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Application of Critical Chain Project Management on Engine Maintenance at PT. Rekatama Putra Gegana Aviation

Ridha Azka Raga[1], Husna Putri Pertiwi[2], Jasrial[3]
[123]Universitas Terbuka, Indonesia
Correspondent: husna@ecampus.ut.ac.id[2]

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ABSTRACT: Planning is a crucial element for aircraft maintenance companies to achieve higher profitability. However, in practice, the company still employs traditional planning methods, which are deemed inefficient as they do not consider the productivity of each task involved, leading to issues arising from human behavior tendencies causing additional time for task completion. Aircraft maintenance planning can be improved by employing the Critical Chain Project Management (CCPM) method, which offers a different approach to determining the time and cost of aircraft maintenance. This method addresses multitasking, student syndrome, Parkinson's law, and provides buffers at the end of tasks. Analysis results show that the completion time for tasks within the company, totaling 76 days, differs by 14 days compared to the completion time using the CCPM method, which is 62 days. This indicates that employing the CCPM method for engine maintenance is more effective and efficient. The efficiency achieved amounts to Rp7,036,323.

Keywords: Critical Chain Project Management, Buffering, Machine Maintenance

INTRODUCTION

Indonesia is a country in Southeast Asia traversed by the equator and situated between the continents of Asia and Australia, as well as between the Pacific Ocean and the Indian Ocean. Furthermore, Indonesia is the world's largest archipelagic country, consisting of 17,504 islands. To access various regions, transportation with high-speed characteristics capable of penetrating all areas unreachable by other modes of transportation is required, known as air transportation. The development of the national air transport industry in Indonesia is significantly influenced by the geographical conditions of the archipelagic nation. Therefore, air transportation plays a crucial role in strengthening political life, economic development, socio-cultural aspects, and security & defense (Gunawan & Sukhairi, 2011; Kadarisman et al., 2016). Additionally, air transport is considered the safest mode of transportation compared to others because, according to the Dutch aviation consulting company To70, the fatal accident rate for commercial air passengers on large aircraft is 0.06 per 1 million flights or 1 accident for every 16 million flights (Asosiasi Pilot Garuda, 2017).

The increasing demand for air transportation by society has led to competition among companies employing various marketing strategies. However, this has become a reason for aviation stakeholders to reduce services and diminish the quality of aircraft maintenance, resulting in increased accident risks due to decreased safety and security in aviation (Indriani et al., 2023). Although air transportation accidents are rare compared to land transportation accidents, if accidents occur on land, not only flight crews and passengers but also residential areas bear the consequences (Latipulhayat, 2015; Wahyuni, 2019). Factors influencing aviation accidents include environmental factors such as adverse weather and technical factors such as the Instrument Landing System (ILS) and aircraft conditions. The ILS is used by pilots as a landing instrument to facilitate aircraft landings in all weather conditions, while aircraft conditions encompass aircraft age, payload, type, and operation. These factors need to be considered to ensure aircraft remain airworthy (Saputra, 2016).

Prevention of aircraft accidents can be achieved through planning and maintenance. Planning is a crucial stage as it can streamline and optimize a product or service (Taan, 2021), while maintenance is essential as it ensures operational fitness to maintain engines and equipment in prime condition for safe and controllable operation in case of damage (Ansori & Mustajib, 2014; Meyers, 2002)

One of the aircraft maintenance planning methods can be planned using the Critical Path Method (CPM). This method identifies critical paths in activities determined based on their interdependencies (Perdana & Rahman, 2019). However, practically CPM method and other traditional methods are considered inefficient because they do not consider the productivity of each task involved and the problems associated with human behavior tend to cause project completion delays (Nugroho & Suroso, 2023; Wirawan, 2017). Examples of such human behaviors include the student's syndrome, Parkinson's law, multitasking, and overestimated activity durations (Leach, 2014). In line with this issue, a new method for project scheduling has emerged, namely Critical Chain Project Management (CCPM). CCPM is a project planning method that focuses on the resources needed to perform project tasks and improves project completion time by eliminating human behaviors, thus making project completion faster and more efficient (Wirawan, 2017).

Previous research conducted by (IDAWATI, 2019) revealed that the difference in calculation time between CPM and manual planning was 19 days. CPM calculations required 29 working days, whereas using manual methods even took 48 working days. However, comparative research conducted by (Nasution & Arvianto, 2015; Suyuti & Basuki, 2022) between CPM and CCPM, found that planning and scheduling with old methods like CPM were still considered ineffective. According to (Barihazim, 2018; S. Sugiyanto & Insan, 2022) the CCPM method can also optimize direct labor costs as well as reducing project execution time from previous scheduling.

Based on the phenomenon, our study aims to investigate the initial planning of engine maintenance activities using the CCPM method, and discover the total duration and direct labor cost obtained from the application of the CCPM method. This study was conducted to apply the CCPM method in engine maintenance in air transportation at PT. Rekatama Putra Gegana (RPG) Aviation. The rationale for choosing PT. Rekatama Putra Gegana (RPG) Aviation is its crucial role in Indonesia, serving nearly all airlines in the country and government agencies, and its membership in the Indonesia Aircraft Maintenance Service Association (IAMSA), focusing on aircraft component repairs. By using the CCPM method, it is expected to accelerate future project completion and save costs, thereby enhancing the company's quality of service to airline owners.

Project management

(Kerzner, 2017) observed that project management is an evolution of system management, driven by advancing human civilization, sophisticated technology, and increasingly complex projects involving the utilization of resources in the form of human labor, materials, and funds, which are growing in magnitude. Another perspective is presented by Sitanggang et al. (2019), stating that project management is the application of knowledge, expertise, and skills to determine the best technical approach with limited data resources to achieve predefined goals or objectives in order to attain optimal results in terms of performance, time, quality, and safety.

Similarly, (Suhartono et al., 2022) assert that Project Management is a discipline that every professional individual within an organization must possess due to the dynamic nature of organizations, which necessitates the ability to generate ideas materialized in projects. Furthermore, according to (Syamsuir et al., 2023), project management involves the application of knowledge, expertise, and skills to plan, organize, lead, and control resources to achieve project objectives. The urgency of understanding project management is concurrent with the industry's needs for skills in project execution. From the above opinions, it can be concluded that project management evolves due to dynamic operational activities and the need for appropriate approach adjustments in managing projects to align with predefined objectives optimally.

Maintenance Standard

According to (Rosyidin, 2017), broadly speaking, maintenance programs can be divided into two major groups: preventive maintenance and corrective maintenance. Preventive maintenance is aimed at preventing component failures before they occur, whereas corrective maintenance is performed after a failure has occurred to restore the component to its original condition.

Preventive maintenance for aircraft can be categorized into two types. Namely, Periodic maintenance or hard time maintenance, which is performed based on time limits from the maximum aircraft cycle life, such as the A-Check, which is routinely conducted after a certain number of flight hours/flight cycles. Furthermore, On-condition maintenance, which requires inspection to determine the condition of an aircraft component. This includes situations such as bird strikes, hard landings, or other conditions.

On the other hand, corrective maintenance for aircraft (condition monitoring) is maintenance performed after damage to a component has been identified, as indicated in the Cabin Maintenance Log.

Network Planning

According to (Somantri, 2005), network planning is a model widely used in project management, producing information about the activities within the relevant network diagram. Similarly, (Wirawan, 2017) defines network planning as a project planning and control method that depicts the interdependencies among each task represented in the network diagram. This viewpoint is echoed by Fahmi (2018), who describes network planning as a condition and situation faced by a manager by placing emphasis on time and cost considerations in decision-making, particularly decisions related to networks. From the definitions above, it can be concluded that network planning is a planning condition depicted in an interconnected diagram.

Gantt Chart

According to (Jay & Barry, 2016), the Gantt Chart is the most straightforward method to assist a manager in ensuring planned activities, documenting work sequences or tasks, recording activity durations, and estimating the overall project duration. Similarly, (Barihazim, 2018) defines the Gantt Chart as a scheduling method where activities are represented along the vertical axis, dates or time along the horizontal axis, and the duration of activities is depicted by horizontal bar graphs positioned according to their start and end times.

Critical Chain Project Management

According to Leach (2014), Critical Chain Project Management (CCPM) is a method that extends the concept of CPM with the aim of maximizing performance by reducing the duration of each activity within a project while still incorporating safety time durations. This is consistent with (I. Sugiyanto & MT, 2021) perspective, which describes CCPM as a development of the Critical Path Method (CPM), where this scheduling method is considered to have a drawback, namely the allocation of excessively long durations due to the placement of buffer times for each activity, leading resources to tend to consume the available time (Parkinson's law effects) (I. Sugiyanto & MT, 2021).

According to Sugiyanto (2021), Critical Chain Project Management (CCPM) is a method of project planning and management that places primary emphasis on the resources needed to execute project tasks. Meanwhile, according to (Mufahri & Oetomo, 2023), CCPM is a method that strongly discourages multitasking among employees as it can lead to prolonged work involving activities that are not always the same, causing employees to lose focus on their tasks.

The steps in CCPM, as summarized by (Valikoniene, 2015), conclude that the CCPM method involves steps based on the Theory of Constraints (TOC), including identifying the Critical Chain, deciding how to exploit the critical chain, subordinating other work, paths, and resources to the critical chain, and developing the critical chain.

Buffer Management

According to (Hu et al., 2015), buffer management is considered the key to monitoring and controlling project performance. This viewpoint aligns with (I. Sugiyanto & MT, 2021), where Buffer Management is regarded as essential for managing activities in the critical chain of project schedules. There are three types of uncertainty in project planning and scheduling: activity time uncertainty, path time uncertainty, and resource uncertainty. To address uncertainties in construction projects, buffer management is utilized to assess the need for buffers in each activity. Additionally, according to Sirait et al. (2022), buffer management is a method of managing storage space according to the situation and method used. Buffers utilized within the critical chain include project buffers, feeding buffers, and resource buffers (Leach, 2014; I. Sugiyanto & MT, 2021).

According to (Baskara & Noer, 2012), Buffer Management is divided into three equally sized divisions, as illustrated in Table 1. There are several colors, namely: green, yellow, and red.

Table 1. Buffer Management Zone Indicator

Buffer Consumption Zone	Information
0% - 33%	There is no action to be taken
34% - 66%	Plan preventive actions
67% - 100%	Implement preventive actions

The green color indicates the area from negative value to one-third utilization, signifying a safe zone where no action is required. The yellow color indicates the transition zone, where actions should already be planned if needed. If buffer consumption is deemed significant, preventive actions involve identifying issues and devising strategies to resolve them. Meanwhile, the red color signifies planned recovery actions that must be executed.

METHOD

This study employs qualitative research with a case study method. According to (Sekaran & Bougie, 2016), case studies focus on gathering information about a specific object, event, or activity, such as a particular business unit or organization. In case studies, the case refers to the individual, group, organization, event, or situation the researcher is interested in. This research was conducted at PT. Rekatama Putra Gegana Aviation, with data collection based on interviews with predetermined informants. Engine maintenance in this study focuses on the CASA 212 aircraft with the code HC-B4MN-5AL. The calculation method used in the research is the Critical Chain Project Management (CCPM) method, compared with traditional methods to determine which method provides the best value for money. The research stages are depicted in the flow chart below.

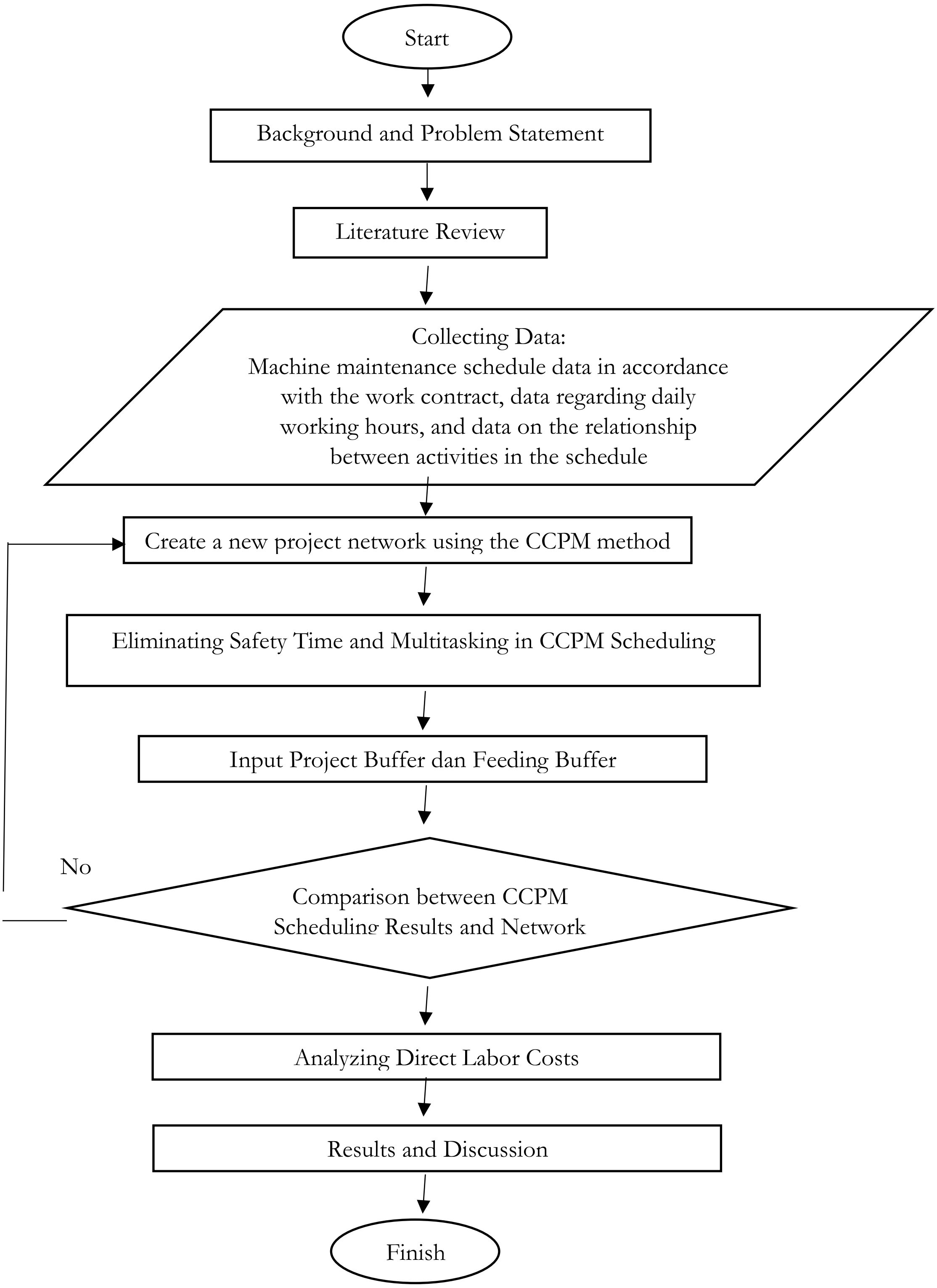


Figure 1. Research Stage

The tool used to process data in this study is Microsoft Project, utilized for processing CCPM calculations using data from the maintenance of the HC-B4MN-5AL propeller engine, as depicted in the image below:

Figure 2. Propeller Hartzel HC-B4MN-5AL on CASA 212 Aircraft

This study employs the Root Square Method (RSEM), which is akin to calculating 2 (two) standard deviations by inputting the initial duration (S) and the CCPM duration (A), each of which is 50% of the safe estimate. The size of the buffer can be determined by solving the equation as proposed by (Wirawan, 2017) below:

$$Buffer\ Size = 2 \times \sqrt{\left(\frac{S_1 - A_1}{2}\right)^2 + \left(\frac{S_2 - A_2}{2}\right)^2 + \cdots + \left(\frac{S_n - A_n}{2}\right)^2}$$

Figure 3. Buffer Size Equation

RESULT AND DISCUSSION

The initial step employed in this research involves the development of network planning by inventorying maintenance activities for the HC-B4MN-5A engine. The activities conducted include preparation, disassembly, cleaning & removal paint, visual inspection & dimensional check, non-destructive test, electroplating, repair/rework, painting, reassembly, testing & leakage check, static balance, marketing/final inspection, and delivery. After calculating the work activity durations, the subsequent step involves computation using Critical Chain Project Management.

The application of Critical Chain Project Management entails reducing the duration of each activity by 50% of the initial duration. This reduction aims to eliminate safety times, thereby addressing issues such as student's syndrome, Parkinson's Law, and Overestimated Activity Durations (Leach, 2014). The table below presents the calculation of activity durations:

Table 2. Calculation of Activity Duration Reduction

Num.	Activity	Activity Code	Previous Activities	Initial Duration (Working day)	CCPM Duration (Working day)	Type
1	Preparation	A	-	1	0,5	Work
2	Disassembly	B	A	5	2,5	Work
3	Cleaning & removal paint	C	B	14	7	Work
4	Visual Inspection & Dimensional Check	D	C	5	2,5	Work
5	Non-Destructive Test	E	C	7	7	Cost
6	Electro Plating	F	E	7	7	Cost
7	Repair/Rework	G	E	10	5	Work
8	Painting	H	G	11	5,5	Work
9	Reassembly	I	G	28	14	Work
10	Testing & Leakage Check	J	I	10	5	Work
11	Static Balance	K	J	5	2,5	Work
12	Marketing/Final Inspection	L	K	5	2,5	Work
13	Delivery	M	L	2	2	Cost

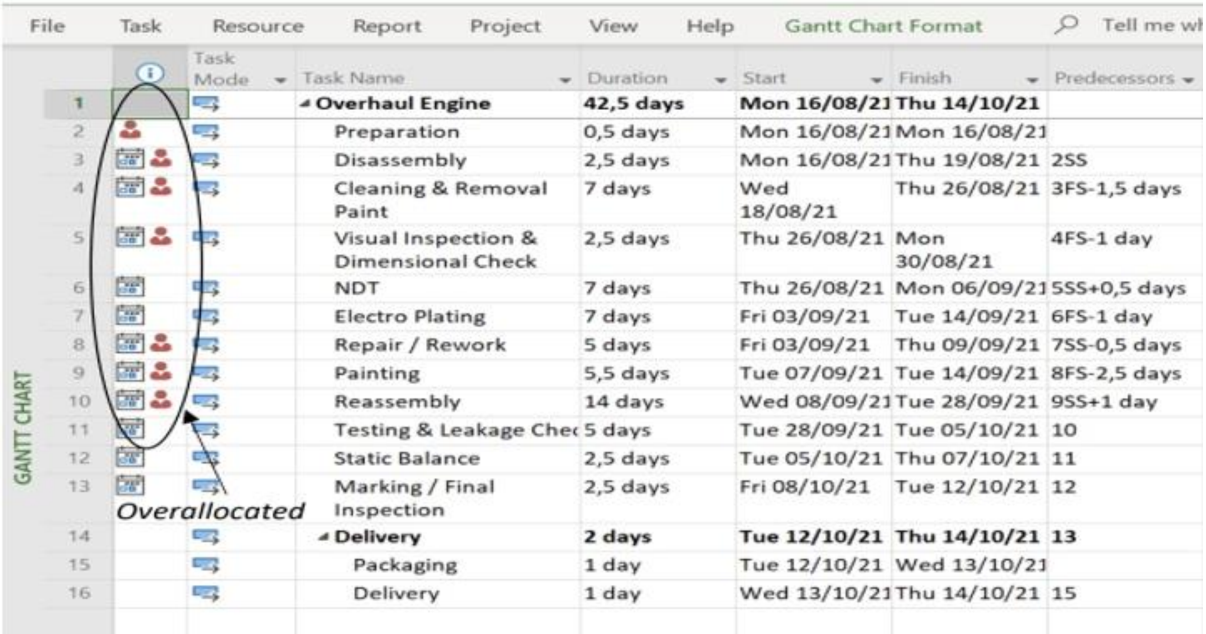
Activities subject to duration reduction are marked with the "work" type. "Work" refers to tasks based on available resources. On the other hand, "cost" tasks require specialized labor and payment with a package system. For instance, activities with codes E, F, and M are tasks with fixed durations, thus only the cost aspect is altered.

The next step involves eliminating multitasking in scheduling. Based on data from PT. RPG, a maximum of one type of worker can operate at a time, with a total of 5 individuals comprising 1 inspector, 2 mechanics, and 2 helpers. Following scheduling using the CCPM method, the total number of workers obtained is as follows, as illustrated in Figure 3 below:

	Resource Name	Type	Material	Initials	Group	Max.	Std. Rate	Ovt. Rate	Cost/Use	Accrue	Base Calendar
1	Inspektor	Work		I		1	Rp21,387/hr	Rp0/hr	Rp0	End	Standard
2	Mekanik	Work		M		2	Rp19,075/hr	Rp0/hr	Rp0	End	Standard
3	Helper	Work		H		2	Rp17,919/hr	Rp0/hr	Rp0	End	Standard
4	NDT	Cost		N						Prorated	
5	Electro Plating	Cost		E						Prorated	
6	Packaging	Cost		P						Prorated	
7	Delivery	Cost		D						Prorated	

Figure 4. Resource Sheet Microsoft Project CCPM Method Scheduling Results with Errors

Based on the diagram, errors are identified in the resources of Inspector, Mechanic, and Helper. These errors indicate overallocation of these resources, resulting in some workers performing two tasks that utilize the same resource simultaneously. As depicted in Figure 4 above:



	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1		Overhaul Engine	42,5 days	Mon 16/08/21	Thu 14/10/21	
2		Preparation	0,5 days	Mon 16/08/21	Mon 16/08/21	
3		Disassembly	2,5 days	Mon 16/08/21	Thu 19/08/21	2SS
4		Cleaning & Removal Paint	7 days	Wed 18/08/21	Thu 26/08/21	3FS-1,5 days
5		Visual Inspection & Dimensional Check	2,5 days	Thu 26/08/21	Mon 30/08/21	4FS-1 day
6		NDT	7 days	Thu 26/08/21	Mon 06/09/21	5SS+0,5 days
7		Electro Plating	7 days	Fri 03/09/21	Tue 14/09/21	6FS-1 day
8		Repair / Rework	5 days	Fri 03/09/21	Thu 09/09/21	7SS-0,5 days
9		Painting	5,5 days	Tue 07/09/21	Tue 14/09/21	8FS-2,5 days
10		Reassembly	14 days	Wed 08/09/21	Tue 28/09/21	9SS+1 day
11		Testing & Leakage Chec	5 days	Tue 28/09/21	Tue 05/10/21	10
12		Static Balance	2,5 days	Tue 05/10/21	Thu 07/10/21	11
13		Marking / Final Inspection	2,5 days	Fri 08/10/21	Tue 12/10/21	12
14		Delivery	2 days	Tue 12/10/21	Thu 14/10/21	13
15		Packaging	1 day	Tue 12/10/21	Wed 13/10/21	
16		Delivery	1 day	Wed 13/10/21	Thu 14/10/21	15

Figure 5. Types of Work Occurring Overallocated

Therefore, to address these errors, the maximum units of resources or workers for Inspector, Mechanic, and Helper need to be increased. After adding resources or workers for Inspector, Mechanic, and Helper, no more errors or overallocation occur in each type of task. The reduction of activity durations in this method increases the risk of delays. Hence, buffers or time cushions must be applied to prevent delays. Buffers are added to the activity times whose durations have been reduced, aiming to create a safer schedule. The calculation of buffers is provided in the table below:

Table 3. Buffer Calculation

Num.	Activity	Activity Code	Previous Activities	Initial Duration (Working day)	CCPM Duration (Working day)	(1) $\frac{S-A}{2}$	(2) $(\frac{S-A}{2})^2$
1	Preparation	A	-	1	0,5	0,25	0,0625
2	Disassembly	B	A	5	2,5	1,25	1,5625
3	Cleaning & removal paint	C	B	14	7	3,5	12,25
4	Visual Inspection & Dimensional Check	D	C	5	2,5	1,25	1,5625
5	Non-Destructive Test	E	C	7	7	0	0
6	Electro Plating	F	E	7	7	0	0
7	Repair/Rework	G	E	10	5	2,5	6,25

8	Painting	H	G	11	5,5	2,75	7,5625
9	Reassembly	I	G	28	14	7	49
10	Testing & Leakage Check	J	I	10	5	2,5	6,25
11	Static Balance	K	J	5	2,5	1,25	1,5625
12	Marketing/Final Inspection	L	K	5	2,5	1,25	1,5625
13	Delivery	M	L	2	2	0	0
			Total				87,625

Based on the data calculations above, the project buffer is:

Project buffer =

$$=2 \text{ x } \sqrt{\sum_{i=1}^{n}(\frac{S_n - A_n}{2})^2}$$

$$= 2 \text{ x} \sqrt{87{,}625}$$

= 2 x 9,36

= 18,7

= rounded up to 19 working days

From the data above, the next step involves columns (1) and (2), which will be used in the subsequent calculation to determine the Feeding Buffer and Project Buffer. These buffers serve different purposes; the feeding buffer is placed at the end of the non-critical chain, while the project buffer is placed at the end of the activity. Below is the CCPM scheduling data:

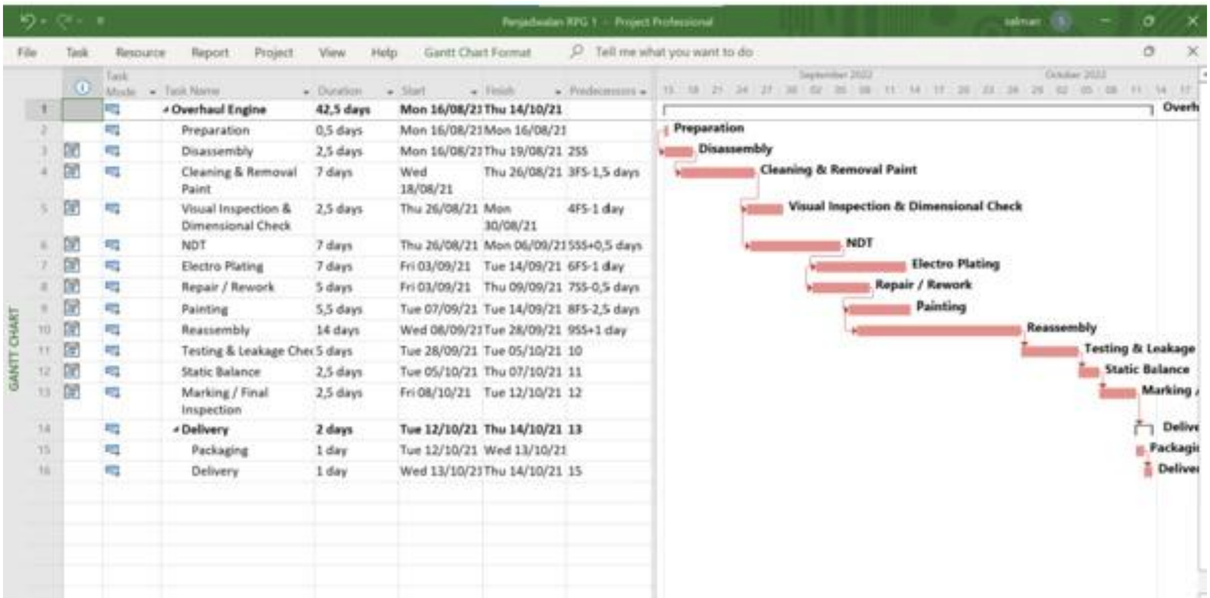


Figure 6. Feeding Buffer

Information

Non critical chain

Critical chain

Inserting the feeding buffer aims to secure the non-critical chain from delays to avoid jeopardizing the critical chain. However, since no non-critical chain was found, there is no addition of a feeding buffer. After calculating the feeding buffer, from the results of Table 3 above, a project buffer of 19 working days is obtained, which is incorporated into the CCPM scheduling. Consequently, the total duration of scheduling with the CCPM method becomes 61.5 working days or 62 working days. The next step is to identify the critical path, starting with forward calculations as shown in the table below:

Table 4. CCPM Forward Calculation

Num.	Activity	Activity Code	CCPM Duration (Working day)	Predecessor	Forward Calculation	
					ES	EF
1	Overhaul Engine		42,5			
2	Preparation	A	0,5		0	0,5
3	Disassembly	B	2,5	2SS	0	2,5
4	Cleaning & removal paint	C	7	3FS-1,5 day	1	8
5	Visual Inspection & Dimensional Check	D	2,5	4FS-1 day	7	9,5
6	Non-Destructive Test	E	7	5SS+0,5 day	7,5	14,5
7	Electro Plating	F	7	6FS-1 day	13,5	20,5
8	Repair/Rework	G	5	7SS-0,5 day	13	18
9	Painting	H	5,5	8FS-2,5 day	15,5	21
10	Reassembly	I	14	9SS+1 day	16,5	30,5
11	Testing & Leakage Check	J	5	10FS	30,5	35,5
12	Static Balance	K	2,5	11FS	35,5	38
13	Marketing/Final Inspection	L	2,5	12FS	38	40,5
14	Delivery	M	2	13FS	40,5	42,5

After performing forward calculations to obtain ES (Early Start) and EF (Early Finish), the process continues with backward calculations to determine the values of LS (Latest Start) and LF (Latest Finish). Below is the backward calculation in the table:

Table 5. CCPM Countdown

Num.	Activity	Activity Code	CCPM Duration (Working day)	Predecessor	Countdown	
					LS	LF
1	Overhaul Engine		42,5			
2	Preparation	A	0,5		0	0,5
3	Disassembly	B	2,5	2SS	0	2,5
4	Cleaning & removal paint	C	7	3FS-1,5 day	1	8
5	Visual Inspection & Dimensional Check	D	2,5	4FS-1 day	7	9,5
6	Non-Destructive Test	E	7	5SS+0,5 day	7,5	14,5
7	Electro Plating	F	7	6FS-1 day	13,5	20,5
8	Repair/Rework	G	5	7SS-0,5 day	13	18
9	Painting	H	5,5	8FS-2,5 day	15,5	21
10	Reassembly	I	14	9SS+1 day	16,5	30,5
11	Testing & Leakage Check	J	5	10FS	30,5	35,5
12	Static Balance	K	2,5	11FS	35,5	38
13	Marketing/Final Inspection	L	2,5	12FS	38	40,5
14	Delivery	M	2	13FS	40,5	42,5

Next, the total float is calculated by the difference LF-EF, then it can be determined that the critical path has a float of 0 (zero), thus it can be explained that:

a) Activities with a total float = 0 are activities A-B-C-D-E-F-G-H-I-J-K-L-M, so the path passing through these activities is critical.
b) The total duration for completing the maintenance activities for engine HC-B4MN-5AL using the network planning scheduling method is 42.5 working days.
c) The obtained results are consistent with the scheduling using Microsoft Project.

After calculating the float, the direct costs are computed based on the data collected regarding labor wages applicable to the maintenance activities for engine HC-B4MN-5AL. It is known that the wage rate per hour for Inspector is Rp21,387, for Mechanic is Rp19,075, and for Helper is Rp17,919. Below are the direct labor costs with CCPM scheduling:

	Task Name	Fixed Cost	Fixed Cost Accrual	Total Cost	Baseline	Variance	Actual	Remaining
1	**Overhaul Engine**	**Rp0**	**Prorated**	**Rp67,414,698**	**Rp0**	**Rp67,414,698**	**Rp0**	**Rp67,414,698**
2	Preparation	Rp0	Prorated	Rp408,667	Rp0	Rp408,667	Rp0	Rp408,667
3	Disassembly	Rp0	Prorated	Rp2,043,335	Rp0	Rp2,043,335	Rp0	Rp2,043,335
4	Cleaning & Removal Paint	Rp0	Prorated	Rp5,721,338	Rp0	Rp5,721,338	Rp0	Rp5,721,338
5	Visual Inspection & Dimensional Check	Rp0	Prorated	Rp2,043,335	Rp0	Rp2,043,335	Rp0	Rp2,043,335
6	NDT	p20,000,000	Prorated	Rp20,000,000	Rp0	Rp20,000,000	Rp0	Rp20,000,000
7	Electro Plating	Rp3,000,000	Prorated	Rp3,000,000	Rp0	Rp3,000,000	Rp0	Rp3,000,000
8	Repair / Rework	Rp0	Prorated	Rp4,086,670	Rp0	Rp4,086,670	Rp0	Rp4,086,670
9	Painting	Rp0	Prorated	Rp4,495,337	Rp0	Rp4,495,337	Rp0	Rp4,495,337
10	Reassembly	Rp0	Prorated	Rp11,442,676	Rp0	Rp11,442,676	Rp0	Rp11,442,676
11	Testing & Leakage Chec	Rp0	Prorated	Rp4,086,670	Rp0	Rp4,086,670	Rp0	Rp4,086,670
12	Static Balance	Rp0	Prorated	Rp2,043,335	Rp0	Rp2,043,335	Rp0	Rp2,043,335
13	Marking / Final Inspection	Rp0	Prorated	Rp2,043,335	Rp0	Rp2,043,335	Rp0	Rp2,043,335
14	**Delivery**	**Rp0**	**Prorated**	**Rp6,000,000**	**Rp0**	**Rp6,000,000**	**Rp0**	**Rp6,000,000**
15	Packaging	Rp3,500,000	Prorated	Rp3,500,000	Rp0	Rp3,500,000	Rp0	Rp3,500,000
16	Delivery	Rp2,500,000	Prorated	Rp2,500,000	Rp0	Rp2,500,000	Rp0	Rp2,500,000

Figure 7. Initial Direct Labor Costs

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	Task Name	Fixed Cost	Fixed Cost Accrual	Total Cost	Baseline	Variance	Actual	Remaining
1	**Overhaul Engine**	**Rp0**	**Prorated**	**Rp60.378.375**	**Rp0**	**Rp60.378.375**	**Rp0**	**Rp60.378.375**
2	Preparation	Rp0	Prorated	Rp333.813	Rp0	Rp333.813	Rp0	Rp333.813
3	Disassembly	Rp0	Prorated	Rp1.669.063	Rp0	Rp1.669.063	Rp0	Rp1.669.063
4	Cleaning & Removal Paint	Rp0	Prorated	Rp4.673.375	Rp0	Rp4.673.375	Rp0	Rp4.673.375
5	Visual Inspection & Dimensional Check	Rp0	Prorated	Rp1.669.063	Rp0	Rp1.669.063	Rp0	Rp1.669.063
6	NDT	Rp20.000.000	Prorated	Rp20.000.000	Rp0	Rp20.000.000	Rp0	Rp20.000.000
7	Electro Plating	Rp3.000.000	Prorated	Rp3.000.000	Rp0	Rp3.000.000	Rp0	Rp3.000.000
8	Repair / Rework	Rp0	Prorated	Rp3.338.125	Rp0	Rp3.338.125	Rp0	Rp3.338.125
9	Painting	Rp0	Prorated	Rp3.671.938	Rp0	Rp3.671.938	Rp0	Rp3.671.938
10	Reassembly	Rp0	Prorated	Rp9.346.750	Rp0	Rp9.346.750	Rp0	Rp9.346.750
11	Testing & Leakage Chec	Rp0	Prorated	Rp3.338.125	Rp0	Rp3.338.125	Rp0	Rp3.338.125
12	Static Balance	Rp0	Prorated	Rp1.669.063	Rp0	Rp1.669.063	Rp0	Rp1.669.063
13	Marking / Final Inspection	Rp0	Prorated	Rp1.669.063	Rp0	Rp1.669.063	Rp0	Rp1.669.063
14	**Delivery**	**Rp0**	**Prorated**	**Rp6.000.000**	**Rp0**	**Rp6.000.000**	**Rp0**	**Rp6.000.000**
15	Packaging	Rp3.500.000	Prorated	Rp3.500.000	Rp0	Rp3.500.000	Rp0	Rp3.500.000
16	Delivery	Rp2.500.000	Prorated	Rp2.500.000	Rp0	Rp2.500.000	Rp0	Rp2.500.000

Figure 8. CCPM Scheduling Direct Labor Costs

Based on the initial duration calculation and labor costs, the total duration obtained is 76 working days with a total cost of Rp. 67,414,698. With CCPM scheduling and labor costs, the total duration is 61.5 working days or 62 working days with a total cost of Rp. 60,378,375. Based on the previous calculations and analysis, the size of the project buffer is determined to be 18.7 working days. Subsequently, this result will be divided into 3 (three) equal parts that will determine their respective areas, as shown in the table below:

Table 6. Project Buffer Duration Usage Percentage

Buffer Consumption Zone	Project Buffer (Working Days)	Description
0% - 33%	18,7	<6,358
34% - 66%	18,7	6,358 to 12,529
67% - 100%	18,7	>12,529

The utilization of the project buffer duration can provide information for the implementing parties regarding the actions related to control during the activity implementation, especially in controlling the risks that may cause delays in the activities. By mitigating the risks, the usage of the project buffer duration can be directly reduced. Table 6 identifies when the implementing parties need to take action, particularly if the buffer usage has reached the red zone.

The scheduling results using the Critical Chain Project Management (CCPM) method reveal its critical path, where the critical path is the path that must not be delayed, as indicated by a Total Float (TF) calculation equal to zero, as it would impact other activities. The calculated results based on the network design indicate the critical path in the CCPM network design activity code, namely activities A-BC-D-E-F-G-H-I-J-K-L-M. The path passing through these activities is critical. Below is the network planning CCPM diagram as shown in the image below:

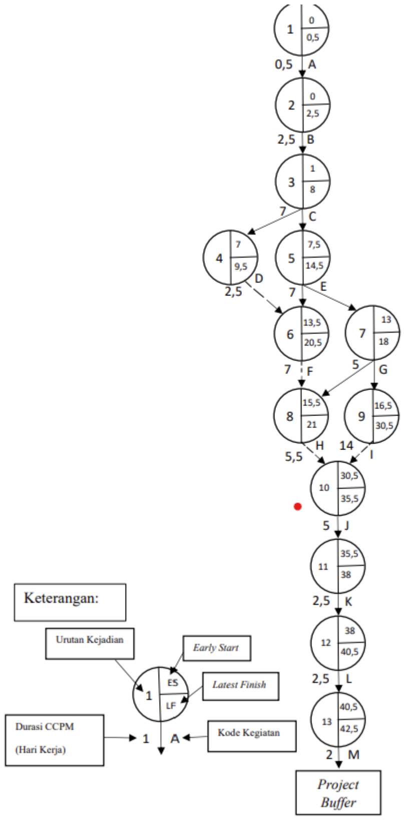

Figure 9. CCPM Network Planning Diagram

Findings:

1) The duration of activities resulting from a 50% reduction in time to address human behaviors such as student's syndrome, Parkinson's law, and overestimated activity durations is 42.5 working days.
2) The addition of Feeding Buffer or safe time for non-critical paths is 0 working days, or equivalent to no Feeding Buffer addition, as there are no non-critical activities in the scheduling using the CCPM method.

3) The addition of Project Buffer or additional time at the end of all activities is 18.7 working days. This additional time aims to secure activities from delays in each activity that may cause losses.
4) The total duration of activities is the result of points 1-3, where in scheduling using the CCPM method, it is 62 days based on the Work Breakdown Structure. Below is the Gantt Chart for the CCPM Scheduling.

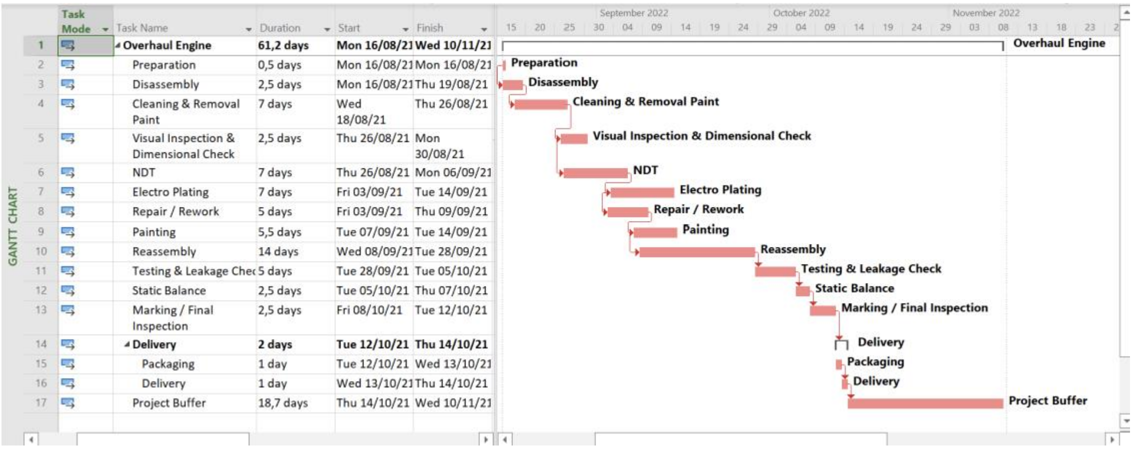

Figure 10. Gantt Chart CCPM method scheduling

5) The total labor cost for scheduling using the CCPM method amounts to Rp. 60,378,375.
6) There are 1 Inspector, 2 Mechanics, and 2 Helpers.
7) Additional Resource Buffer of 2 Inspectors, 4 Mechanics, and 4 Helpers is allocated to critical activities to address multitasking issues.
8) The total workforce comprises 3 Inspectors, 6 Mechanics, and 6 Helpers.

CONCLUSION

Based on the data processing results from the maintenance activities of the HC-B4MN-5AL engine, several points can be concluded as follows. The total duration of activities obtained in the initial scheduling was 76 working days, with a total direct labor cost of Rp. 67,414,698. Meanwhile, the total duration of activities obtained in the scheduling using the CCPM method was 62 working days, with a total direct labor cost of Rp. 60,378,375. From the results of both scheduling approaches, it can be inferred that the CCPM method will result in a faster duration by 14 days. Consequently, there is an efficiency of Rp. 7,036,323. The utilization of the CCPM method is capable of reducing the time required for maintenance activities; however, the CCPM method needs to be further scrutinized regarding the occurrence of critical paths.

Recommendations for the company include the necessity of initial planning during the execution of maintenance work to have a backup plan in case of delayed goods or when component stocks have not arrived, thus not altering the initial schedule during planning. Preparation should be made from document processing to the purchase of engine spare parts needed for maintenance. For future researchers, in the application of the CCPM method, productivity calculations for each activity can be conducted to ensure accurate reduction of activity duration based on field conditions. Additionally, risk analysis should be added to buffer management to determine the extent of buffer usage and required actions. Cost analysis can also be enhanced by including material, service, and equipment costs.

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