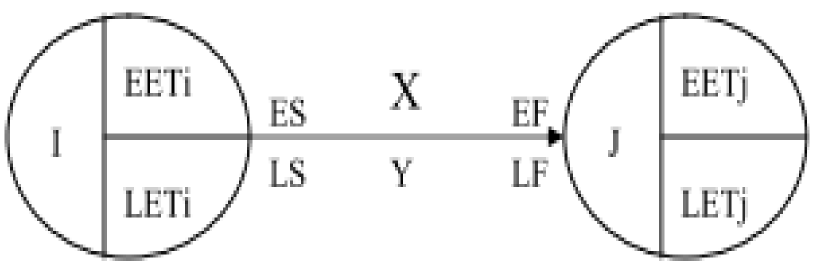

Fig. 1. Activity on Arrow (AOA)

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.

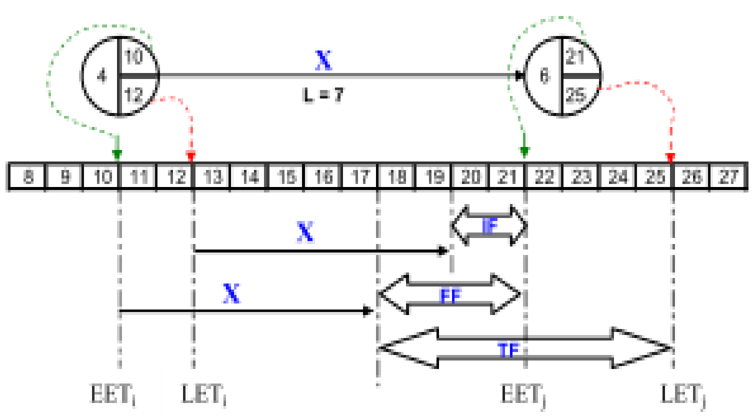

Fig. 2. Float variation of an activity

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].

Table 7. Productivity value of main tools

Equipment	Job section	Prod.
Excavator Komatsu PC128US-2	Work Platform and compaction	59.94 m3/hr
Dump Truck Hino FM 260 JD		16.48 m3/hr
Vibrator Roller CatCB54B		136 m3/hr
Excavator Komatsu PC128US-2	Drainage	20.54 m3/hr
Dump Truck Hino FM 260 JD		7.53 m3/hr
Flatbed Truck Tata LPS 4018 TC EX		7.45 m'/hr
Drill Machine SR60	Drilling Bored Pile	11.03 m'/hr
Watertank Truck Henghe HHR5160GSS4EQ		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		22.20 ton/hr
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, Pier, Slab	6.23 m3/hr
Concrete Pump		21.86 m3/hr
Concrete Vibrator REDFOX		3.00 m3/hr
Wheel Loader CDM816		47.52 m2/hr
Dump Truck Hino FM 260 JD		3.37 m3/hr
Asphalt finisher Sumitomo HB45W	AC-WC	48.11 ton/hr
Tandem roller Sakai SW350		21.99 ton/hr
Pneumatic Tire Roller Sakai TS7409		51.26 ton/hr
Thermoplastic Machine Jili Jlcrj	Street Marking	9.34 m2/hr
Air Compressor		8.305 m2/hr

Rebar installation						
1	Rebar installation					
	Volume			V	18157,9	Kg
	duration plan *(Specification)*			D	5	Day
	Labor			W	11	
	- Labor			w	6	Man
	- Skilled labor			tw	2	Man
	- Skilled labor			tw	1	Man
	- Foreman			m	1	Man
	Productivity Kg/Day	= V / D		Q	3631,59	Kg/Day
	Coefficient of Manpower					
	- Labor	6 Man	= 6 : Q		**0,00165**	**MD**
	- Skilled labor	2 Man	= 2 : Q		**0,00055**	**MD**
	- Skilled labor	1 Man	= 1 : Q		**0,00028**	**MD**
	- Foreman	1 Man	= 1 : Q		**0,00028**	**MD**
1	Rebar Pier installation					
	Volume *(Specification)*			V	4815,27	Kg
	duration plan			D	1	Day
	Labor			W	6	
	- Labor			w	2	Man
	- Skilled labor			tw	2	Man
	- Skilled labor			tw	1	Man
	- Foreman			m	1	Man
	Productivity Kg/Day	= V / D		Q	4815,27	Kg/Day
	Coefficient of Manpower					
	- Labor	2 Man	= 2 : Q		**0,00042**	**MD**
	- Skilled labor	2 Man	= 2 : Q		**0,00042**	**MD**
	- Skilled labor	1 Man	= 1 : Q		**0,00021**	**MD**
	- Foreman	1 Man	= 1 : Q		**0,00021**	**MD**
1	Rebar Pier Head installation					
	Volume *(Specification)*			V	14936,7	Kg
	duration plan			D	7	Day
	Labor			W	10	
	- Labor			w	6	Man
	- Skilled labor			tw	2	Man
	- Skilled labor			tw	1	Man
	- Foreman			m	1	Man
	Productivity Kg/Day	= V / D		Q	2133,81	Kg/Day
	Coefficient of Manpower					
	- Labor	6 Man	= 6 : Q		**0,00281**	**MD**
	- Skilled labor	2 Man	= 2 : Q		**0,00094**	**MD**
	- Skilled labor	1 Man	= 1 : Q		**0,00094**	**MD**
	- Foreman	1 Man	= 1 : Q		**0,00047**	**MD**
1	Rebar Slab & Barrier installation					
	Volume *(Specification)*			V	196941	Kg
	duration plan			D	20	Day
	Labor			W	22	
	- Labor			w	14	Man
	- Skilled labor			tw	6	Man
	- Skilled labor			m	1	Man
	- Foreman			m	1	Man
	Productivity Kg/Day	= V / D		Q	9847,05	Kg/Day
	Coefficient of Manpower					
	- Labor	14 Man	= 14 : Q		**0,00142**	**MD**
	- Skilled labor	6 Man	= 6 : Q		**0,00061**	**MD**
	- Skilled labor	1 Man	= 1 : Q		**0,0001**	**MD**
	- Foreman	1 Man	= 1 : Q		**0,0001**	**MD**

Pile Demolition						
1	Pile demolition					
	Volume *(Specification)*			V	8	Point
	duration plan			D	3	Day
	Labor			W	8	Man
	- Labor			w	4	Man
	- Tukang Batu			tw	2	Man
	- Tukang Batu			m	1	Man
	- Foreman			m	1	Man
	Productivity Kg/Day	= V / D		Q	2,667	Point/Day
	Coefficient of Manpower					
	- Labor	4 Man	= 14 : Q		**1,5**	**MD**
	- Tukang Batu	2 Man	= 6 : Q		**0,75**	**MD**
	- Tukang Batu	1 Man	= 1 : Q		**0,375**	**MD**
	- Foreman	1 Man	= 1 : Q		**0,375**	**MD**

Fig. 3. The productivity of each labor/workers

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	ES	LS	EF	LF	Slack Time
1	General Work		-							
	Traffic Protection and Treatment									
	Mob and Demod									
2	Preliminary Work		-							
	Measurement And Blowplank	A	-	2	Yes	0	0	2	2	0
	Site Office	B	A	18	Yes	2	2	20	20	0
3	Earthworks									0
	Site Clearing, Stripping & Grubbing	C	A	9	No	2	11	11	20	18
	Land Filling & Compaction	D	B, C	1	Yes	20	20	21	21	0
	Excavation 0-2 M	E	A	2	No	2	4	19	21	4
Substructure										
4	Bored Pile Foundation									
	Drilling	F	D, E	10	Yes	21	21	31	31	0
	Reinforcement	G	D, E	12	No	21	33	25	37	24
	Material Removing	H	F	10	Yes	31	31	41	41	0
	Concrete Structure	I	F, G	4	No	33	37	37	41	8
5	Pile Cap Work									0
	Ssp Driving	J	H, I	4	Yes	41	41	45	45	0
	Footing Excavation	K	J	4	Yes	45	45	49	49	0
	Pile Demolition	L	K	6	No	49	63	55	69	28
	Reinforcement Work	M	K	20	Yes	49	49	69	69	0
	Formwork Installation	N	L, M	2	Yes	69	69	71	71	0
	Concrete Cast + Waiting Time	O	N	6	Yes	71	71	77	77	0
	Curing	P	O	14	Yes	77	77	91	91	0
6	Pier									0
	Reinforcement Work	Q	O	10	No	77	87	87	97	20
	Scaffolding + Climbing Platform Installation	R	P	6	Yes	91	91	97	97	0
	Formwork Installation	S	Q, R	6	Yes	97	97	103	103	0
	Concrete Cast + Waiting Time	T	S	6	Yes	102	103	109	109	0
	Curing	U	T	14	Yes	109	109	123	123	0
7	Pier Head									0
	Shoring Installation	V	U	2	No	123	123	125	125	0
	Formwork Installation	W	V	10	No	125	125	135	135	0
	Sosrobahu Tool Installation	X	W	10	No	135	135	145	145	0
	Reinforcement Work	Y	U	22	Yes	123	123	145	145	0
	Concrete Cast+ Waiting Time	Z	W,X,Y	6	Yes	145	145	151	151	0
	Curing	AA	Z	14	Yes	151	151	165	165	0
	Erection + Stressing Tendon	AC	AA	2	Yes	165	165	167	167	0
	Pedestal + Temporary Bearing Installation	AD	AA	2	No	165	167	165	167	4
	Uninstalling Formwork + Shoring	AB	AC, AD	7	Yes	167	167	174	174	0
Superstructure										
8	Steel Box Girder									
	Sbg Mobilization	AE	AB	1	No	174	174	175	175	0
	Erection	AF	AB	1	Yes	174	174	175	175	0
	Diaphragm Installation	AG	AE, AF	6	No	175	198	181	204	46
9	Slab									0
	Reinforcement Work	AH	AE, AF	46	Yes	175	175	221	221	0
	S-Form Installation	AI	AG	17	No	181	204	198	221	46
	Deck Drain	AJ	AG	2	No	181	219	183	221	76
	Concrete Structure	AK	AH,AI,AJ	3	Yes	221	221	224	224	0
	Curing	AL	AK	7	Yes	224	224	231	231	0
	Moving S-Form	AM	AL	2	No	231	242	233	244	22
Barrier Structure										
	Formwork Installation	AN	AL	2,00	Yes	231	231	233	233	0
	Concrete Structure	AO	AN	3,00	Yes	233	233	236	236	0
	Curing	AP	AO	7,00	Yes	236	236	243	243	0
Drainage										
	Excavation 0-2 M	AQ	AM	2,00	No	233	244	235	246	22
	Rc Pipe Installation	AR	AQ	2,00	No	235	246	237	288	62
Finishing		AS	AP	5,00	Yes	243	243	248	248	0

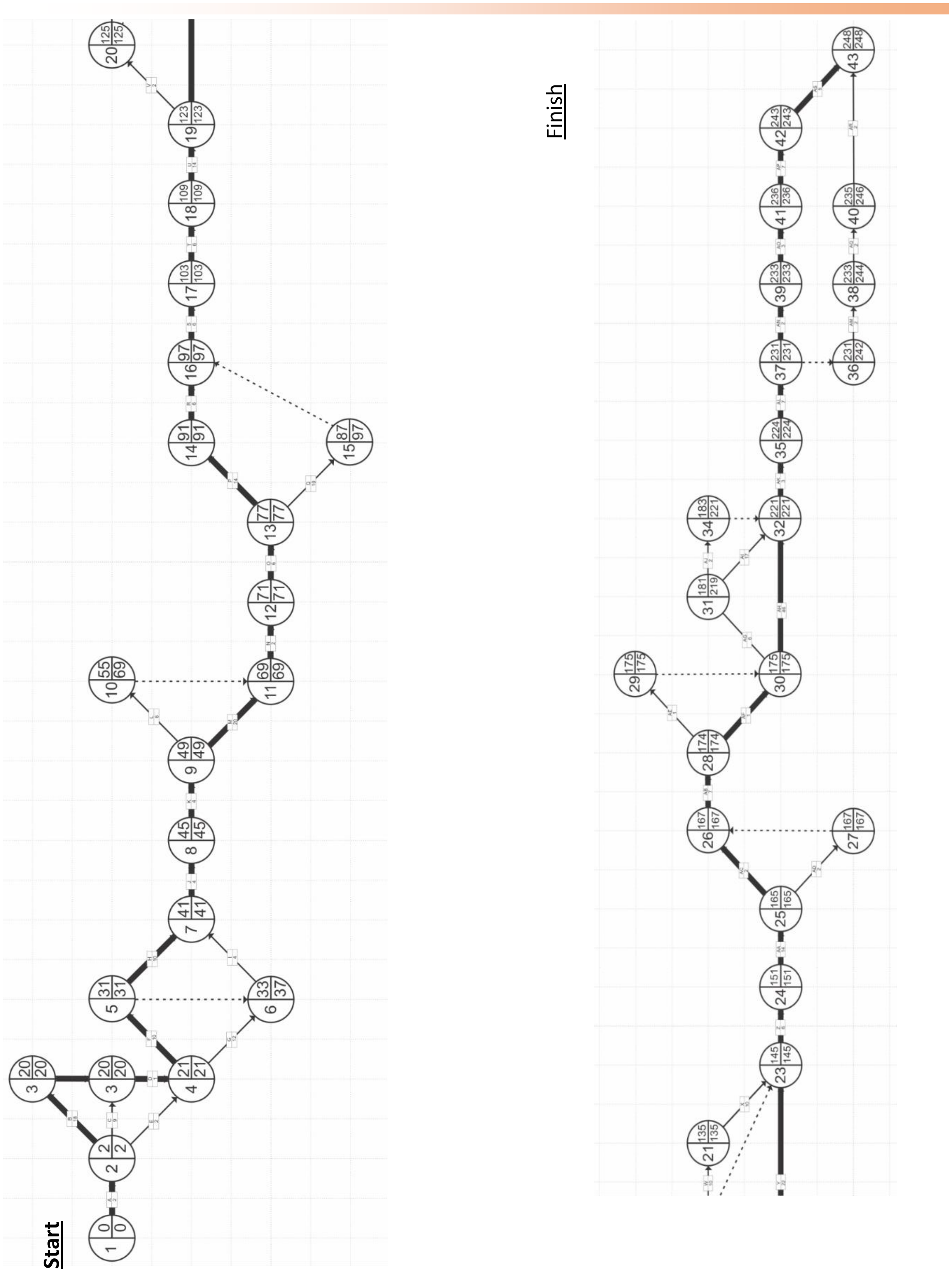

Fig. 4. Network diagram using critical path method (CPM)

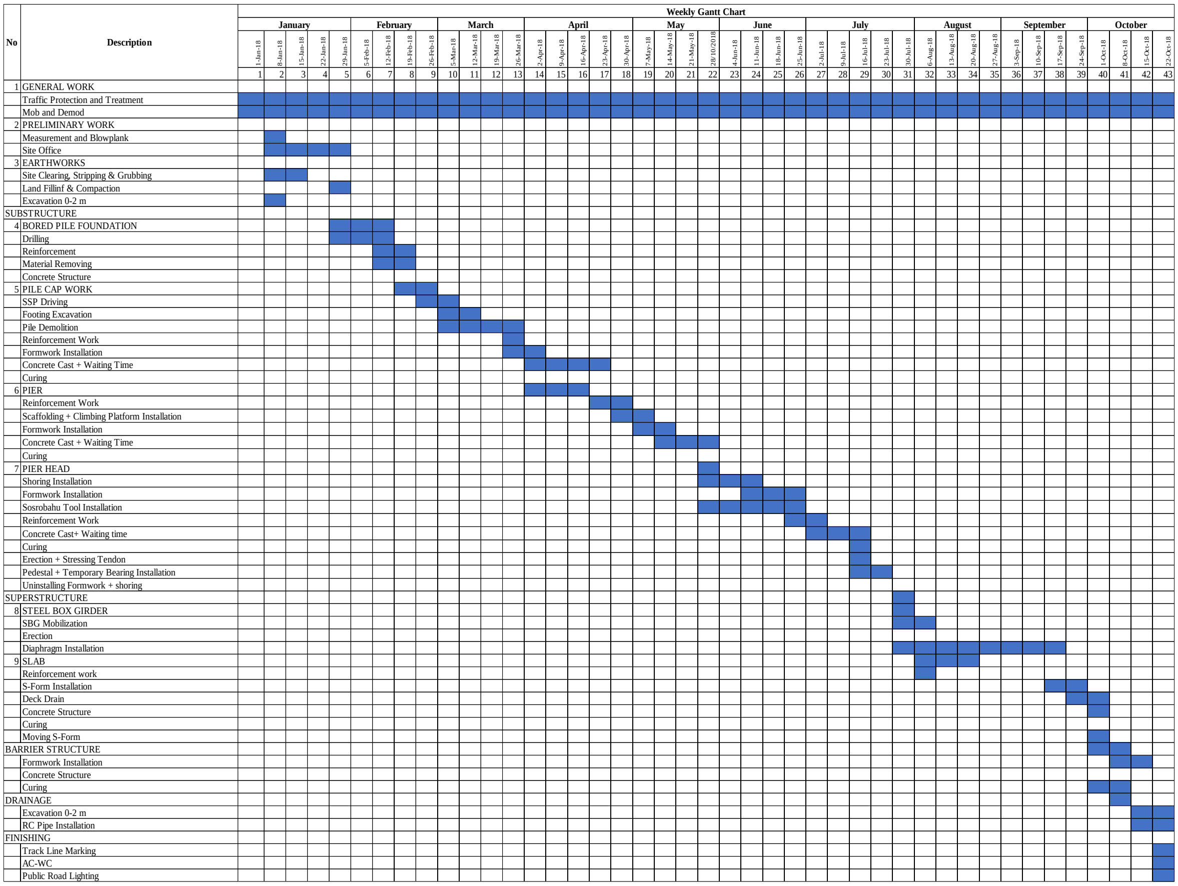

Fig. 5. Gantt chart

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.

Fig. 6. Project location simulation in the planning of concrete cast for slab structure

Fig. 7. The momentum of Erection for Pier Head structure

Fig. 8. Installing the first (plywood) and second (white sand) layer dilatation for pierhead

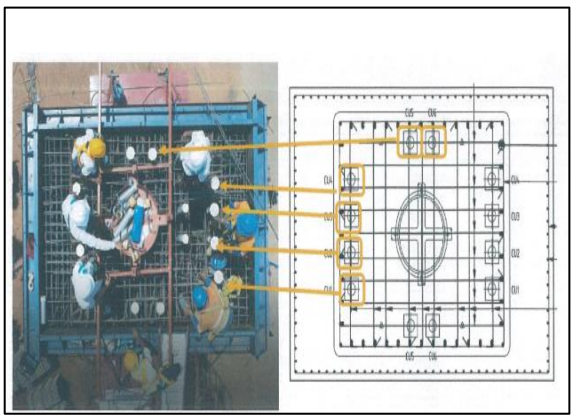

Fig. 9. Installing Sosrobahu template on the top of the crown pier

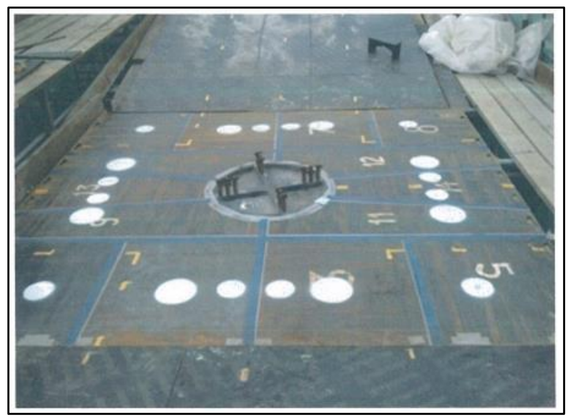

Fig. 10. Installing the third layer dilatation

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.

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