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Repetitive Construction Scheduling for Solo-Yogyakarta-NYIA Kulon Progo Toll Road Overpass using Line of Balance

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Abstract Repetitive construction requires continuous and uninterrupted supply of resources; hence, a suitable scheduling method matching the work characteristics is required. Line of Balance is a scheduling method in the form of a line chart that represents recurring work. Considering the existing work items, Ngasem Overpass Bridge Solo -Yogyakarta-NYIA Kulon Progo Toll Road Project can be categorized as a repetitive construction project. Therefore, this research tries to apply Line of Balance (LoB) to this overpass project to determine whether LoB can efficiently manage a repetitive construction project. Two scheduling scenarios are applied in this study. The first scenario is implemented with the aim of producing a schedule that uses resources continuously and uninterruptedly. While the second scenario is applied to produce a schedule with the shortest duration. LoB is based on the first scenario succeeded in compiling a schedule that uses resources continuously and uninterruptedly. Schedule based on the second scenario results in the shortest duration by severing the use of resources for short-duration jobs that are preceded and followed by longer-duration jobs. In addition to generating schedules according to the desired scenario, LoB has proved its ease in managing scheduling in terms of the continuity of resource use and the speed of completion of work.

Keywords: Repetitive Construction, Line of Balance, Overpass Bridge

INTRODUCTION

The Solo -Yogyakarta - New Yogyakarta International Airport Kulon Progo toll road project is a National Strategic Project that requires good management. One management method that can be applied to toll road construction is scheduling. Toll road construction involves many repetitive tasks, such as underpasses, underpass bridges, box culverts, and river bridges. With many repetitive tasks, an efficient scheduling method is required. There are several scheduling methods used in the construction industry, including bar charts, S curves, and Line of Balance (LoB) diagrams. This research focuses on the Line of Balance method to determine whether it can be applied to repetitive bridge projects. LoB is a scheduling method that allows for effective resource management. It is presented in the form of a simple line diagram that is easy to understand and highlights potential obstacles that may arise during the construction process [1]. This enables construction stakeholders to focus on areas that may cause disruptions in the project timeline and take preventive measures to minimize delays and cost overruns.

This research was conducted on the Overpass Bridge Ngasem STA 0+616 of the Solo – Yogyakarta – NYIA Kulon Progo Toll Road Project, which spans approximately 204 meters and has a width of around 35 meters. The aim of the research was to determine whether the LoB method could be applied to a bridge project.

Although similar studies have been conducted before, this is the first time that the LoB scheduling method has been used on the Overpass Bridge project. Therefore, references from previous studies were utilized to aid in conducting this research.

TABLE 1. Previous Researcher

Researcher	Title	Analysis result
Muhammad Abrar Aulia, Aulia Hashemi Farisi, M. Agung Wibowo, Arif Hidayat (2017)	Analisis Penggunaan Line of Balance Pada Proyek Konstruksi Repetitif (Studi Kasus: Proyek Pembangunan Apartemen Candiland – Semarang)	● Line of balance is a scheduling method that is suitable for construction projects with repetitive work packages because LoB is able to show the schedule of repetitive work packages for each unit in a line chart properly. ● LoB is simple and easy to understand because it is in the form of a line which shows productivity.
Wahyu Tri Prasetyo (2017)	Analisis Penjadwalan Ulang Waktu Pelaksanaan Proyek Jalan Dengan *Line of Balance* Studi Kasus: Proyek Rehabilitasi/Peningkatan Jalan Lingkungan RW I – RW IV Kelurahan Kedungsari Kota Magelang Tahun Anggaran 2016	● LOB can increase productivity by adding a buffer on several jobs, using the LOB, the time originally allocated was 60 days to 47 days. ● Increase project productivity by adding manpower.
Slamet Widodo, Faried Desembardi dan Simons Hans Sahuburua (2022)	Analisis Penjadwalanan Proyek Dengan Metode Line of Balance Pada Proyek Pembangunan Perumahan Grand Efata Malibela	● Scheduling using the Line of Balance on the Grand Efata housing development project resulted in a duration of 184 days, while the existing scheduling lasted 456 days. There is a difference of 272 days, this difference makes LOB better used for the project.

RESEARCH METHODOLOGY

The subject of this research is the Ngasem Overpass Bridge of the Solo – Yogyakarta – NYIA Kulon Progo Toll Road Project. The survey and data collection were carried out in September 2022. To make schedules with the Line of Balance, the data used in this study were the duration of one cycle of work and the number of workers in each type of work. These data were obtained through interviews with PT. Adhi Karya (Persero) Tbk, the main contractor for the Solo-Yogyakarta-NYIA Kulon Progo toll road project Section 1 Package 1.

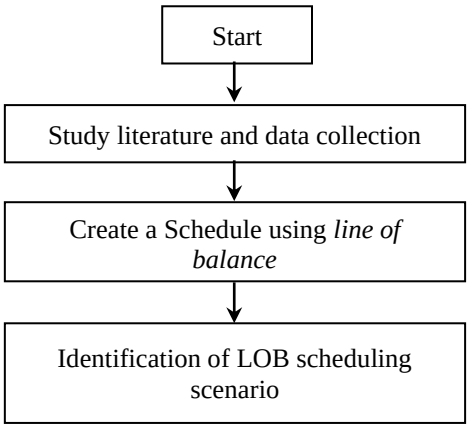

FIGURE 1. Research Flowchart

Before starting the research, the researcher conducted a literature review from various scientific journals as a reference for processing the data. The data used in this research were secondary data obtained through interviews with the staffs of PT. Adhi Karya (Persero) Tbk. The research was conducted through identification and exploration, meaning it was flexible and creative. The step for creating a schedule was to calculate the variables in the Line of Balance (LoB), with the details of the variables to be presented in the results and discussion. The variables were then plotted on the diagram, starting from the variable's start day unit 1 and ending on the finish day. If there was an intersection of lines between jobs, a delay was introduced. If the results

of the delay were still optimizable, interruption and acceleration could be carried out. The last stage of the research was to identify LoB scheduling scenarios for efficiently managing resources on the Ngasem Overpass Bridge.

TABLE 2. Data of Case Study

Data	Explanation
Location	Ngasem, Colomadu, Karanganyar, Central Java, Indonesia
Function	Overpass Bridge for Solo – Yogyakarta Toll Road
Length and width	± 204 meter and ± 35 meter
Number of piers	5 pier and 2 Abutment

RESULT AND DISCUSSION

Line of Balance Schedule

The Line of Balance (LoB) has a basic format, where the vertical axis represents the number of repeating components, and the horizontal axis represents the amount of time [4]. LoB refers to the knowledge of how many repetitive work components can be completed within a predetermined time [5]. Implementing LoB offers several advantages, including the ability for the project manager to monitor all project work, pinpoint obstacles, focus on potential obstacles, prevent problems that may arise due to worker recruitment during the construction process, and provide ease of reducing waiting time for work and equipment when moving between work units with minimal risk [6]. To create a schedule using the Line of Balance, there is a procedure [3] that should be followed, including the following steps::

1. Determine the logical relationship of the work order.
2. Calculate the Line of Balance variables.
3. Plot the calculation results onto a Line of Balance diagram.
4. Postpone if there is work that precedes each other.

1. Job sequence logic and job type data

TABLE 3. Overpass Bridge Ngasem work

No	Type of Work	Duration of one cycle	Number of Workers
1	Bored pile	14 Days	5
2	Structure excavation	7 Days	1
3	Lean concrete casting	1 Day	5
4	Footing	11 Days	30
5	Wall abutment/ column pier	16 Days	30
6	Wingwall abutment / pier head	15 Days	30
7	Bearing pad istallation	1 Days	4
8	Erection Girder	4 Days	10
9	Diaphragm beam	14 Days	7
10	Bondex plate installation	1 Day	20
11	Deckslab	15 Days	20
12	Parapet	4 Days	15

Note: 1) Bored pile work - Bearing pad installation has 7 repetitions
2) Erection girder work - Parapet has 6 repetitions

2. Variable Line of Balance

In the LOB calculation there are several variables that are determined to make a schedule [3]

TABLE 4. Data of Work Time Overpass Bridge Ngasem

Data	Explanation
Working days	7 calendar days
Working hour per day	12 hours
Working hour per week	84 hours
Number of work units	5 Pier and 2 Abutment

a. Calculation of the number of hours worked on the type of work per unit.
$M = total\ workers \times\ duration\ of\ work\ \times\ working\ hour\ per\ day$
b. Determine the estimated number of workers in work groups per type of work.

(n= people per group)

c. Determine the number of work groups needed (H)
   H in this study was obtained during an interview with the project scheduler.
d. Calculation of the number of workers needed for one job (A)
e. Calculation of the actual average working group used (R)

$$R = \frac{A \times Working\ Hours\ per\ Week}{M}$$

f. Calculation of time to work on the type of work in one unit (t)

$$t = \frac{M}{n \times Working\ Hours\ Per\ Day}$$

g. Calculation of the time required to start work in the last unit (T)

$$T = \frac{Target\ of\ Unit\ Works - 1}{R} \times working\ days$$

TABLE 5. Variable Line of Balance

Type of Work	M	n	H	A	R	t	T
Bored pile	840	5	1	5	0,5	14	84
Structure excavation	84	1	1	1	1	7	42
Lean concrete casting	60	5	1	5	7	1	6
Footing	3960	30	1	30	0,636	11	66
Wall abutment/ column pier	5760	30	1	30	0,4	16	96
Wingwall abutment / pier head	5400	30	1	30	0,467	15	90
Bearing pad istallation	48	4	1	4	7	1	6
Erection Girder	480	10	1	10	1,75	4	20
Diaphragm beam	1176	7	1	7	0,500	14	70
Bondex plate installation	120	10	1	10	7	1	5
Deck slab	3600	20	1	20	0,467	15	75
Parapet	960	20	1	20	1,8	4	20

3. Diagram Line of Balance

TABLE 6. Calculation of time to star work unit 1, unit 7 / 6 and finish

Type of Work	t	T	Star day Unit 1		Star day Unit 7 / 6		Finish	
Bored pile	14	84		0	0+84	84	84+14	98
Structure excavation	7	42	0+14	14	42+14	56	56+7	63
Lean concrete casting	1	6	7+14	21	6+21	27	27+1	28
Footing	11	66	1+21	22	66+22	88	88+11	99
Wall abutment/ column pier	16	96	11+22	33	96+33	129	129+16	145
Wingwall abutment / pier head	15	90	16+33	49	90+49	139	139+15	154
Bearing pad istallation	1	6	15+49	64	6+64	70	70+1	71
Erection Girder	4	20	1+64	65	20+65	85	85+4	89
Diaphragm beam	14	70	4+65	69	70+69	139	139+14	153
Bondex plate installation	1	5	14+69	83	5+83	88	88+1	80
Deck slab	15	75	1+83	84	75+84	159	159+15	174
Parapet	4	20	15+84	99	20+99	119	119+4	123

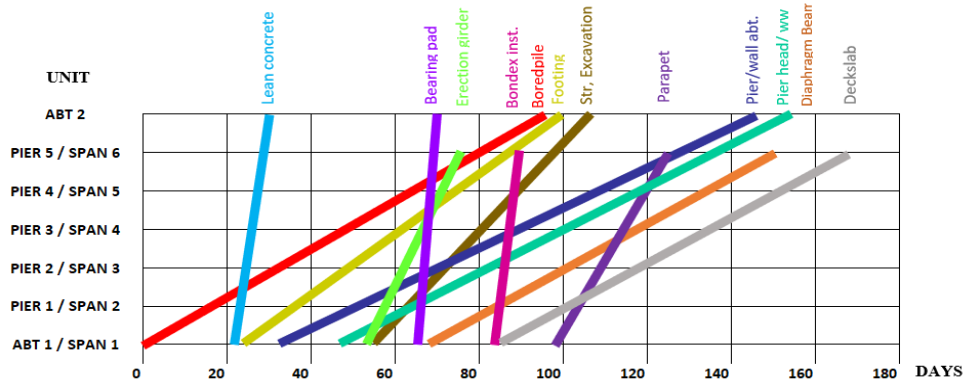

FIGURE 2. Line of Balance Diagram

Figure 1 shows that the Ngasem Overpass Bridge when the line of balance is applied, there are jobs that precede each other. This is due to differences in the duration of one cycle that are not constant between jobs. Line of balance scheduling requirements that can be used are that no work may precede each other, meaning that the following work (successor) may not precede the work that precedes it (successor) [7]. To overcome this, a delay is made so that a predecessor and successor situation occur.

4. Delay in the Line of Balance Method

Delays in the line of balance method are carried out if there is work that precedes each other. Thus, the delays are carried out by trial, namely by trying to add days to the start time until the work does not cut off the successors. The following is a trial delay on the Ngasem Overpass Bridge

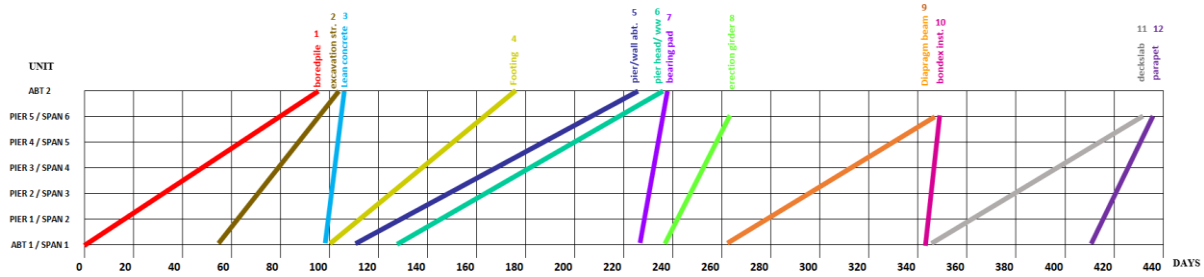

FIGURE 3. Diagram Line of Balance After Delay

The delay analysis shows that no work precedes each other, which means the situation predecessor and successor have occurred, and scheduling can be applied to the Overpass Bridge Ngasem,with a total duration of 437 calendar days. However, when viewed from the result of the delay, there is a pattern where work with a short duration is preceded and followed by work with a long duration; in this situation, a compromise can be made to speed up the star time of the short-duration work successor.

TABLE 7. Delay Trial in the Line of Balance Method

Type of Work	T	T	star unit 1		star unit 7 / 6		finish	Delay
Bored pile	14	84		0	0+84	84	98	0
Structure excavation	7	42	14 +42	56	56+42	98	105	42
Lean concrete casting	1	6	21+78	99	99+6	105	106	78
Footing	11	66	22+78	100	100+66	166	177	78
Wall abutment/ column pier	16	96	33+78	111	111+96	207	223	78
Wingwall abutment / pier head	15	90	49+84	133	133+90	223	238	84
Bearing pad istallation	1	6	64+168	232	232+6	238	239	168
Erection Girder	4	20	65+174	239	239+20	259	263	174
Diaphragm beam	14	70	69+194	263	263+70	333	347	194
Bondex plate installation	1	5	83+259	342	342+5	347	348	259
Deck slab	15	75	84+259	343	343+75	418	433	259
Parapet	4	20	99+314	413	413+20	433	437	314

Compromise is a situation where a short-duration job is preceded and followed by a long-duration job. For example, casting lean concrete lasts one day's work, preceded by the excavation of structures with a duration of seven days, and followed by footing work with a duration of fourteen days. In this situations, lean concrete casting work can be compromised to terminate resource in each unit to speed up the star time of successors. A compromise is an option to speed up the start time of a work by cutting resources on works with a short duration or to make the resources of a works usable continuously. In this case study, a compromise will be made on several jobs to speed up the start time of work to cut the total duration of the Ngasem overpass bridge.

5. Interruption and Acceleration in the Line of Balance Method

Interruptions and accelerations are the results of compromises made from delays to shorten the total duration of the Ngasem Overpass Bridge. interruptions are delays or termination of resources for the next unit, but still in the same type of work. Many factors can cause interruptions, including lack of resources, technical problems, etc [8]. In this study case interruption is used to compromise short-duration work preceded and followed by long-duration work.

TABLE 8. Interruption and Acceleration in the Line of Balance Method

Type of Work	t	T	star unit 1	star unit 7/6	finish	Acceleration	Explanation
Bored pile	14	84	0	84	98	0	No interuption or Acceleration
Structure excavation	7	42	56	98	105	0	No interuption or Acceleration
Lean concrete casting	1	6	63	105	106	0	Interruption
Footing	11	66	64	130	141	36	Acceleration
Wall abutment/ column pier	16	96	75	171	187	36	Acceleration
Wingwall abutment / pier head	15	90	97	187	202	36	Acceleration
Bearing pad installation	1	6	112	202	203	36	Interruption and Acceleration
Erection Girder	4	20	203	223	227	36	Acceleration
Diaphragm beam	14	70	227	297	311	36	Acceleration
Bondex plate installation	1	5	241	311	312	36	Interruption and Acceleration
Deck slab	15	75	242	317	332	101	Acceleration
Parapet	4	20	257	332	336	156	Interruption and Acceleration

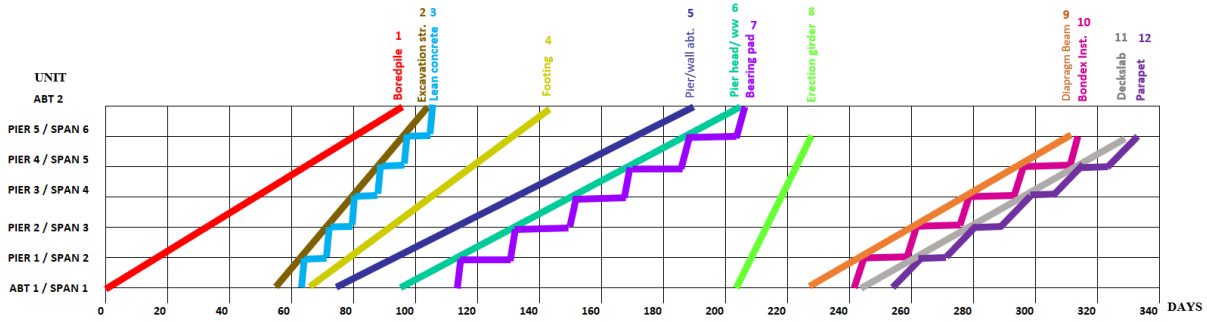

FIGURE 4. Diagram Line of Balance After Interruption and Acceleration

Based on the diagram of the results of interruptions and acceleration in the second scenario scheduling, it can be concluded that a compromise on short-duration jobs preceded and followed by long-duration jobs has succeeded in accelerating schedule. This is proven in several works as an example of the casting of lean concrete, which was interrupted, then its successor the footing work, which was the time began on the 100th day after a compromise was made for the interruption to be the 64th day. Compromise on work with a short duration preceded and followed by a long duration is ineffective when applied to jobs with many complex resources. This is proven on the erection girders, which have many complex resources such as heavy equipment cranes, girders, trucks, and significant manpower. If a compromise is still made interruption, the resource in each unit will take additional time than planned, which will result in additional costs because in general, the erection girder resource is provided by a subcontractor. Compromise will be effective if it is done on a job that has not to have many complex resources, even though the job has a short duration compared to other jobs, but if it has many complex resources, then the compromise will not work effectively.

Interruption is made by stopping the resource after the first unit is completed in a short-duration job which is preceded and followed by a long-duration job, then resume in the second unit after the work predecessor has finished the third unit, and so on. As an example of lean concrete casting work, the work initially scheduled to start on the 99th day, because due to interruptions the lean concrete casting work began on the 63rd day. After the completion of the first unit on the 64th day, the lean concrete casting work was postponed until the excavation work for the second unit was completed on the 70th day, and then the second unit of lean concrete work started on the same day. There was a time lag of 6 days between the units, which continued until the lean concrete work was completed on the 106th day. Following the interruption of the lean concrete work, there was a gap of 36 days before the footing work began. This time gap can be utilized for acceleration, and the footing work, which was originally scheduled to start on the 100th day, can now start on the 64th day. If the footing work is accelerated, the subsequent work can also be accelerated, as any delay will create a time gap between the subsequent jobs.

After the delay treatment, which becomes the first LoB scenario where all work is not interrupted, the total time needed to complete the Ngasem Overpass bridge is 417 days. Then the interruption and acceleration treatment due to a compromise becomes the second LoB scenario where some work is

interrupted to speed up its successors; the total time needed for this scenario is 336 days. A conclusion is reached.

- Scenario 1 Line of Balance without Interruptions and Acceleration

The result of the delay shows that both predecessor and successor situations have occurred, as well as all resources, and the work can be used optimally because there is no delay in each unit. However, it should be considered that with a delay without any other treatment, the construction of the Ngasem Overpass Bridge will take 417 calendar days. This is certainly quite long because it takes more than a year. Thus, scenario 1 LoB scheduling can be the contractor's choice if they want a schedule that has the advantage that all work resources can be used optimally because there are no delays in each unit, but the time needed to work on one bridge unit is quite long.

- Scenario 2 Line of Balance with Interruptions and Acceleration

The results of interruptions and acceleration show that there was a difference in the completion time, which was originally 417 calendar days, and now it takes 336 calendar days. Therefore, acceleration is the right step when there is work being interrupted because it will make the schedule finish earlier. Thus, scenario 2 LoB is an option if the contractor wants faster processing time provided that there are some jobs that must be postponed.

The first scenario is aimed at contractors with sufficient time on the contract; scenario one can be an option because it offers optimal resource use. After all, there are no delays in each unit. But suppose you only have a little time due to various factors. In that case, the second LoB scenario can be an option because it has a shorter duration than the first scenario, resulting in some jobs being interrupted for acceleration. Still, interruptions are only made on jobs with a short duration that is preceded and followed by work with a long duration and have uncomplicated resources. So that the second LoB scenario is a recommendation to complete the Ngasem Overpass Bridge.

CONCLUSIONS

1. Line of Balance suitable to be applied to the Ngasem Overpass Bridge, which has a lot of repetitive work done segmentally. Thus, repetitive construction works such as construction of roads, railroads, and multi-story buildings can be applied to the Line of Balance.
2. Significant differences in the duration of one cycle that are not constant in each job greatly affect the results diagram.
3. Work patterns in LoB with short-duration work preceded and followed by long-duration work can be compromised to speed up the successor's start time so that if the contractor sees this pattern, they can immediately compromise by interrupting the resources in each unit to speed up the successor. If there is a work that has been interrupted, compromise can also make the work resource work continuously.
4. The Line of Balance can help manage resources and generate scheduling scenarios that can be adjusted to the contractor's goals.

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