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Analysis of Train Maintenance Capacity with Discrete Event Simulation Modeling: Case Study of Train Depot

Dela Safitri Kartikaningtyas[1a◆], Sri Raharno[1b], Vani Virdyawan[1c]

Abstract. *Indonesian Railways is facing a significant increase in passenger volume year by year, along with the planned arrival of new trains. An expansion of maintenance capacity at the Train Depot is needed due to the current limitations in resources to face the increasing maintenance demands. This research aims to evaluate the current maintenance capacity and provide recommendations for increasing the maintenance capacity with the utilization of discrete event simulation modeling to simulate the train maintenance process based on the current conditions. The simulation considers several scenarios involving adjustments in the number of trains maintained, work shifts, the number of maintenance teams, and maintenance equipment. By enhancing the maintenance capacity at the Train Depot, Indonesian Railways will be able to prevent potential lossess of passenger transport revenue. These recommendations are expected to serve as a basis for decision-making in developing a master plan of train maintenance in the future.*

Keywords: *discrete event simulation; maintenance capacity; train maintenance*

I. INTRODUCTION

Indonesia has consistently experienced an increase in railway passenger volumes over the years. The passenger volume has shown a relatively stable increase from 2017 to 2023, and it is projected to continue rising in 2024. To accommodate this growing demand, Indoneswian Railways plans to procure new trains in stages from 2023 to 2026 and the Train depot is responsible for the maintenance of passenger trains and coaches. The objective of maintenance is to preserve a system by preventing failures and breakdowns, while capacity enhancement serves to improve the quality, productivity, and efficiency of maintenance operations (Marais & Saleh, 2009; Rotab Khan & Darrab, 2010).

In a previous study conducted by Abril et al., several methods for evaluating railway capacity were identified, including analytical methods, optimization methods, and simulation methods (Abril et al., 2008). Simulation has the potential to reduce both time and costs, enabling the assessment of system modifications without the necessity for direct experimentation (Corrotea et al., 2024; Iwata & Mavris, 2013).

Discrete Event Simulation (DES) is often used to model dynamic and complex systems, such as manufacturing systems, computer networks, healthcare services, and transportation (Iwata & Mavris, 2013). DES can also be employed to study the behavior of processes within a system and to detect any deviations in system behavior. DES is frequently integrated with optimization algorithms to solve complex problems and enhance system performance, such as optimizing maintenance schedules and workforce planning (Corrotea et al., 2024).

There is specialized software designed for DES modeling, which is used to create simulation models that replicate real-world systems for the purpose of validating and comparing alternatives (Alwadood, Z., Kassim, I., & Rani, 2010). This software is beneficial for system analysis, efficiency improvement, process visualization, cost savings, and risk reduction (Mohhid, 2007).

This discrete event simulation modeling software has been utilized in research across various fields. Mohhid applied it to modeling and simulation of manufacturing systems; Na used it for terminal operations process simulation;

[1] Mechanical Engineering Department, Faculty of Mechanical And Aerospace Engineering, Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40116, Indonesia.

[a] email: 23122016@mahasiswa.itb.ac.id
[b] email: harnos@itb.ac.id
[c] email: vani.virdyawan@itb.ac.id
◆ corresponding author

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Alwadood employed it for technician scheduling in maintenance departments; Rudi Zelmido applied it in aeronautical system simulation; Muhammad Utomo used it for avtur fuel supply chain simulation; Meliala applied it in analyzing queuing systems in health insurance; and Shargawi used it for optimizing machine maintenance processes (Alwadood, Z., Kassim, I., & Rani, 2010; Br Meliala, C. D., Amri, A., & Syukriah, 2019; Mohhid, 2007; Na U.J., 2009; Shargawi, A. A., Abed, S. Y., & Knopp, 2003; Utomo, 2013; Zelmido, 2013).

Given the projected increase in passenger volume and the addition of the new trains over 2023-2026, the maintenance workload is expected to rise significantly. However, the current maintenance resource of Train Depot remains unclear. Therefore, further research is needed to determine the depot's maximum maintenance capacity using a simulation model based on current conditions.

The objectives of this study are to develop a simulation model of the passenger train maintenance process based on the current maintenance resources at the Train Depot, to determine the maximum number of trains that can be maintained with these resources, and to propose alternative solutions and the associated costs for enhancing maintenance capacity at the depot.

This study will focus on simulating the maintenance process based on the current resources (maintenance tracks, work shifts, maintenance teams, and maintenance equipment) at Depo Kereta SMC, using discrete event simulation software. The simulation will consider various scenarios involving adjustments in the number of trains maintained, work shifts, the number of maintenance teams, and maintenance equipment, with the aim of optimizing the depot's maintenance capacity.

II. Research Method

This study used a systematic approach to achieve its objectives. The research begins with a literature review, followed by the identification of the current conditions, problem identification, data collection, data processing and analysis, simulation model development, verification and validation of the simulation model, creation of simulation scenarios, and finally, the formulation of recommendations for capacity enhancement as seen in Figure 1.

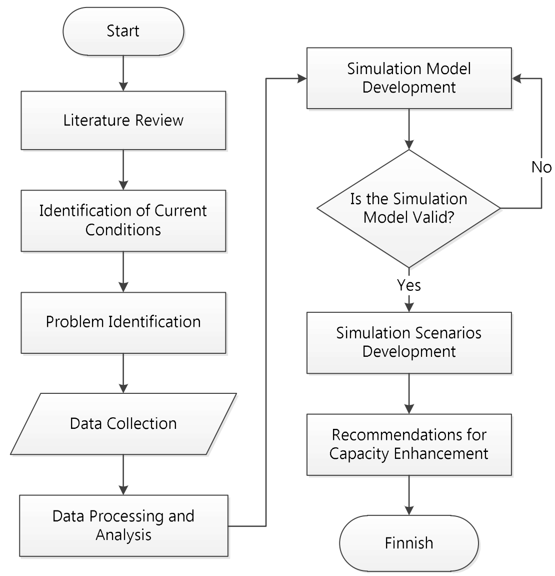

Figure 1. Research methodology flowchart

The literature review involves gathering information from various sources, including books, research journals, specific websites, national and international standards, as well as a comprehensive analysis of related previous studies. The purpose of the literature review is to acquire information from diverse sources to support the completion of the research. This review includes concepts and types of railway maintenance, particularly for trains, effective maintenance management methods including resource allocation, methods for measuring and enhancing maintenance capacity, and discrete event simulation.

The next step is to identify the current conditions regarding various aspects, including maintenance resources, maintenance equipment, maintenance materials, maintenance budget, maintenance methods, and the maintenance environment at the Train Depot and then identify the main problem that need to be solve within the research problem limitations.

After identifying the current conditions at the Train Depot, data collection is conducted. This stage involves discussing the data collection process, which includes both direct observation and discussions with relevant stakeholders. The important data that need to be collected are train maintenance process, current train maintenance resources including number of trains maintained, work shifts, the number of maintenance teams, and maintenance equipment, also the duration of maintenance process which come from direct observation.

The data processing in this research begins with classifying the data based on the type and maintenance cycle of the trains, identifying the amount of observational data, visualizing the data, fitting the distribution of maintenance process duration, performing analitical calculations for maintenance capacity, and projecting the addition of new trains at the Train Depot. This is followed by the creation of simulation inputs and models, verification and validation of the model, scenario development, and finally, formulating recommendations for enhancing the maintenance capacity at the Train Depot.

Next is to develop a simulation model by creating a block diagram of the maintenance process, inputting variables into the simulation model, determining the potential probability distributions for each input variable, and configuring the model across various alternatives to calculate relevant outputs. Before running the simulation model with various alternative scenarios, it is essential to first verify and validate the model to ensure that the simulation results closely match or even replicate the actual data. Subsequently, an output analysis and evaluation are conducted from the simulation results.

From the analysis of maintenance capacity enhancement at the Train Depot, recommendations are then formulated based on the simulation scenarios developed in the previous stage. These recommendations can be used to plan more effective actions to ensure the reliability and availability of trains through improved capacity at the Train Depot. This aims to enhance the productivity and efficiency of train maintenance.

III. Result and Discussion

Existing Condition of Train Depot: Maintenance resource and time allocation of train maintenance in Train Depot as shown in Table 1. The availability of maintenance resources currently at the Train Depot serves as input for developing the train maintenance process simulation model based on existing conditions. Given the limitations of these resources, they will be used to calculate both the existing capacity and the maximum maintenance capacity that the Train Depot can accommodate.

Table 1. Existing condition of Train Depot

Parameter	Value
Number of trains	136 coaches
Number of trains maintain	544 coach maintenance/ year
Maintenance track	1 track
Available working days	313 days/year
Work hours	7 hours/shift
Maintenance Teams	1 mechanical team, 1 interior team, 2 electrical team, 1 quality control
Maintenance Equipment	1 set mechanical, 1 set interior team, 2 set electrical, 1 set final check equipment

Time Between Train Arrival: Time Between Train Arrival data is derived from the number of trains that can be maintained based on the existing maintenance resources, which is 2 coaches per day. Therefore, the train arrival interval in the "Create" module is set to a constant rate of 2 coaches per day, resulting in approximately 544 coaches maintenance per year. The entity that enters from the "Create" module is “Coach” that moves through the system, interacts with resources, and undergoes the maintenance process in this maintenance simulation model.

Train Characteristics: Each coach requires 3-month maintenance (P3) twice and 6-month maintenance (P6) twice, totaling 4 maintenance cycles per year at the Train Depot. These characteristics are established by assigning attributes and variables to each entity that enters the system. The type of maintenance is an attribute assigned to each coach, determined by the categories of train and the maintenance cycle. As a result, four distinct attributes are formed: 6-month coach maintenance, 3-month coach maintenance, 6-month power maintenance, and 3-month power maintenance. While variables are assigned to each maintenance type attribute, generating output values from the simulation will calculate the quantity, time, and cost for each entity and variable. This assignment is implemented using the "Assign" module within the simulation model. Demand proportion of each train categories for each maintenance cycle shown in Table 2.

Table 2. Distribution fitting result

Train Category	Maintenance Cycle	
	P6	P3
Passenger coach	43%	43%
Power coach	7%	7%

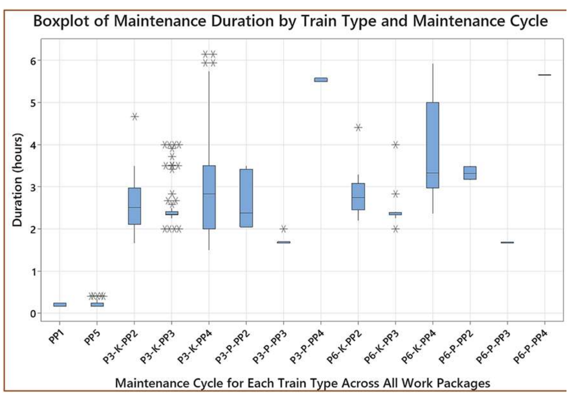

Figure 2. Boxplot of maintenance duration data

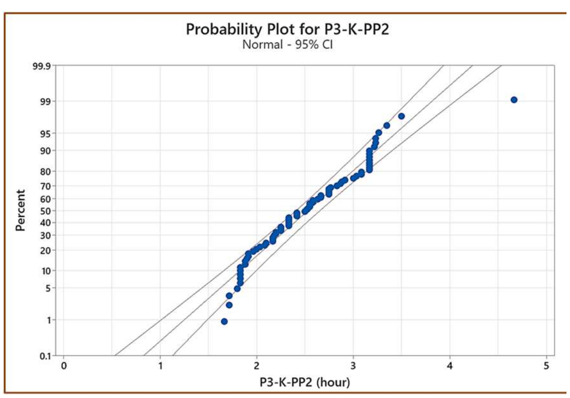

Figure 3. Probability plot from duration of P3-K-PP2

Train Maintenance Process: The maintenance process at the Train Depot is organized into the following work packages: Preparation Work Package (PP1), Underframe Mechanical Work Package (PP2), Interior, Exterior, and Sanitation Work Package (PP3), Electrical Work Package (PP4), and Final Inspection Work Package (PP5). Each of these work packages has its own duration and resource utilization, including both maintenance teams and equipment. Additionally, in PP2, PP3, and PP4, the duration of the maintenance process varies depending on the type of train and the maintenance cycle.

Train Maintenance Duration: The duration to complete the maintenance process was obtained based on observations conducted over a 3-month period at the Train Depot. The initial step in processing the maintenance duration data involves visualizing the data using a boxplot to examine the data distribution visually, as shown in Figure 2.

Subsequently, distribution fitting was performed using the Anderson-Darling method to assess the suitability of the data against specific distributions. According to Tsarouhas and Alwadood, the duration required to restore a system from a non-operational state to full operation typically follows a Weibull or Lognormal distribution (Alwadood, Z., Kassim, I., & Rani, 2010; Tsarouhas, 2018). This distribution fitting is conducted to obtain the distribution parameters of the maintenance process duration, which will later be used as input in the simulation model. For example, the distribution fitting results for the 3-month train maintenance duration in work package PP2 (P3-K-PP2) are shown in Figure 3.

The Q-Q plot in Figure 3 shows a probability plot for the variable P3-K-PP2 with the assumption of a normal distribution and a 95% confidence interval. This plot is used to assess the normality of the data distribution. The data points generally follow the reference line (the straight line) closely, particularly in the middle range. This indicates that the distribution is reasonably consistent with a normal distribution. AD values and distribution parameters obtained from the distribution fitting results are presented in Table 3.

Table 3. Distribution fitting result

Distribution type	AD Value	Parameter		
		Location	Shape	Scale
Normal	0.713	2.53203		0.55117
Weibull	0,822		4.60614	2.75357
Lognormal	0.657	0.90647		0.21288

Based on the results in Table 3., using the central limit theorem approach and the second smallest AD value, the duration of P3-K-PP2 follows a Normal Distribution. Central limit theorem states that the distribution of sample means will approximate a normal distribution as the sample size becomes sufficiently large, regardless of the original population distribution. This data processing will also be conducted for other work packages, encompassing all types of trains and each maintenance cycle.

Train Addition Projections: The Train Depot manages 136 coaches with requires four times maintenance per year for each coach. This results in a total of 544 coaches maintenance per year. Given the available working days-313 days per year-and the depot's current capacity to perform maintenance on 2 coaches per day, the total maintenance capacity is 626 coaches maintenance per year. Consequently, the Train Depot has the potential to conduct an additional 82 coaches maintenance per year, or a maximum of 20 additional trains that can be maintained.

Based on the projected arrival of new coaches by 2026, which is estimated to be 9% of the total number of coaches currently owned by Indonesian Railways, the Train Depot is expected to receive an additional 56 new trains soon. Of these 56 new trains, the Train Depot will only be able to maintain 20 trains with its current maintenance resources. This leaves 36 trains that will not be accommodated by the depot's maintenance capacity. Therefore, it is crucial to expand the maintenance capacity to accommodate this future growth.

Potential Revenue Loss: For the train that cannot be accommodated for maintenance, there is a potential revenue loss due to the trains being unfit for operation because can not undergoing the necessary maintenance. The calculation of potential revenue loss is based on the daily revenue generated per train, assuming a passenger occupancy rate of 80% for a total of 50 seats in one executive class train, and an operational coefficient of 85% for the 36 trains that could not be maintained at the Train Depot. Consequently, the potential revenue loss could

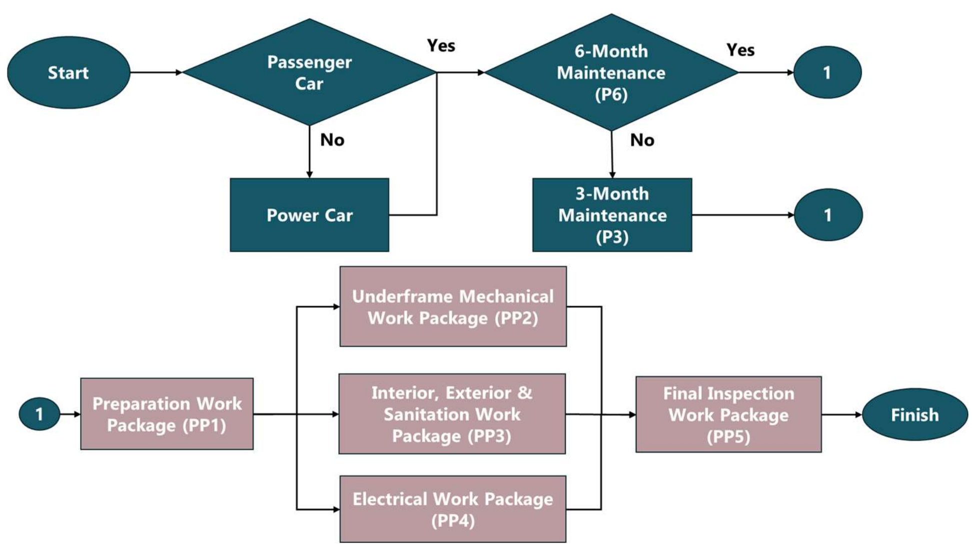

Figure 4. Flowchart of simulation model

amount to IDR 190 billion per year, or 1.9% of the passenger train revenue for the year 2023, if the maintenance capacity at the Train Depot is not expanded.

Simulation Model: The simulation model is developed based on the train maintenance process at the Train Depot as illustrated in Figure 4.

The simulation initiates with the introduction of a train into the maintenance system as an entity. The train's category and maintenance cycle are then determined, followed by the initiation of the PP1, then PP2, PP3 and PP4 simultaneously, then continue to complete PP5 until the train is ready for operation. The successfully developed simulation model of train maintenance process at the Train Depot is presented in Figure 5.

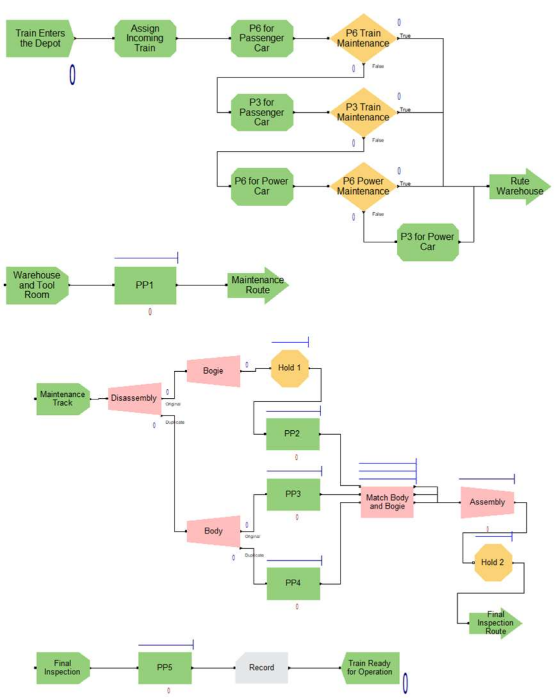

Figure 5. Simulation model of train maintenance

As shown in Figure 5, during the process of PP1, the train interacts with maintenance resources, including a team of mechanics, an interior team, and an electrical team. The logic for resource utilization in the simulation model follows a seize-delay-release pattern. Next, the disassembly process is carried out, separating the lower frame (bogie) from the upper frame (body) of the train. The mechanical work package for the lower frame, or PP2, is performed on the bogie, while the interior work package, PP3, and the electrical work package, PP4, are conducted on the train body in parallel, utilizing different teams and equipment for each work package. Once PP2, PP3, and PP4 are completed, the bogie and body are reassembly before proceeding to the final inspection work package, or PP5.

When the designed simulation model functions as intended, aligning with the design outlined in Figure 4. Therefore, it can be concluded that the simulation model has been successfully verified. The next step is to validate the simulation model.

Model Validation: Validation is conducted to ensure that the simulation model functions as it does in the actual system (Alwadood, Z., Kassim, I., & Rani, 2010; Kelton et al., 2015). The commonly accepted tolerance for validation is 10%, meaning that the simulation output should not deviate by more than 10% from the actual system output (Alwadood, Z., Kassim, I., & Rani, 2010; Anderson, D.R., Sweeney, D.J. and Williams, 2005). The simulation model validation is carried out in two stages. The first stage involves comparing the input values, output values, and the number of trains per category in each

Table 4. Comparation result of first validation

Category	Descrip-tion	Actual Data	Simula-tion Result	Error
Number of Train	Input	544	544	0%
	Output	544	544	0%
Passenger Car	P3	236	236	0%
	P6	236	236	0%
Power Car	P3	36	36	0%
	P6	36	36	0%

Table 5. Comparation result of second validation

Train Category	Mainte-nance Cycle	Actual Data	Simulation Result	Differ-ence
Passenger Car	P3	3.491	4.269	22%
	P6	4.218	4.720	12%
Power Car	P3	5.946	5.177	13%
	P6	6.073	5.530	9%

maintenance cycle. Equation 1 is utilized to calculate the percentage error during the validation phase (Liong, C. Y., & Loo, 2009).

$$Error = \frac{|Output(simulation) - Output(actual)}{Output(actual)} x\ 100\% \quad \ldots\ldots(1)$$

Output (simulation) refers to the number of entities processed by the simulation model, while the actual output represents the number of entities observed in the real system. Comparation result of the first validation step shown in Table 4.

Based on the results of 10 simulation replications on Table 4., it was found that the input and output values generated by the simulation model were consistent with the actual data.

The second stage of validation is performed by comparing the actual process duration with the simulated process duration. The process time used as input for the simulation model is based on a Normal Distribution parameter, selected due to having the second smallest AD value in the distribution fitting results, which is not significantly different from the smallest AD value.

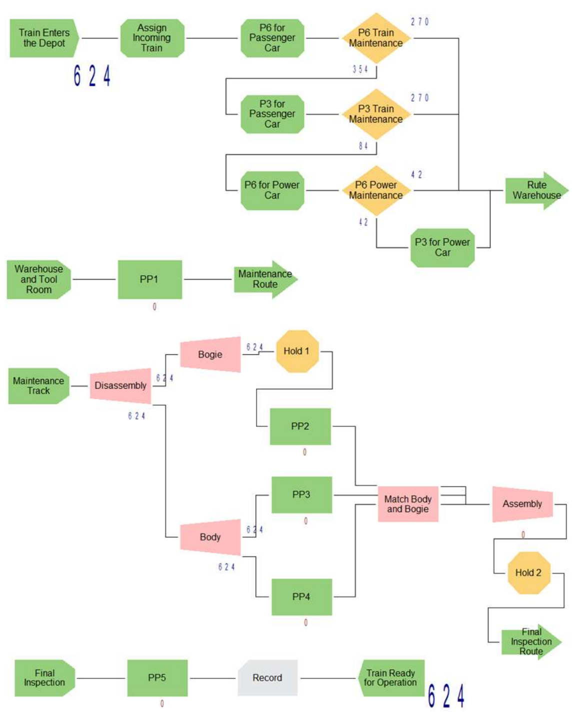

Figure 6. Simulation result of scenario 1

Comparation result of the second validation step shown in Table 5.

According to the results of the second validation shown in Table 5, the simulation model can be considered valid, with the difference between the simulated time data and the actual data ranging from 9% to 22%. After validating the simulation model based on existing conditions, the next step is to develop scenarios to provide recommendations for enhancing the Train Depot's maintenance capacity.

Simulation Scenario: Four simulation scenarios were developed as proposed recommendations. These scenarios were created based on the addition of parameters outlined in Table 6., and the simulation results for Scenario 1 are presented in Figure 6.

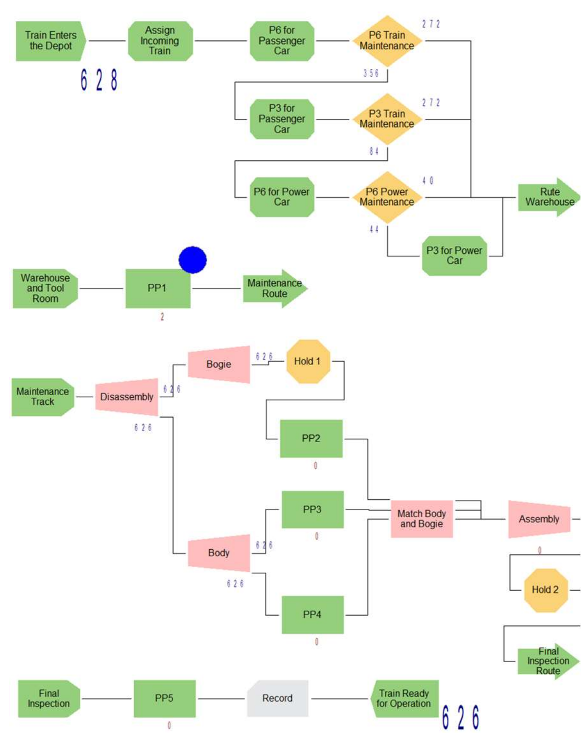

Figure 7. Simulation of additional train in scenario 1

The simulation results from Figure 7. indicate that not all trains can be fully maintained within the current time allocation and available resources if more than 20 trains are added. Simulation results for Scenario 2 are presented in Figure 8.

Tabel 6. Simulation scenario

Parameter	Existing Condition	Addition of Parameters in Scenario 1	2	3	4
Number of trains	136 coaches	Max 156 coaches	192 coaches	Max. 225 coaches	Max. 295 coaches
Number of train maintenance/year	544 train maintenance/year	624 train maintenance/year	768 train maintenance/year	900 train maintenance/year	1180 train maintenance/year
Maintenance track	1 track	-	-	-	1 track
Electric lifting jack	1 set	-	-	-	1 set
Work Shift	1 shift, 7 hours/day	-	-	1 shift, 7hours/day	-
Maintenance team	Mechanic Team: 1 Interior Team: 1 Electric Team: 1 QC Team: 1	-	Mechanic Team: 1	Mechanic Team: 1 Interior Team: 1 QC Team: 1	Mechanic Team: 1 Interior Team: 1 Electric Team: 1
Maintenance Equipment	Mechanics: 1 Interior: 1 Electric: 2 Final Inspection: 1	-	Mechanic: 1 set	-	Mechanic: 1 set Interior: 1 set Electric: 1 set
Details of additional costs per year	Employee		✓	✓	✓
	Equipment		✓		✓
	Overhead			✓	✓
	Electric Lifting Jack Investment				✓
	Maintenance Track Investment (2 Cars)				✓
	Overcapping Investment (2 Cars)				✓

The increase in the number of trains serviced in Scenario 2 is significant, aligned with the gradual arrival of new trains between 2023 and 2026, during which the Train Depot is projected to receive 56 additional trains. In this scenario, the estimated additional costs are moderate, with a substantial increase in capacity. However, by adding only one maintenance team, the wait time between trains increases, potentially reducing the availability rate of trains in this scenario.

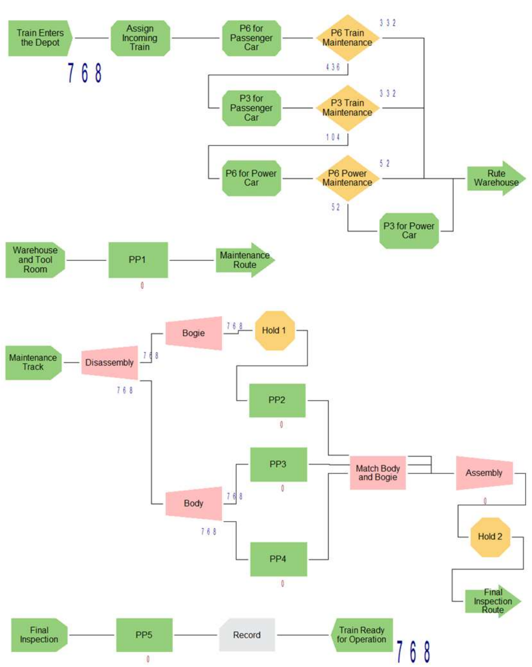

Figure 8. Simulation result of scenario 2

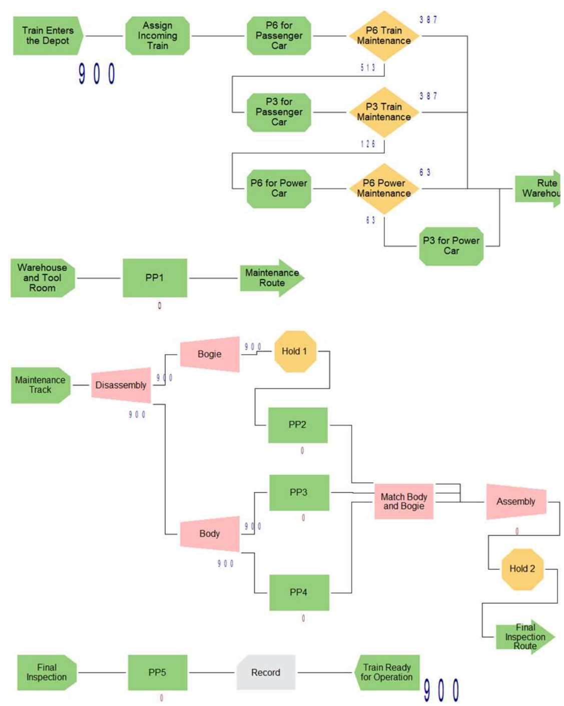

Figure 9. Simulation result of scenario 3

Simulation results for Scenario 3 are presented in Figure 9.

Scenario 3 allows for the maintenance of 89 additional trains, requiring a higher total cost, which includes the addition of teams and an extra work shift. This scenario enables a more significant increase in capacity with additional costs that remain reasonable. However, when considering the cost per additional train, Scenario 3 incurs the highest cost compared to the other scenarios.

Scenario 4 is the scenario with the largest increase, accommodating 159 additional trains-double the current fleet. This scenario involves the highest costs, including the expansion of maintenance resources, equipment, facilities, and maintenance lines. However, Scenario 4 offers the most comprehensive solution for significantly increasing maintenance capacity. With the investments included in this scenario, the Train Depot will be well-prepared to meet the growing demand for train maintenance in the future. Simulation results for Scenario 4 are presented in Figure 10.

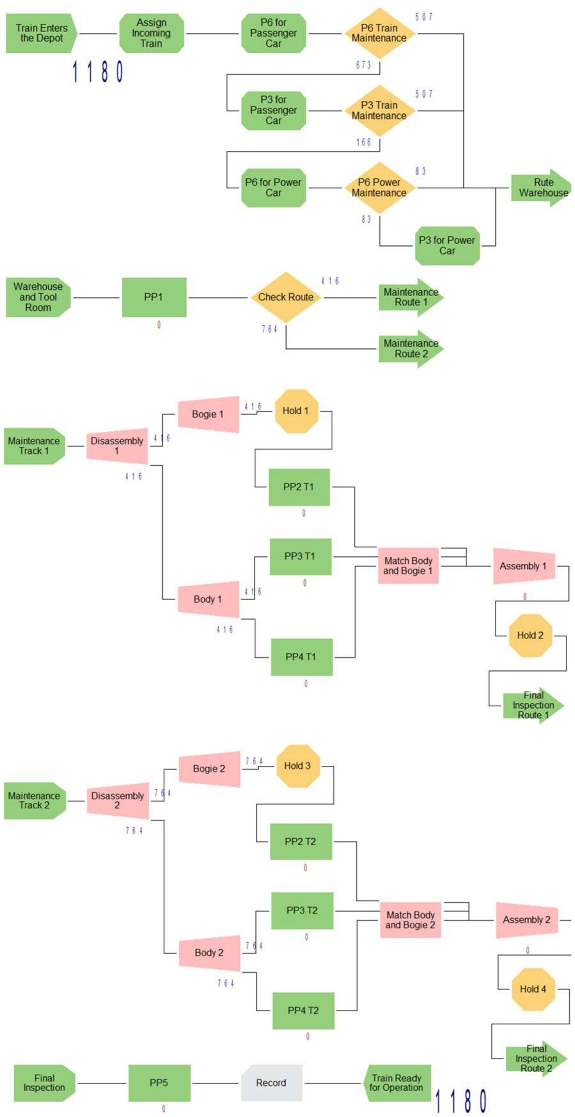

Figure 10. Simulation result of scenario 4

Results and Discussion: A simulation model of the train maintenance process using discrete event simulation software at the Train Depot was successfully developed, with the difference in the total maintenance process duration between the actual and simulated results ranging from 9% to 22%. This discrepancy is due to the limited number of observed samples for power cars, resulting in a significant difference in simulated process durations.

The maximum number of additional trains that can be maintained in the Train Depot, based on analytical calculations and simulation results with the available time allocation and maintenance resources, is 20 trains. And based on the projected arrival of new trains between 2024 and 2026, the recommended alternative solutions and associated costs for increasing maintenance capacity at the Train Depot should align with the scenarios that have been developed.

Increasing the maintenance capacity at the Train Depot is necessary to prevent potential revenue losses in passenger transport due to trains being unfit for operation because of unmet maintenance needs.

IV. Conclusion

Key considerations in selecting a scenario include the urgency of the need to increase maintenance capacity, the potential revenue loss of 1.9% from the 2023 passenger transport revenue due to trains being out of service because of unmet maintenance needs, and the availability of the maintenance budget. If there is an urgent need to significantly increase the number of trains serviced, Scenario 2 or 3 may be more appropriate. However, Scenario 4 would be the best choice if a substantial long-term increase in capacity is required, and a sufficient budget is available to support the necessary investments.

The simulation model can be further developed to consider the availability of spare parts and materials, as well as more detailed factors such as the number of personnel required per team. The sample size for data collection on maintenance process durations should be increased to reduce the error margin between the simulation results and actual conditions.

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