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Resource Leveling using Two-Stage Scheduling Model for a Highway Construction Project at Jakarta

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ABSTRACT

Project scheduling relates to series of activities that can have dependencies on each other during implementation. Each series of activities can cause problems from planning resource such as labor, costs, time, and heavy equipment to project implementation. The purpose of this study is to find out how to apply the two-stage scheduling optimization method for resource leveling, create a workforce histogram, and print the results of optimization resource scheduling in the form of LSM (Linear Scheduling Method) diagram. The existence of resource leveling is expected to avoid the problem of sudden resource needs or excessive resource accumulation. The biggest challenge in doing resource leveling is the increasing project duration. The two-stage scheduling optimization model has characteristics of CSP (Constraint Satisfaction Problem) so it will avoid increasing project duration. This optimization model will be carried out twice, assisted by using Microsoft Excel software with add-ins solver. The first stage will optimize the entire activities while the second stage will optimize the segment of non-controlling activities based on the CAP (Controlling Activity Path) that was formed during the first stage. The object of research used is a highway construction project at Jakarta. The results showed a new schedule with lower resource fluctuations.

Keywords: optimization; resource; resource leveling; project; model

INTRODUCTION

Project may have several sets of activities that are interdependent on each other. Each series of activities can cause problems, starting from planning resource arrangements such as labor, costs, time, and other equipment to project implementation. If these problems can’t be resolved correctly, there will be various problems that arise such as quality deviations from the original plan, the duration of project completion becomes late, financing increases, waste of resource use, etc. Thos problems can be detrimental to project [1]. There are aspects that are closely related to the completion date of a project, namely labor (resource). When the required resource is insufficient, the project has greater risk of experiencing delays from the planned schedule. An insufficient number of resource will make the project delayed [2]. This problem can be avoided if project implements resource management which consists of resource allocation and resource leveling.

The biggest challenge in doing resource leveling is achieving project completion targets because the application of resource leveling tends to increase the overall duration of the project. Resource leveling will make the labor histogram more evenly distributed in order to avoid sudden short resource needs or excessive resource accumulation in a period of time, reduce management and resource costs, and avoid unnecessary costs [3]. A commonly used method in construction scheduling is Network Scheduling, but this traditional method causes debate because it is not suitable to be used for repetitive projects such as highway projects, pipe installation, railroad tracks, or tunnels [4]. Obstacle in carrying out resource leveling is usually found in the duration of the project which must be sacrificed to achieve evenly distribution resource in a project hence it can avoid sudden resource needs [5].

Resource Leveling

The management of resources is as important as using an appropriate scheduling method. There are two common approaches for management of resources; (1) resource allocation, and (2) resource leveling [6].

Resource leveling is a technique that determines when a project activity starts and ends based on the constraints of the resources owned with the aim of balancing resource needs with existing inventory. This technique seeks to ensure that resource needs will not exceed the available resource supply [7].

The concept of resource leveling is establishment of scheduling in which the need for resources is same as possible along within the project period without changing the deadline for project completion. That way, the goal can be achieved, to reduce sudden resource needs or avoid the occurrence of excess resource usage. This will provide efficiency because any fluctuations in the recouce that occur will have an impact on the costs that must be incurred. These costs can be from recruiting new members of the workforce to the project or purchasing new equipment [8]. **FIGURE 1** shows the difference between before resource leveling and after resource leveling.

Naturally, as an effective resource optimization technique, resource leveling has been widely adopted, which also leads to extensive research on the resource leveling problem (RLP) in the academic community. The aim of the classical RLP is to minimize the fluctuations in resource usage by specifying the starting times of activities under precedence constraints and the project deadline constraint. There are many benefits to leveling project resources, such as avoiding hastily deploying temporary resources, shifting peaks in resource usage, reducing resource idleness, and so on [9].

In today's market condition, the survivability of any construction contractor essentially depends on its capability of managing resources. Ineffective resource management escalates the operational expense or even gives rise to financial and scheduling problems. Without doubt, the excess requirement of resources in the construction site leads to the extension of project duration [10].

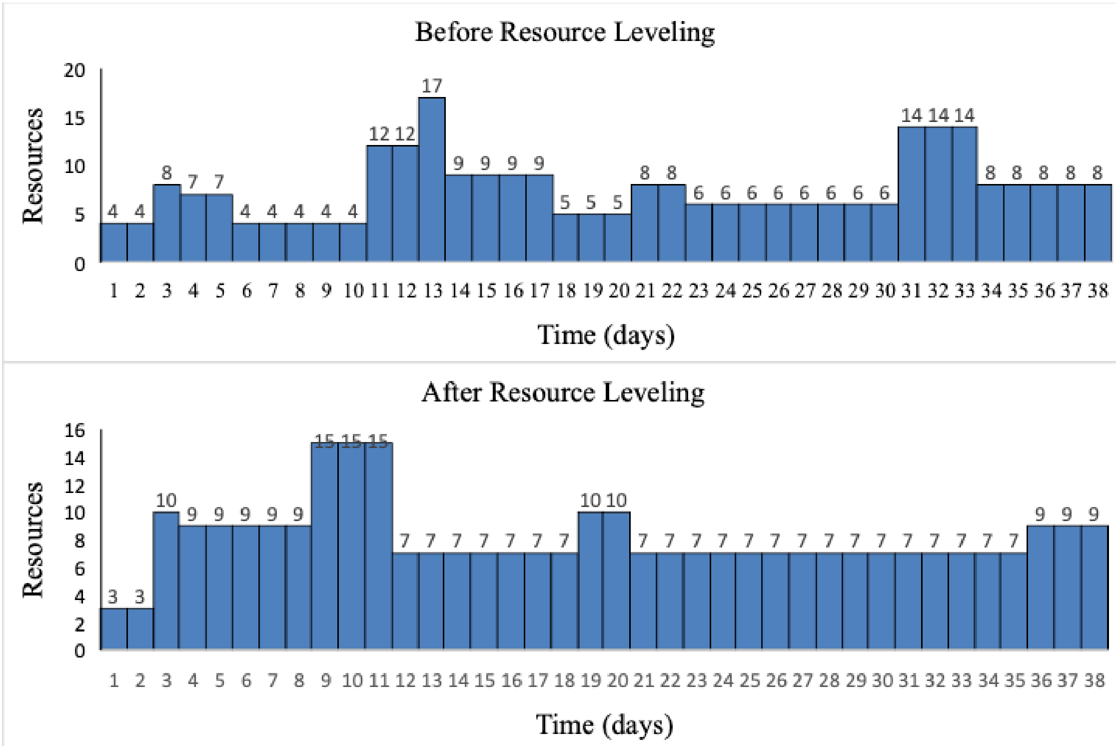

FIGURE 1. Example Comparison Between Before and After Resource Leveling [11]

Linear Scheduling Method

Linear scheduling method (LSM) is a set of scheduling techniques specifically designed to be suitable for repetitive project models. Most linear projects can be seen from examples of highway projects, toll roads, or high-rise buildings that are almost symmetrical. Linear scheduling considers project location as an important component in project planning and control. [12]

This method describes scheduling in the form of cartesian coordinates, where a straight line will represent as a cumulative progress that has been completed based on the time axis [4]. The Y-axis can be represented as the location of the project and the X-axis can be represented as the duration time needed to complete the activity, but it is not uncommon to find graphs that can apply the inverse axis when the time component is represented as the Y-axis while the location is represented on the X-axis as shown in **FIGURE 2**.

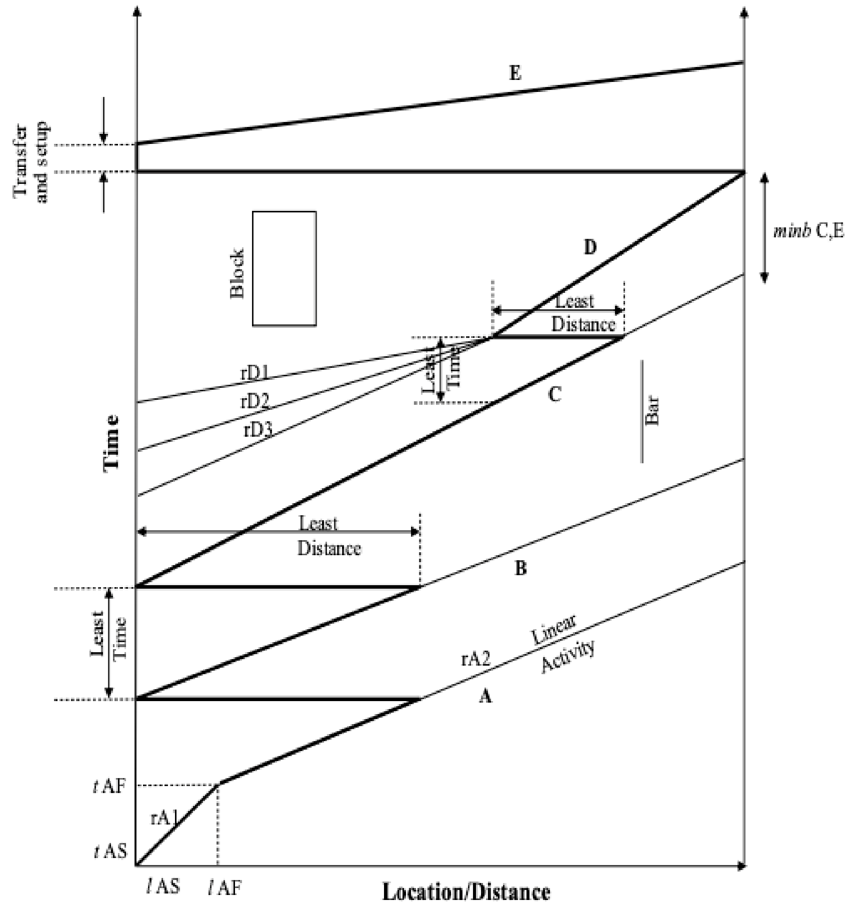

FIGURE 2. Example of LSM [11]

The main purpose of implementing linear scheduling is to assist the project manager in seeing the visualization between location and time as well as possible conflict activities that may occur during the duration of the project work. Traditional time-driven scheduling methods such as bar chart, plan evaluation and review technique (PERT), and critical path method (CPM) do not provide efficient planning of repetitive construction projects as they do not guarantee crew work continuity, do not show the location and time at which a certain crew will be working on an activity and require more computational efforts because of large number repetitive activities that need to be modeled. Instead, resource-driven planning techniques such as line of balance (LOB) and linear scheduling method (LSM) are shown to be more efficient in planning repetitive construction projects as they overcome the above issues. [13]

Optimization Model

Optimization is a process of determining the best solution to make something as functional and effective as possible by minimizing or maximizing the parameters involved in the problems [14]. The proposed two-stage scheduling model for resource leveling is a CSP (Constraint Satisfaction Problem) optimization type for linear projects.

This model will directly generate a schedule with a resource leveling optimization target. The optimization process will be divided into two stages as shown in **FIGURE 3**. Before carrying out the optimization process, the necessary data will be input, namely activity data and limiting settings for the targeted project. Activity data descriptions include the activity name, activity type, start location, end location, and work productivity speed. Constraints can be buffer time, activity flow, and project duration.

The first stage of two-stage scheduling will optimize the entire set of work activities based on resources and requirement constraints that have been set through the scheduling process of the CSP optimization model. The second optimization stage can be seen in **FIGURE 3** of section (c). This process will be carried out based on data from the results of the first stage of optimization [3].

Controlling Activity Path (CAP) is a path that connects the beginning of the activity to the final activity of a linear project. This line will connect the various project activities according to the predetermined sequence of activities on the project scheduling. While lines that do not include CAP will be referred to as non-controlling segments of activity. The CAP is indicated by the bolded line in **FIGURE 3** of section (c).

This second stage of the optimization process is more focused on the non-controlling segment of activity. Optimization will be carried out once again the same as the first stage of the process, but the difference for this second stage will only be optimization for a series of activities that do not control. CAP will be considered constant in the second stage of the optimization process so that it will not be changed [3].

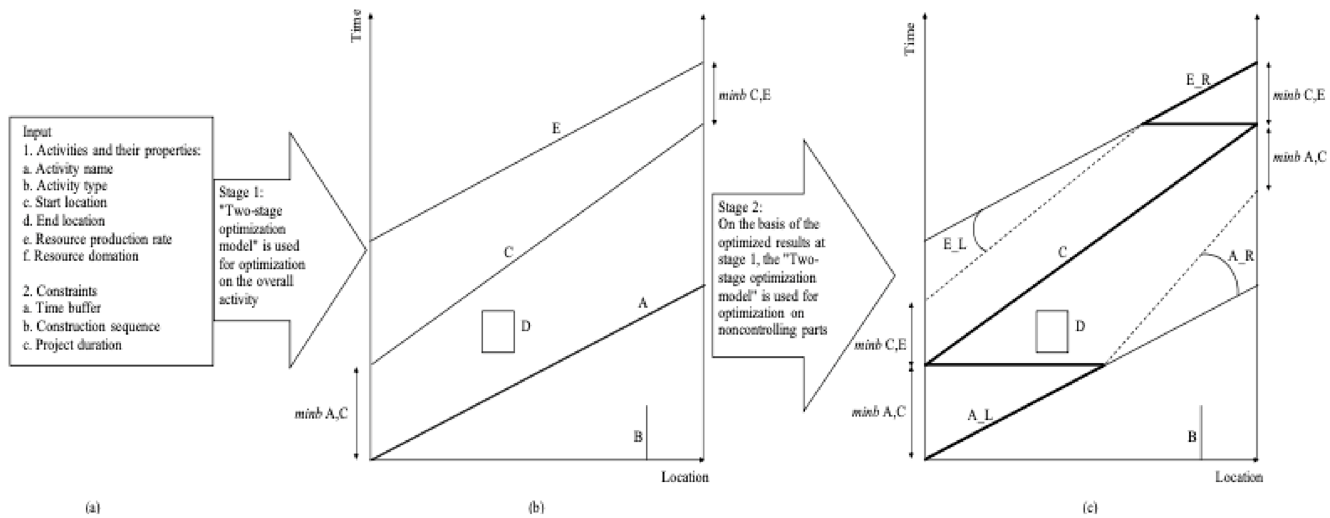

FIGURE 3. Optimization Process of Two-Stage Scheduling Method for Resource Leveling [3]

RESEARCH METHODOLOGY

The method used in this study is quantitative research using two-stage scheduling method with flow chart attached below at **FIGURE 4**. This research was conducted to generate scheduling with lowest fluctuation resource without increasing project duration. The object of this research is a highway construction project in Jabodetabek area. The highway distance is estinmated 300 to be meters with five major activities. STA (station) starts with +600 until +900. Each station unit equals one meter. The optimization process is assisted by software Microsoft Excel with solver add- ins.

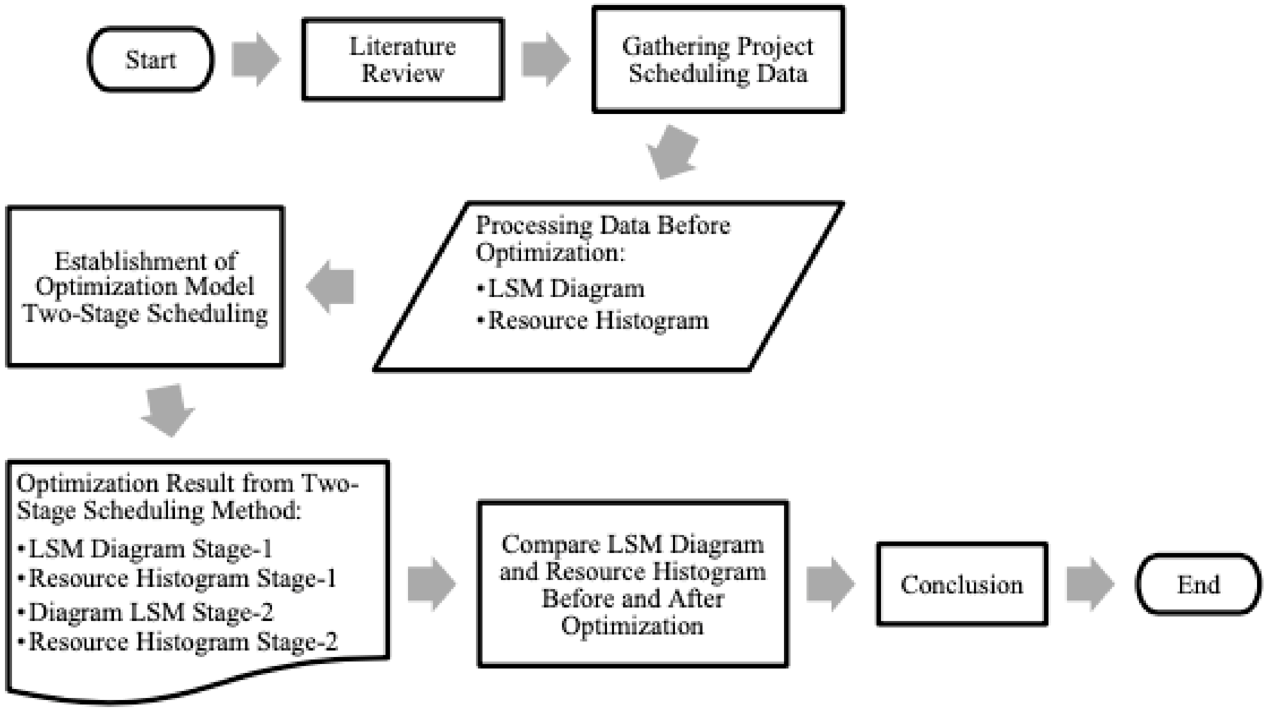

FIGURE 4. Flow Chart Research

RESULT AND DISCUSSION

Application of Two–Stage Scheduling Method for Highway Construction Project in Jabodetabek

The project has five main activities. In this study, four main activities will be used because the initial preparation activities are assumed to not be included in the calculation so that the activity will start on the 11th day.

Based on the scheduling in **TABLE 1**, scheduling can be made with the LSM diagram and resource histogram which can be seen in **FIGURE 5** and **FIGURE 6**. Resource histogram is also created to show the visualization of the resource needs to be used in this project before resource leveling was carried out using the two-stage scheduling method.

TABLE 1. Initial Scheduling Data for Highway Construction Project

Num.	Detail Activity	Type	Station Start (STA)	Station End (STA)	Time Buffer (Day)	Resource Min (Unit)	Resource Use (Unit)	Resource Max (Unit)	Start Time (Day-)	End Time (Day-)
A.	**HIGHWAY ACTIVITIES**									
1.	Compaction Subgrade	Linear	600	900	2	13	18	23	11	28
2.	Telford stone t: 35cm	Linear	600	900	2	12	17	22	18	33
3.	Basecoarse t: 5/7;2/3;0/5 (t: 12cm)	Linear	600	900	2	12	17	22	23	38
4.	Edge stone	Linear	600	900	2	5	8	11	29	40
5.	Kansteen	Linear	600	900	2	5	8	11	34	45

TABLE 1. Initial Scheduling Data for Highway Construction Project (Continuation)

Num.	Detail Activity	Type	Station Start (STA)	Station End (STA)	Time Buffer (Day)	Resource Min (Unit)	Resource Use (Unit)	Resource Max (Unit)	Start Time (Day-)	End Time (Day-)
B.	**CHANNEL**	Linear								
1.	Soil excavation	Linear	600	900	2	8	14	16	45	57
2.	Brick laying	Linear	600	900	2	4	6	8	49	59
3.	Plaster	Linear	600	900	2	10	15	20	52	64
4.	Concrete slab t:15 cm	Linear	600	900	2	4	7	10	61	66
5.	Drainage	Linear	600	900	2	4	7	10	63	68
C.	**DUIKER 110/150 30 M'**									
1.	Duiker 110/150 (STA +660)	Block	660	660	0	5	5	5	68	76
2.	Duiker 110/150 (STA +880)	Block	880	880	0	5	5	5	76	84
D.	**DUIKER 200/160 20 M' (STA +752,5)**	Block								
1.	Soil excavation	Block	752,5	755	0	6	6	6	68	79
2.	Brick laying	Block	752,5	755	0	6	6	6	75	83
3.	Plaster	Block	752,5	755	0	5	5	5	79	89
4.	Concrete slab and beam (K-350)	Block	752,5	755	0	4	4	4	84	91

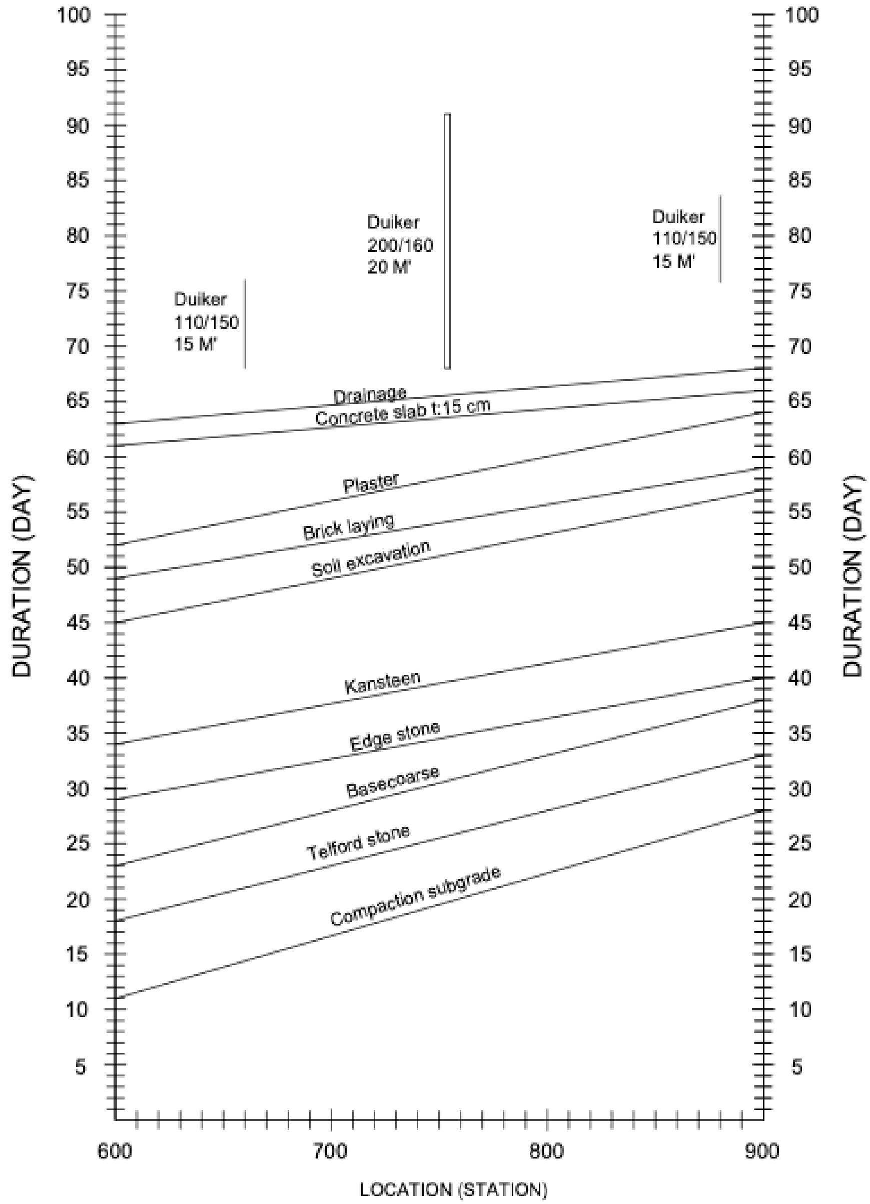

FIGURE 5. LSM Diagram for Initial Project Scheduling Before Resource Leveling

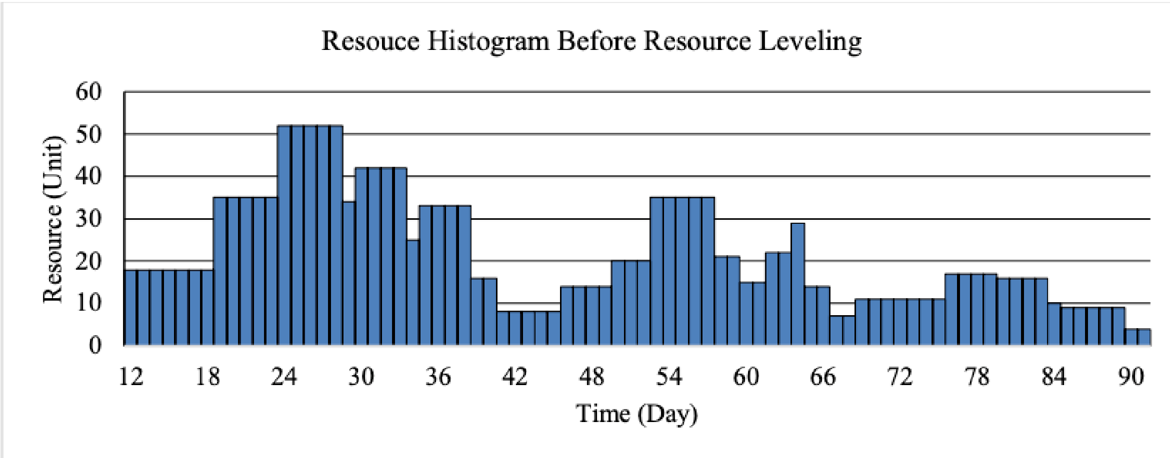

FIGURE 6. Resource Histogram Before Resource Leveling

The fluctuating resource is shown as an objective function in the optimization model that will be minimized in this study. The calculation of objective functions is indicated by equation (1).

$$\sum_{i=1}^{D-1} |R_{i+1} - R_i| \tag{1}$$

with R_{i+1} = the number of resource usage in the day $i + 1$ and R_i = the number of resource usage in day i

Based on the equation (1) the value of objective function before the resource leveling is |18 – 18| + |18 – 18| + |18 – 18| + ... = 216 units.

Then optimization is carried out with the two-stage scheduling method for the first stage with the results shown in **TABLE 2** below. Equation (2) is used to calculate work productivity based on the amount of resource used. Equation (3) is used to calculate the duration of the activity. Equation (4) is used to calculate end time of an activity.

$$pu_i = r_i \times u_i \tag{2}$$

$$d_i = \frac{q_i}{pu_i} \tag{3}$$

$$ET_i = ST_i + d_i \tag{4}$$

with pu_i = the rate of work productivity, r_i = the amount of resource used of an activity in units, u_i = the coefficient of work productivity per day, d_i = the duration of an activity, q_i = the difference from the end location with the start STA, ET_i = the end time of an activity, ST_i = the start time of an activity.

TABLE 2 Scheduling Data for Highway Construction Project After Resource Leveling Optimization Stage-1

Num.	Detail Activity	Type	Time Buffer (Day)	Prod/res/ day (/Day)	Resource (Unit)	Start Time (Day)	Duration (Day)	End Time (Day)
A.	**HIGHWAY ACTIVITIES**							
1.	Compaction Subgrade	Linear	2	0,9804	13	11	22	33
2.	Telford stone t: 35 cm	Linear	2	1,1765	13	15	21	36
3.	Basecoarse t: 5/7;2/3;0/5 (t: 12cm)	Linear	2	1,1765	13	17	21	38
4.	Edge stone	Linear	2	3,4091	5	30	18	48
5.	Kansteen	Linear	2	3,4091	5	32	18	50
B.	**CHANNEL**							
1.	Soil excavation	Linear	2	1,7857	8	38	15	53
2.	Brick laying	Linear	2	5	4	49	15	64
3.	Plaster	Linear	2	1,667	10	53	18	71
4.	Concrete slab t: 15 cm	Linear	2	8,5714	5	66	7	73
5.	Drainage	Linear	2	8,5714	4	69	9	78
C.	**DUIKER 110/150 30 M’**							
1.	Duiker 110/150 (STA +660)	Block	0	-	5	75	8	83
2.	Duiker 110/150 (STA +880)	Block	0	-	5	81	8	89
D.	**DUIKER 200/160 20M’ (STA +752,5)**							
1.	Soil excavation	Block	0	-	6	77	11	88
2.	Brick laying	Block	0	-	6	80	8	88
3.	Plaster	Block	0	-	5	81	10	91
4.	Concrete slab and beam (K-350)	Block	0	-	4	84	7	91

Optimization with the two-stage scheduling method will produce an optimal start time and number of resource to minimize objective functions in order to avoid resource fluctuations in the scheduling of ongoing projects while still maintaining the project duration. The constraint from this project is buffer time to prevent collisions between one activity and another. Then there is a constraint to the total duration of the project for limiting the duration of the project. The limit will be set to be same as initial project duration or less.

In the result of the first stage of optimization, objective function is obtained with 161 units. This number is lower than the objective function before resource leveling. The scheduling result also remains to have a total project duration of 91 days just like the original plan. **FIGURE 7** shows the visualization of scheduling after the first stage of optimization with LSM diagram. **FIGURE 8** shows a histogram of resource needs from the 12th to the last day of the project. At first glance, there is a major difference in the histogram between before and after optimization. The difference can be seen that **FIGURE 8** shows a more evenly distributed bar as a whole.

The two-stage scheduling method will be continued with the second stage. The second stage of optimization will change the scheduling based on CAP. CAP will divide the activity into controlling and noncontrolling. The CAP of the results of the first stage of optimization will be the basis for the optimization of the second stage. In **FIGURE 7**, there is a bold line showing the CAP of the first stage of the optimization model.

Based on CAP, an activity will be divided into controlling and noncontrolling parts. **TABLE 3** shows which activity is controlling or noncontrolling. The use of resource and the start time for controlling activities have been identified based on **FIGURE 7** therefore the float no longer exists. As for noncontrolling activities, they still have a float with additional restrictions, namely the continuity between activities.

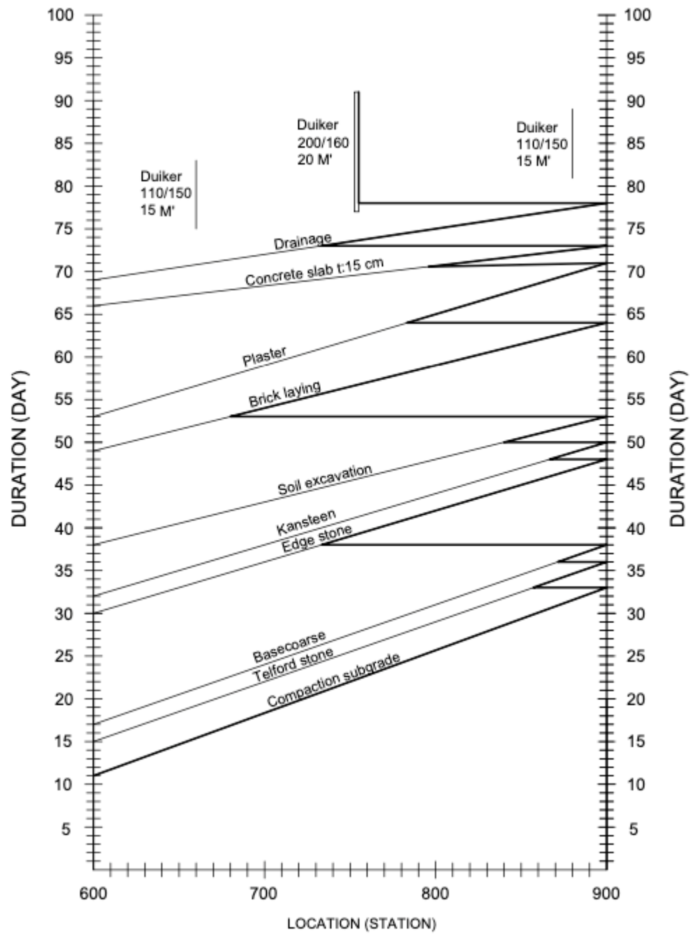

FIGURE 7. LSM Diagram After Resource Leveling Optimization Stage-1

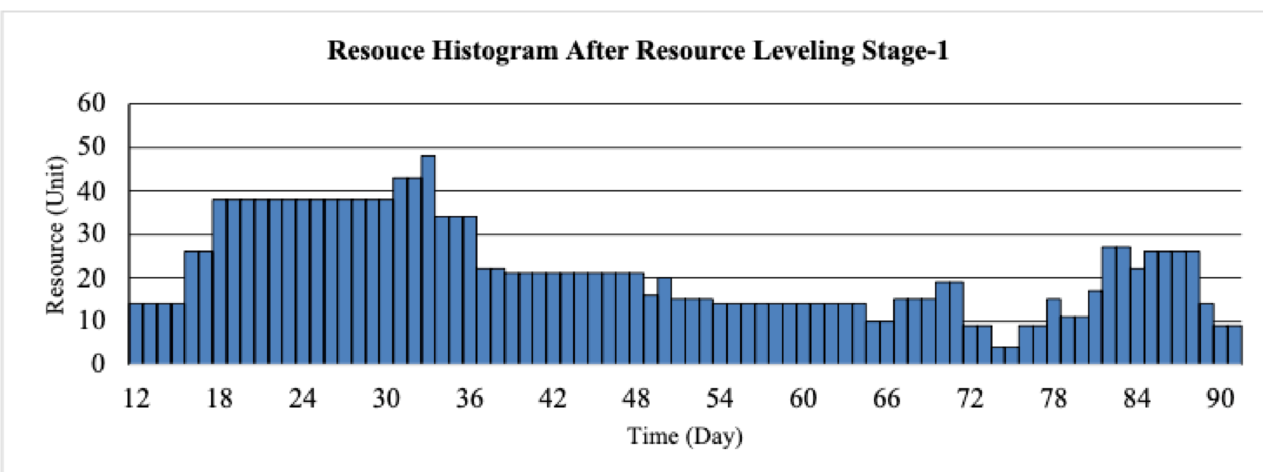

FIGURE 8. Resource Histogram After Resource Leveling Optimization Stage-1

In the second stage of optimization, it will only focus on noncontrolling activities because controlling activities can no longer be optimized so that the data on controlling activities will remain the same and will not be changed. In the second stage of optimization, the elements of objective functions, decision variables, and also constraints will be redefined [15]. The definition will be similar to the first optimization stage, but there will be slight differences in the constraint section.

B. Objective Function
The objective function from the two-stage scheduling method model is to find the minimum value of the total difference in resource usage per two days in sequence.
Objective function: Minimize value $\sum_{i=1}^{D-1}|R_{i+1} - R_i|$

C. Decision Variable
The decision variables in this optimization model are the schedule of project activities and also the amount of resource to be used. In this study, the activity schedule refers to the start time of each activity in the project. This variable is annotated as STi. If the variable is summed to the duration of the activity, it will result the variable ETi which means the end time of an activity.

D. Constraint
The constraint in this modeling is time buffer that aims to prevent the series of activities from colliding with each other at one station location. In addition, there is also a constraint on the total duration of the project which must be smaller or equal to the initial duration of the project. Constraints are $ST_i, ET_i, r_i \in [\min r_i, \max r_i]$. In the second stage, there is an addition of constraint to the optimization model by using the formula $ET_{ncA\_Li} = ST_{cAi}$ for the CAP activity condition that is placed on the right while $ST_{ncA\_Ri} = ET_{cAi}$ for the CAP condition which is on the left of the activity segment.

ET_{ncA_Li} = the end time of noncontrolling activity, ST_{ncA_Ri}= the start time of noncontrolling activity, ST_{cAi} = start time of controlling activity, ET_{cAi} = end time of controlling activity. The results of optimization for the second stage
on this project, can be seen in **TABLE 4** then visualized with the LSM scheduling method which can be seen in
FIGURE 9. The histogram chart indicates the resource needs per day from the beginning to the end of the project is shown in **FIGURE 10**. The second stage optimization produces a number in the objective function of 159 so there is a reduction in the value from the first stage to the second stage.

TABLE 3 Activity Based on CAP Highway Construction Project

Activity	CAP	*Resources*	Location		ST_i	ET_i	Duration
			Start	End			
		(Unit)	(STA)		(Day)		(Day)
B1	Controlling	14	600	900	11	33	22
B2 – Left	Noncontrolling	–	600	860	–	33	–
B2 – Right	Controlling	12	860	900	33	36	3
B3 – Left	Noncontrolling	–	600	870	–	36	–
B3 – Right	Controlling	12	870	900	36	38	2
B4 – Left	Noncontrolling	–	600	730	–	38	–
B4 – Right	Controlling	12	730	900	38	48	10
B5 – Left	Noncontrolling	–	600	865	–	48	–
B5 – Right	Controlling	5	865	900	48	50	2
C1 – Left	Noncontrolling	–	600	840	–	50	–
C1 – Right	Controlling	11	840	900	50	53	3
C2 – Left	Noncontrolling	–	600	680	–	53	–
C2 – Right	Controlling	4	680	900	53	64	11
C3 – Left	Noncontrolling	–	600	785	–	64	–
C3 – Right	Controlling	10	785	900	64	71	7
C4 – Left	Noncontrolling	–	600	795	–	71	–
C4 – Right	Controlling	5	795	900	71	73	2
C5 – Left	Noncontrolling	–	600	735	–	73	–
C5 – Right	Controlling	4	735	900	73	78	5
D1	Noncontrolling	–	660	660	–	–	–
D2	Noncontrolling	–	880	880	–	–	–
E1	Controlling	6	752,5	755	77	88	11
E2	Controlling	6	752,5	755	80	88	8
E3	Controlling	5	752,5	755	81	91	10
E4	Controlling	4	752,5	755	84	91	7

TABLE 4 Scheduling Data for Highway Construction Project After Resource Leveling Optimization Stage-2

Activity	CAP	*Resources*	Location		ST_i	ET_i	Duration
			Start	End			
		(Unit)	(STA)		(Day)		(Day)
B1	Controlling	14	600	900	11	33	22
B2 – Left	Noncontrolling	12	600	860	15	33	18
B2 – Right	Controlling	12	860	900	33	36	3
B3 – Left	Noncontrolling	12	600	870	17	36	19
B3 – Right	Controlling	12	870	900	36	38	2
B4 – Left	Noncontrolling	5	600	730	30	38	8
B4 – Right	Controlling	12	730	900	38	48	10
B5 – Left	Noncontrolling	5	600	865	32	48	16
B5 – Right	Controlling	5	865	900	48	50	2
C1 – Left	Noncontrolling	8	600	840	38	50	12
C1 – Right	Controlling	11	840	900	50	53	3
C2 – Left	Noncontrolling	4	600	680	49	53	4
C2 – Right	Controlling	4	680	900	53	64	11
C3 – Left	Noncontrolling	10	600	785	53	64	11
C3 – Right	Controlling	10	785	900	64	71	7
C4 – Left	Noncontrolling	4	600	795	65	71	6
C4 – Right	Controlling	5	795	900	71	73	2
C5 – Left	Noncontrolling	4	600	735	69	73	4
C5 – Right	Controlling	4	735	900	73	78	5
D1	Noncontrolling	5	660	660	75	83	8
D2	Noncontrolling	5	880	880	81	89	8
E1	Controlling	6	752,5	755	77	88	11
E2	Controlling	6	752,5	755	80	88	8
E3	Controlling	5	752,5	755	81	91	10
E4	Controlling	4	752,5	755	84	91	7

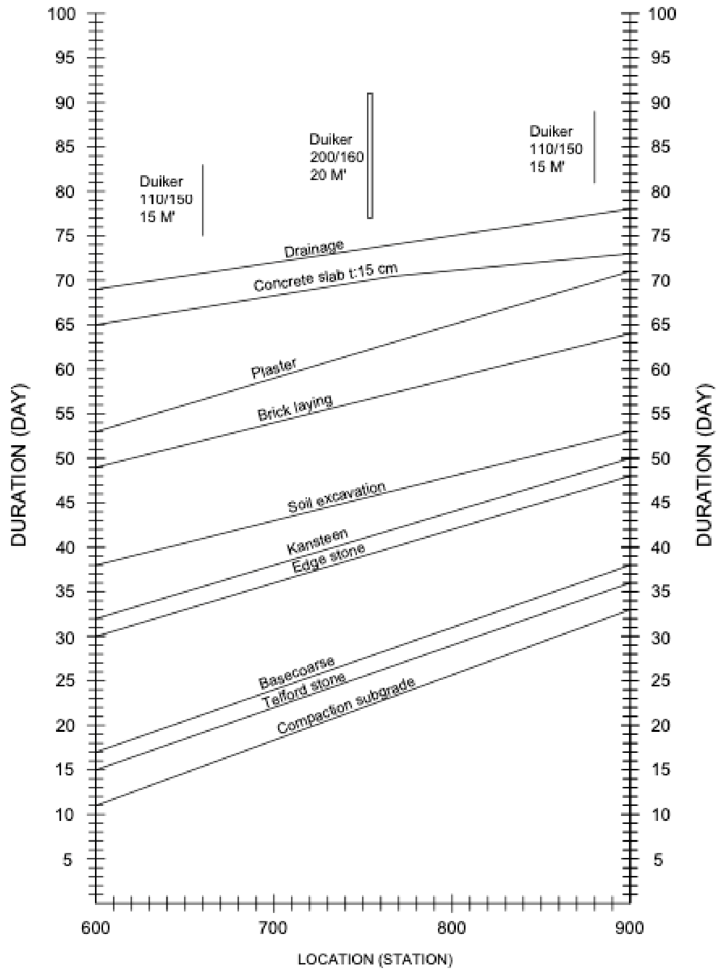

FIGURE 9. LSM Diagram After Resource Leveling Optimization Stage-2

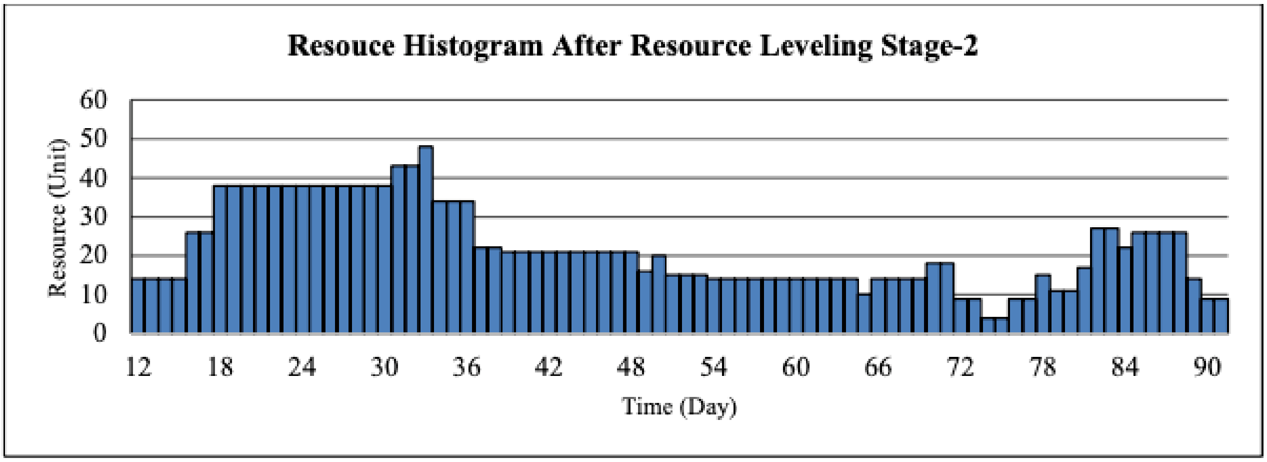

FIGURE 10. Resource Histogram After Resource Leveling Optimization Stage-2

The results of optimization for the second stage on this project, can be seen in **TABLE 4** then visualized with the LSM scheduling method which can be seen in **FIGURE 9**. The histogram chart indicates the resource needs per day from the beginning to the end of the project is shown in **FIGURE 10**. The second stage optimization produces a number in the objective function of 159 so there is a reduction in the value from the first stage to the second stage.

TABLE 5 shows the comparison results of resource leveling in conditions before the optimization of resource leveling, after the optimization of resource leveling with the first stage of two-stage scheduling method, and after the resource leveling method with the second stage on highway construction projects in Jabodetabek.

TABLE 5. Comparison Result Before and After Resource Leveling for Highway Construction Project

Variable	Before Resource Leveling	Two-Stage Scheduling Method	
		Stage-1	Stage-2
D	91 days	91 days	91 days
$\sum_{i=1}^{D-1} \lvert R_{i+1} - R_i \rvert$	216 unit	161 unit	159 unit

CONCLUSION

Based on the results of research and discussion, the following conclusions are obtained.

2. The results of resource leveling with the first stage of two-stage scheduling method.
   a. The first stage two-stage scheduling method will alter the scheduling of all activities whether included in the CAP (Controlling Activity Path) or not with the aim of minimizing the value of the objective function. This method alters the scheduling by following the conditions that have been given in the constraint section.
   b. Based on the results of resource leveling optimization using the first stage of two-stage scheduling method on highway construction projects in Jabodetabek, it is obtained that:
      - The project duration from the calculation of the first stage two-stage scheduling method is 91 days. This number is same as the scheduling plan before the optimization of resource leveling scheduling is carried out.
      - The total of the differences in resource in two sequence days annotated as an objective function on this model is 161 units. This value is lower than the objective function before the scheduling optimization which is 216 units.
3. The results of resource leveling with the second stage of two-stage scheduling method.
   a. The second stage of the two-stage scheduling method will only change the scheduling of project activities that are not included in the CAP (Controlling Activity Path) or non-controlling activity segments with the aim of minimizing the value of the objective function. This method changes the scheduling by following the conditions that have been given in the constraint section similar to the first stage. The additional constraint in the second stage that must be met in the optimization model is the continuity between the connection of noncontrolling activity segment and the controlling activity segment.
   b. Based on the results of resource leveling optimization using the second stage of two-stage scheduling method on highway construction projects in Jabodetabek, it is obtained that:
      - The project duration from the calculation of the second stage two-stage scheduling method is 91 days. This duration is the same as the scheduling plan before the optimization of resource leveling and the results of first stage of resource leveling optimization.
      - The total of the difference in resource in two consecutive days annotated as an objective function is 159 units. This value is lower than the objective function before the scheduling optimization which is 216 units and also the result of the first stage of resource leveling optimization which is 161 units.
4. The advantages and disadvantages by using resource leveling optimization with the two-stage scheduling method.
   a. The advantage of using this optimization method is to get more evenly distributed resource scheduling compared to the initial resource scheduling. This method also has two stages so it can get more optimal results. In addition, the scheduling of the resource obtained does not increase the overall duration of the project.
   b. The disadvantage on the use of this optimization method is the creation of quite complex models and LSM diagram that still has to be drawn manually after obtaining the scheduling results.

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