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Repetitive Construction Scheduling Using Line of Balance (Case Study: One of the 6-Storey Polyclinic Building Construction Project in Batang Regency)

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Abstract. Repetitive work is often encountered by contractors, so effective planning is needed so that the project can achieve its goals within the set time limit. One aspect of planning is project scheduling, which is a method that is used in construction work. One of the scheduling methods suitable for repetitive construction is a line of balance. Therefore, this research was conducted using the line of balance method on a repetitive multi-story building project to find out whether the line of balance can properly organize project implementation. The results of the analysis and calculations that have been carried out obtained the duration required to complete the construction project of the 6-story polyclinic building for 274 days. The schedule in the project plan takes 308 days to complete the project. By comparing the effectiveness of the time whose duration is at odds with 34 days, the schedule plan using the line of balance method is more effective and efficient in completing the construction project of the 6-story polyclinic building in Batang Regency.

Keywords: repetitive work, project scheduling, line of balance

INTRODUCTION

The construction project of a 6-story polyclinic building in Batang Regency involves repetitive work processes that require efficient management. One of the essential aspects needed in constructing a multi-story building is efficient project scheduling that is used according to the type of project. [1]. The construction of a multi-story building involves a lot of repetitive work on each floor, such as structure, architecture, and MEP. With so much repetitive work, an effective scheduling method is needed. Several scheduling methods are used in construction projects, including bar charts, S-curves, line-of-balance diagrams, etc. [2]. This research concentrates on the line-of-balance method to discover whether this method can be implemented in repetitive multi-story building projects. Line of balance is a scheduling method that enables effective resource management. The method is displayed as a simple line diagram that is easy to understand and highlights possible congestion during construction. [3]. This enables construction authorities to concentrate on areas potentially disrupting the project timeline and implement preventive measures to reduce delays and cost escalation. [4].

This study was carried out on a 6-story polyclinic building project, spanning 816 m² and reaching a height of 29.5 meters. The research aims to determine if the line-of-balance method can simplify management in multi-story building construction projects. While similar research has been conducted previously, this study focuses on a different type of project. Consequently, prior research is used as a reference to support this research.

TABLE 1. Previous research

Researcher	Title	Analysis result
Muhammad Abrar Aulia, Aulia Hashemi Farisi, M. Agung Wibowo, Arif Hidayat (2	Analysis of the Use of Line of Balance in Repetitive Construction Projects (Case Study: Candyland Apartment Development Project - Semarang)	Line of Balance (LoB) is an ideal scheduling method for construction projects with repetitive work packages, as it effectively presents the schedule for these works across each unit in a line chart. LoB is simple and easy to interpret due to its linear format, illustrating productivity.
Sri Mutianingsi Kalia, Arfan Utiarahman, Mohamad Yusuf Tuloli (2022)	Application of Line of Balance Method in Repetitive Construction Project (Case Study: Griya Tunas Mandiri Housing)	Scheduling using a Line of Balance resulted in a duration of 132 days. In terms of effectiveness and efficiency of time duration, a comparison of scheduling using Line of Balance, which only has a duration of 132 days, with existing scheduling, which has a duration of 400 days, shows a considerable difference of 268 days. This difference made the Line of Balance more suitable for the project.
Agung Budiwirawan, Edwin Firgyan Raharja, M. Faizal Ardhiansyah Arifin (2023)	Repetitive Construction Scheduling for Solo-Yogyakarta NYIA Kulon Progo Toll Road Overpass using Line of Balance	A line of balance is suitable for application to the Ngasem Overpass Bridge, which has a lot of repetitive work done segmentally. The Line of Balance can help manage resources and generate scheduling scenarios that can be adjusted to the contractor's goals. The LoB can be done with two scenarios: (1) without Interruptions and Acceleration and (2) with Interruptions and Acceleration.

METHODOLOGY

The focus of this research is the duration of the construction project of a 6-story polyclinic building in Batang Regency. Surveys and data collection were conducted in October 2023. To create a schedule using the line of balance method, the data includes the duration of one work cycle and the number of workers for each type of work. This information was collected through interviews with the 6-story polyclinic construction project scheduler.

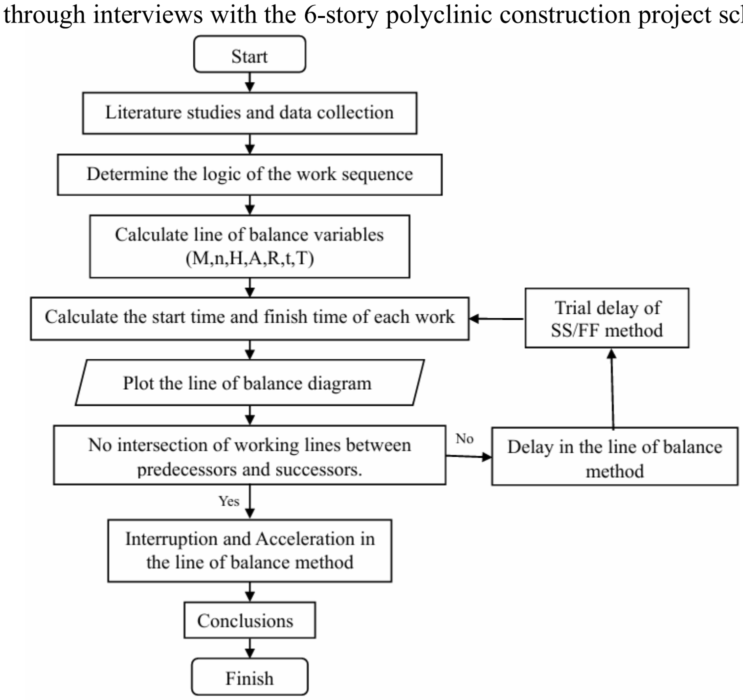

FIGURE 1. Research flowchart

The researcher gathered several scientific journals related to the line of balance from various sources to conduct a literature review, serving as a reference for data processing. The primary data utilized in this study is obtained through interviews with the project scheduler of the 6-story polyclinic building construction project in Batang Regency. The research was conducted through identification and exploration, allowing flexibility and creativity. Creating a schedule involves calculating the variables in the line of balance, with the specific variables detailed in the results and discussion section. These variables are then plotted on a diagram, starting from the start day of unit 1 and concluding on the finish day. [5]. If there is an intersection between the predecessor's and successor's lines, it indicates a delay. [6]. Specific works can be carried out simultaneously, allowing them to start simultaneously and resulting in line intersections between works that can proceed concurrently. The final step of this research focuses on identifying line-of-balance scheduling scenarios to optimize resource management for the 6-story polyclinic building project.

RESULT AND DISCUSSION

The Line of Balance (LoB) features a basic format in which the vertical axis represents the number of repetitions, while the horizontal axis denotes the amount of time. [7]. LoB refers to understanding how many repetitive work components can be completed within a specified timeframe. [8]. Implementing LoB provides several benefits, such as enabling the project manager to monitor all project activities, identify constraints, focus on potential issues, address problems related to worker hiring during construction, and minimize waiting times for work and equipment when transitioning between work units, all while reducing associated risks. [9]. There are several procedures for creating a schedule using LoB. [10] The following procedure must be followed:

1. Determine the logical relationship between work orders.
2. Calculate the line of balance variables.
3. Plot the calculated results on a line of balance diagram.
4. Identify delays if there are predecessor and successor works that overlap.

1. List of job types and number of workers

TABLE 2. Work data of the 6-storey polyclinic building construction project

No	List of work	Duration of one cycle	Number of workers	Type of work
1	Foundation	45	12	Structure
2	Containment basin and WWTP	14	5	Structure
3	Structure	20	23	Structure
4	Electricity connection	5	8	MEP
5	Fire hydrants and sprinklers	7	8	MEP
6	Medical gas installation	5	4	MEP
7	Plumbing	7	5	MEP
8	Wall, door, and window sills	9	8	Architecture
9	Air system	5	4	MEP
10	Sound system	3	4	MEP
11	Elevator	5	10	MEP
12	Floor and wall finishing	9	8	Architecture
13	Countertop wall, protector, and stair railing	7	5	Architecture
14	Facade	7	4	Architecture
15	Painting	7	5	Architecture
16	Plafond	8	8	Architecture
17	Sanitair	7	5	Architecture
18	Fire alarm	2	4	MEP
19	Lighting	2	4	MEP
20	CCTV and data	2	4	MEP

Note:

1) Foundation and Containment basin & WWTP are not repetitive work
2) Structure work has seven repetitions because until the roof structure

2. Work sequence logic diagram

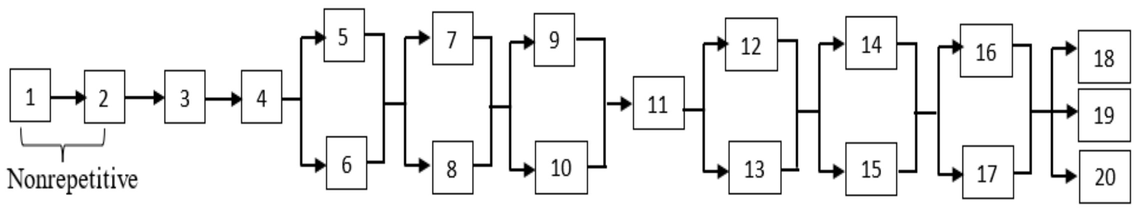

FIGURE 2. Work sequence logic diagram

The diagram above shows the sequence of work in the 6-story polyclinic building construction project. There is work that is done in series and work that can be done simultaneously (parallel). Work that is done simultaneously can start at the same time and allows the intersection of lines between simultaneous work.

3. Variable line of balance

LoB calculation involves determining several variables to create a schedule [3].

TABLE 3. Data of work time of the 6-story polyclinic building construction project

Data	Explanations
Working days	7 calendar days
Working hours in a day	8 hours
Working hours in a week	56 hours
Number of units	6-story

a. Calculation of the number of hours worked per unit of each type of work (M)

$M = \text{total workers} \times \text{duration of work} \times \text{working hour per day}$

b. Estimate the number of workers needed in each work group for each type of work.

(n = people per group)

c. Determine the number of work groups required (H)

In this study, the value of H was obtained through an interview with the project scheduler.

d. Calculation of the number of workers needed for one job (A)

$$A = n \times H$$

e. Calculation of the number of the actual average working group used (R)

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

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

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

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

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

TABLE 4. Line of balance variables calculation result

No	List of work	M	n	H	A	R	t	T
1	Foundation	4320	12	1	-	-	45	-
2	Containment basin and WWTP	560	5	1	-	-	14	-
3	Structure	3680	23	1	23	0,35	20	120
4	Electricity connection	320	8	1	8	1,4	5	25
5	Fire hydrants and sprinklers	448	8	1	8	1	7	35
6	Medical gas installation	160	4	1	4	1,4	5	25
7	Plumbing	280	5	1	5	1	7	35
8	Wall, door, and window sills	576	8	1	8	0,78	9	45
9	Air system	160	4	1	4	1,4	5	25
10	Sound system	96	4	1	4	2,33	3	15
11	Elevator	400	10	1	10	1,4	5	25
12	Floor and wall finishing	576	8	1	8	0,78	9	45
13	Countertop wall, protector, and stair railing	280	5	1	5	1	7	35
14	Facade	224	4	1	4	1	7	35
15	Painting	280	5	1	5	1	7	35
16	Plafond	512	8	1	8	0,875	8	40
17	Sanitair	280	5	1	5	1	7	35
18	Fire alarm	64	4	1	4	3,5	2	10
19	Lighting	64	4	1	4	3,5	2	10
20	CCTV and data	64	4	1	4	3,5	2	10

Symbols:

1. M: Number of hours worked per unit of each type of work
2. n: Number of workers per group
3. H: Number of work groups required
4. A: Number of workers needed for one work
5. R: Number of actual average working groups used
6. t: Number of duration required to complete 1 unit
7. T: Number of time taken to start the last unit

4. Plotting the LoB diagram

Before plotting the LoB diagram, time calculations for each type of work must be carried out to determine the starting time of the first unit, the starting time of the last unit, and the finishing time. Calculating the processing time of the 1st unit (starting time of the 1st unit) is done by summing up the variable t (previous work) with the starting time of the earlier work.

Meanwhile, to find out the starting time of the 6th unit, add up T (type of work in progress) and the starting time of unit 1 (kind of work in progress).

TABLE 5. Calculation of time to start work unit 1, unit 6/7, and finish

No	List of work	t	T	Start day unit 1		Start day unit 6/7		Finish	
1	Foundation	45	-	0	0	-	-	0+45	45
2	Containment basin and WWTP	14	-	0+45	45	-	-	14+45	59
3	Structure	20	120	14+45	59	120+59	179	20+179	199
4	Electricity connection	5	25	20+59	79	25+79	104	5+104	109
5	Fire hydrants and sprinklers	7	35	5+79	84	35+84	119	7+119	126
6	Medical gas installation	5	25	5+79	84	25+84	109	5+109	114

TABLE 6. Continued calculation of time to start work unit 1, unit 6/7, and finish

No	List of work	t	T	Start day unit 1		Start day unit 6/7		Finish	
7	Plumbing	7	35	7+84	91	35+91	126	7+126	133
8	Wall, Door, and Window Sills	9	45	7+84	91	45+91	136	9+136	145
9	Air system	5	25	9+91	100	25+100	125	5+125	130
10	Sound system	3	15	9+91	100	15+100	115	3+115	118
11	Elevator	5	25	5+100	105	25+105	130	5+130	135
12	Floor and Wall Finishing	9	45	5+105	110	45+110	155	9+155	164
13	Countertop Wall, Protector, and Stair Railing	7	35	5+105	110	35+110	145	7+145	152
14	Facade	7	35	9+110	119	35+119	154	7+154	161
15	Painting	7	35	9+110	119	35+119	154	7+154	161
16	Plafond	8	40	7+119	126	40+126	166	8+166	174
17	Sanitair	7	35	7+119	126	35+126	161	7+161	168
18	Fire Alarm	2	10	8+126	134	10+134	144	2+134	146
19	Lighting	2	10	8+126	134	10+134	144	2+144	146
20	CCTV and Data	2	10	8+126	134	10+134	144	2+134	146

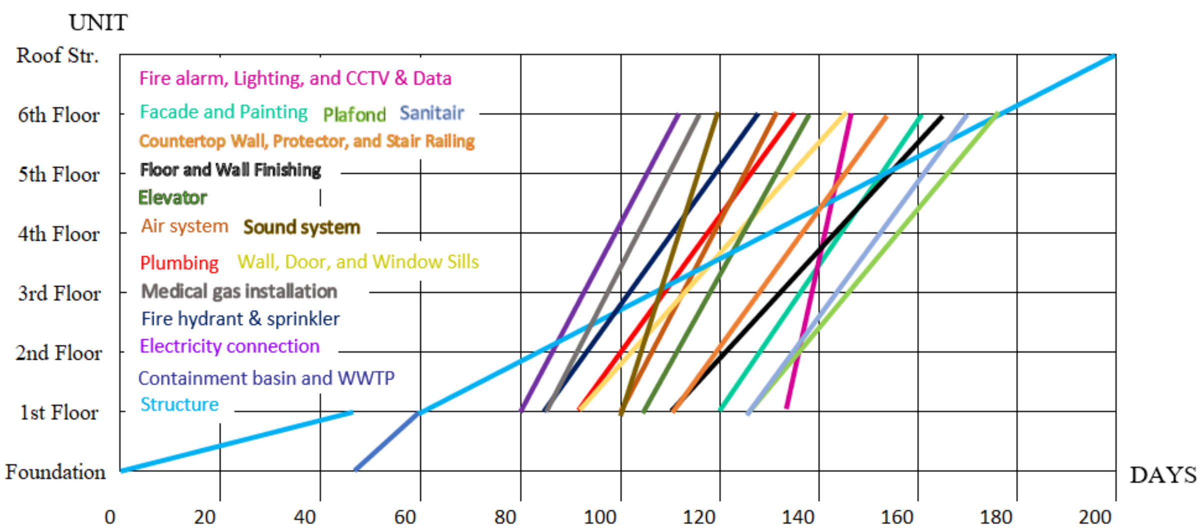

FIGURE 3. Line of balance diagram

Figure 3 shows the 6-storey polyclinic building construction project scheduling using the line of balance. The diagram reveals that some predecessors and successors overlap due to the varying durations of work cycles for different works. For an effective line-of-balance schedule, there should be no overlap between predecessors and successors; in other words, a successor work should not start before its predecessor work is completed. [7]. To address this issue, a postponement is implemented to resolve the situation where predecessors and successors overlap.

5. Line of balance scheduling postponement

In the line of balance method, postponement is used when predecessors and successors overlap. This involves adding days to the start time of work until the work no longer intersects with the preceding works. The following outlines the postponements applied in the 6-story polyclinic building construction project.

TABLE 7. Delay trial in the line of balance method

No	List of work	t	T	Start day unit 1	Start day unit 6/7	Finish	Delay
1	Foundation	45	-	0	-	45	0
2	Containment basin and WWTP	14	-	45	-	59	0
3	Structure	20	120	59	179	199	0
4	Electricity connection	5	25	154	179	184	75
5	Fire hydrants and sprinklers	7	35	161	196	203	77
6	Medical gas installation	5	25	159	184	189	75
7	Plumbing	7	35	168	203	210	77
8	Wall, Door, and Window Sills	9	45	170	215	224	79
9	Air system	5	25	199	224	229	99
10	Sound system	3	15	209	224	227	109
11	Elevator	5	25	214	239	244	109
12	Floor and Wall Finishing	9	45	223	268	277	113
13	Countertop Wall, Protector, and Stair Railing	7	35	221	256	263	111
14	Facade	7	35	242	277	284	123
15	Painting	7	35	242	277	284	123
16	Plafond	8	40	250	290	298	124
17	Sanitair	7	35	249	284	291	123
18	Fire Alarm	2	10	288	298	300	154
19	Lighting	2	10	288	298	300	154
20	CCTV and Data	2	10	288	298	300	154

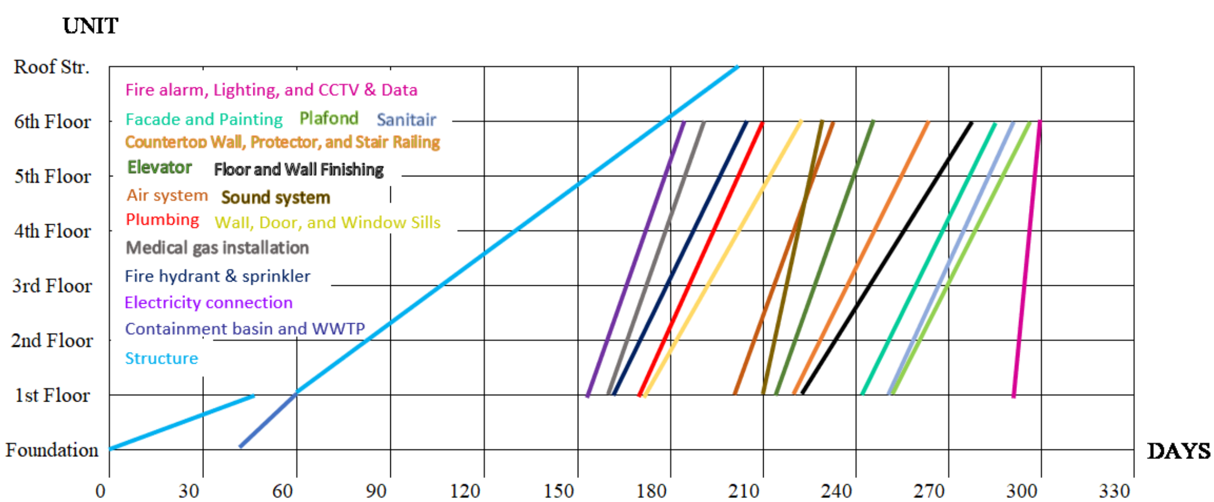

FIGURE 4. Line of balance diagram after postponement

The delay analysis reveals no instances where predecessors and successors overlap, indicating that the predecessor and successor conditions have been met with a total duration of 300 days. However, the analysis also shows a pattern where works with shorter durations are followed by works with longer durations. In this scenario, interruption and acceleration strategies can be applied using the line of balance method to optimize the schedule.

6. Interruption and acceleration in the line of balance method

Interruptions and accelerations can be applied based on delay results to reduce the overall project duration. Interruptions involve delaying or halting resources for the next unit within the same type of work. These interruptions can be caused by various factors, including resource shortages, technical issues, and other challenges [8]. In this case, interruptions optimize works with shorter durations surrounded by longer-duration works. This allows for the acceleration of the start time for subsequent work, improving the overall schedule efficiency.

TABLE 8. Interruption and acceleration in the line of balance method

No	List of work	t	T	Start day unit 1	Start day unit 6/7	Finish	Acceleration	Explanation
1	Foundation	45	-	0	-	45	0	No I & A
2	Containment basin and WWTP	14	-	45	-	59	0	No I & A
3	Structure	20	120	59	179	199	0	No I & A
4	Electricity connection	5	7	79	179	184	0	I
5	Fire hydrants and sprinklers	7	35	149	184	191	12	A
6	Medical gas installation	5	25	159	184	189	0	No I & A
7	Plumbing	7	35	164	199	206	4	A
8	Wall, Door, and Window Sills	9	45	164	209	218	6	A
9	Air system	5	25	173	218	223	6	I & A
10	Sound system	3	15	173	218	221	6	I &A
11	Elevator	5	25	198	223	228	16	A
12	Floor and Wall Finishing	9	45	203	248	257	20	A
13	Countertop Wall, Protector, and Stair Railing	7	35	203	238	245	18	A
14	Facade	7	35	212	257	264	20	I & A
15	Painting	7	35	212	257	264	20	I & A
16	Plafond	8	40	224	264	272	26	A
17	Sanitair	7	35	229	264	271	20	A
18	Fire Alarm	2	10	262	272	274	26	A
19	Lighting	2	10	262	272	274	26	A
20	CCTV and Data	2	10	262	272	274	26	A

Note:

1) A: Acceleration
2) I: Interruption

Based on the TABLE 8. In the second scheduling scenario, the line of balance method, interruption, and acceleration techniques successfully shortened the project duration. This optimization was achieved by adjusting the schedule of short-duration works preceded and followed by long-duration works. For example, the electrical connection work was interrupted, allowing its successor, the fire hydrant and sprinkler work, to start earlier. Originally scheduled to begin on the 161st day, the fire hydrant and sprinkler work was advanced to the 149th day after the interruption of the electrical connection work.

Interruptions involve pausing resources after completing the first unit of short-duration work surrounded by long-duration work. The work then resumes on the second unit only after the preceding long-duration work has been completed. For instance, in the electricity connection work, initially scheduled to begin on the 154th day, the start was advanced to the 79th day due to interruptions. After completing the first unit on the 84th day, the electricity connection work was halted until the structural work for the second unit was finished on the 99th day, at which point the second unit's electrical connection work commenced. A 19-day gap occurred between the two units, with the entire electrical connection work concluding on the 184th day. Following this, there was a 12-day delay before starting the fire hydrant and sprinkler work. This time lag presents an opportunity for acceleration.

By advancing the fire hydrant and sprinkler work, initially set for the 161st day, to the 149th day, subsequent works can also be accelerated. Addressing this delay allows for a smoother transition and reduces potential delays in the later stages of the project.

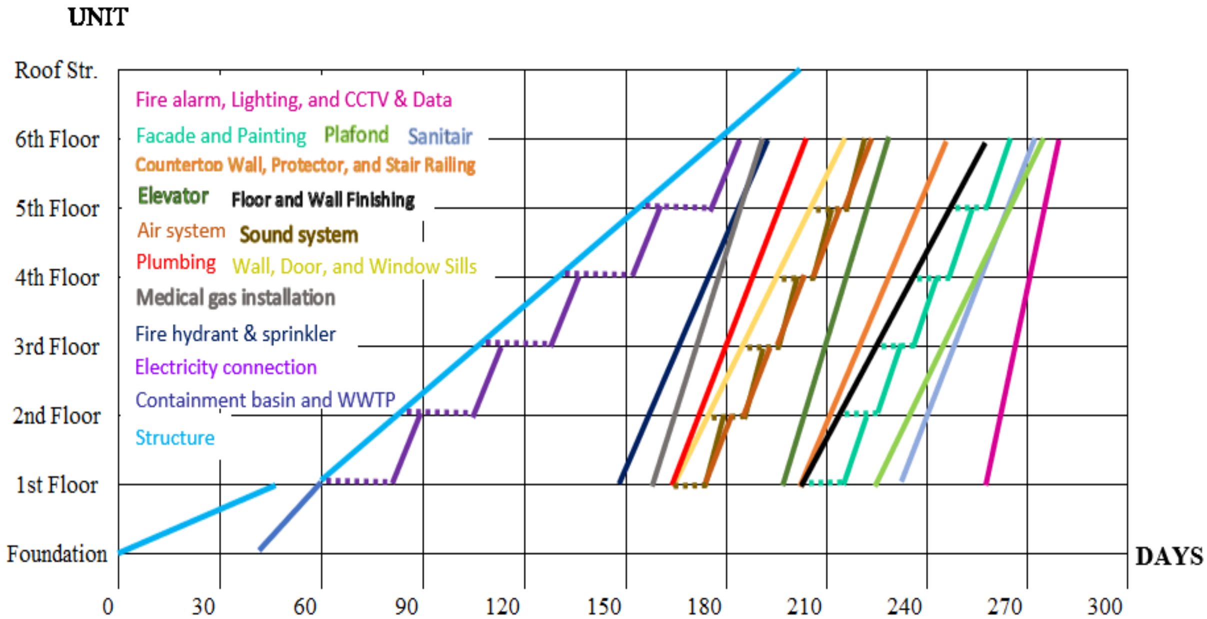

FIGURE 5. Line of balance diagram after interruption and acceleration

After analyzing the delay, the first Line of Balance (LoB) scenario, which involves uninterrupted work, requires 300 days to complete the 6-story polyclinic building. In contrast, the second LoB scenario, which incorporates interruptions and acceleration to expedite the start time of subsequent works, reduces the total duration to 274 days.

The first scenario (without Interruptions and Acceleration) is suited for contractors with ample time in their contract, as it provides optimal resource utilization. However, if the available time is limited, the second scenario (with Interruptions and Acceleration) is preferable, as it shortens the overall duration by allowing interruptions on short-duration works surrounded by longer works. Therefore, the second scenario is recommended for completing the 6-story polyclinic building in Batang Regency within a tighter schedule.

CONCLUSIONS

1. The Line of Balance (LoB) offers ease in project management due to its simplicity and clarity. It is represented as a line diagram where the X-axis indicates the duration (in days) and the Y-axis shows the number of units. The slope of the line reflects productivity: a gentler slope signifies slower work, while a steeper slope indicates faster work completion.
2. Scheduling the 6-storey polyclinic building construction using the Line of Balance (LoB) method resulted in a project duration of 274 days. In comparison, the existing scheduling method had a duration of 308 days, resulting in a 34-day difference. This reduction highlights the effectiveness and efficiency of LoB in shortening the project's completion time.
3. The Line of Balance (LoB) method facilitates resource management and allows for the creation of customizable scheduling scenarios tailored to the specific needs of the project

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