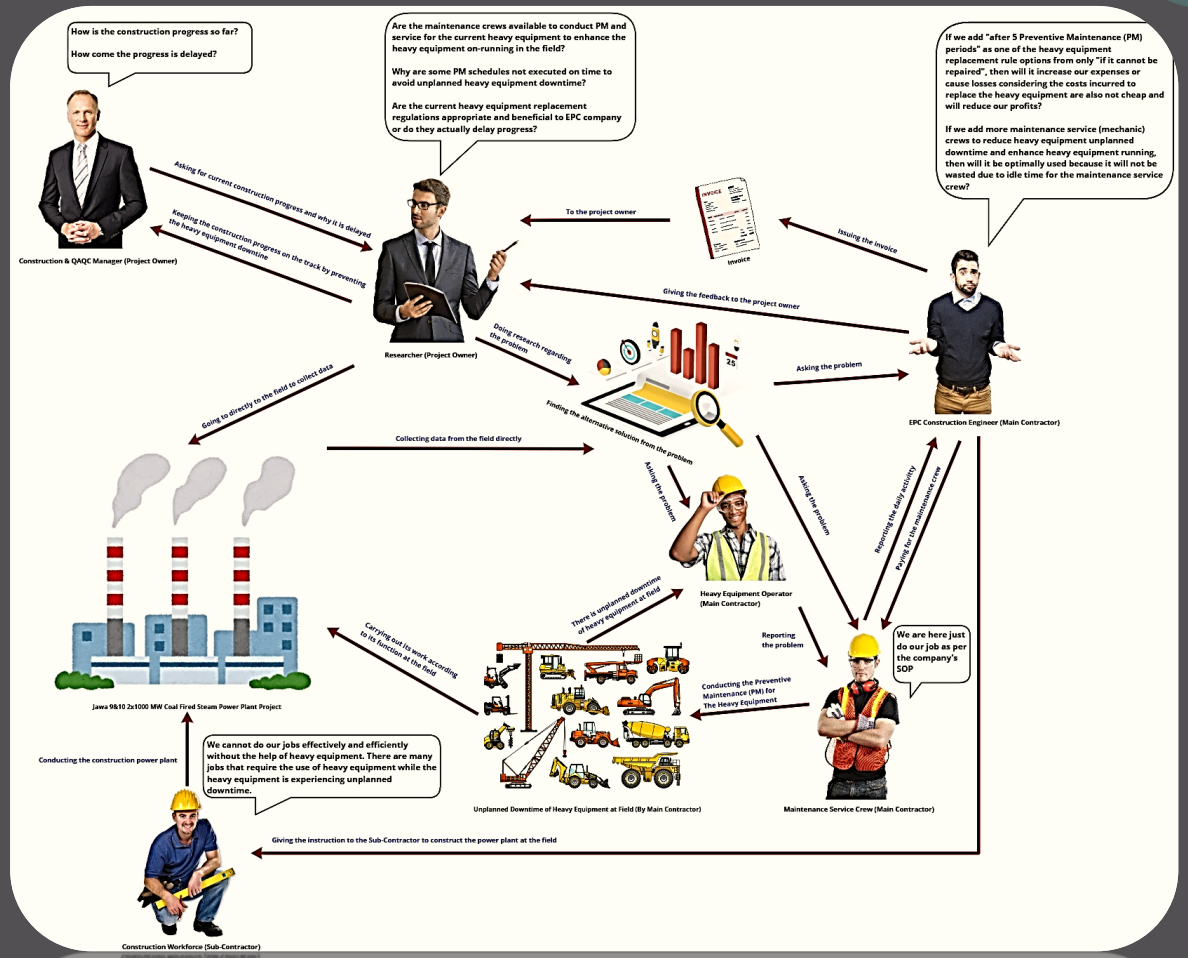
OPTIMIZING THE NUMBER OF MECHANIC CREWS AND HEAVY EQUIPMENT REPLACEMENT RULE OPTIONS TO REDUCE HEAVY EQUIPMENT UNPLANNED DOWNTIME, ENHANCE HEAVY EQUIPMENT ON RUNNING, AND MAXIMIZE PROFIT AT PT. XYZ'S CONSTRUCTION PROJECT: AN AGENT-BASED MODELLING APPROACH

By Using AnyLogic Software Version 8.9.4

Problem Identification



Problem Identification

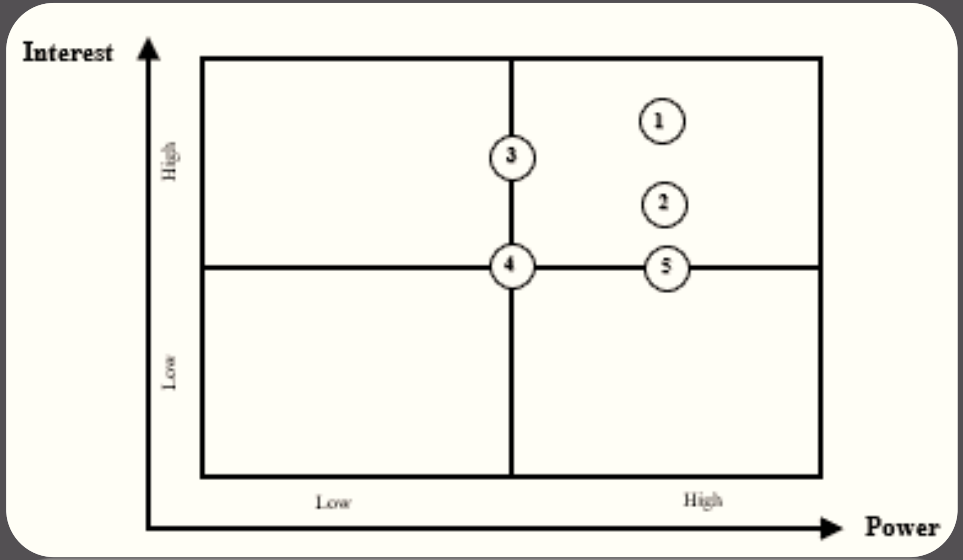
Two main issues that make EPC company dilemma to make a decision:

1. Adding more maintenance service (mechanic) crews to reduce heavy equipment unplanned downtime and enhance heavy equipment running may not be optimally utilized and efficient, as it could be wasted due to idle time for the maintenance service crew.

2. Adding "after 5 Preventive Maintenance (PM) periods" as one of the heavy equipment replacement rule options from only "if it cannot be repaired", may increase EPC company expenses or cause losses considering the costs incurred to replace the heavy equipment are also not cheap.

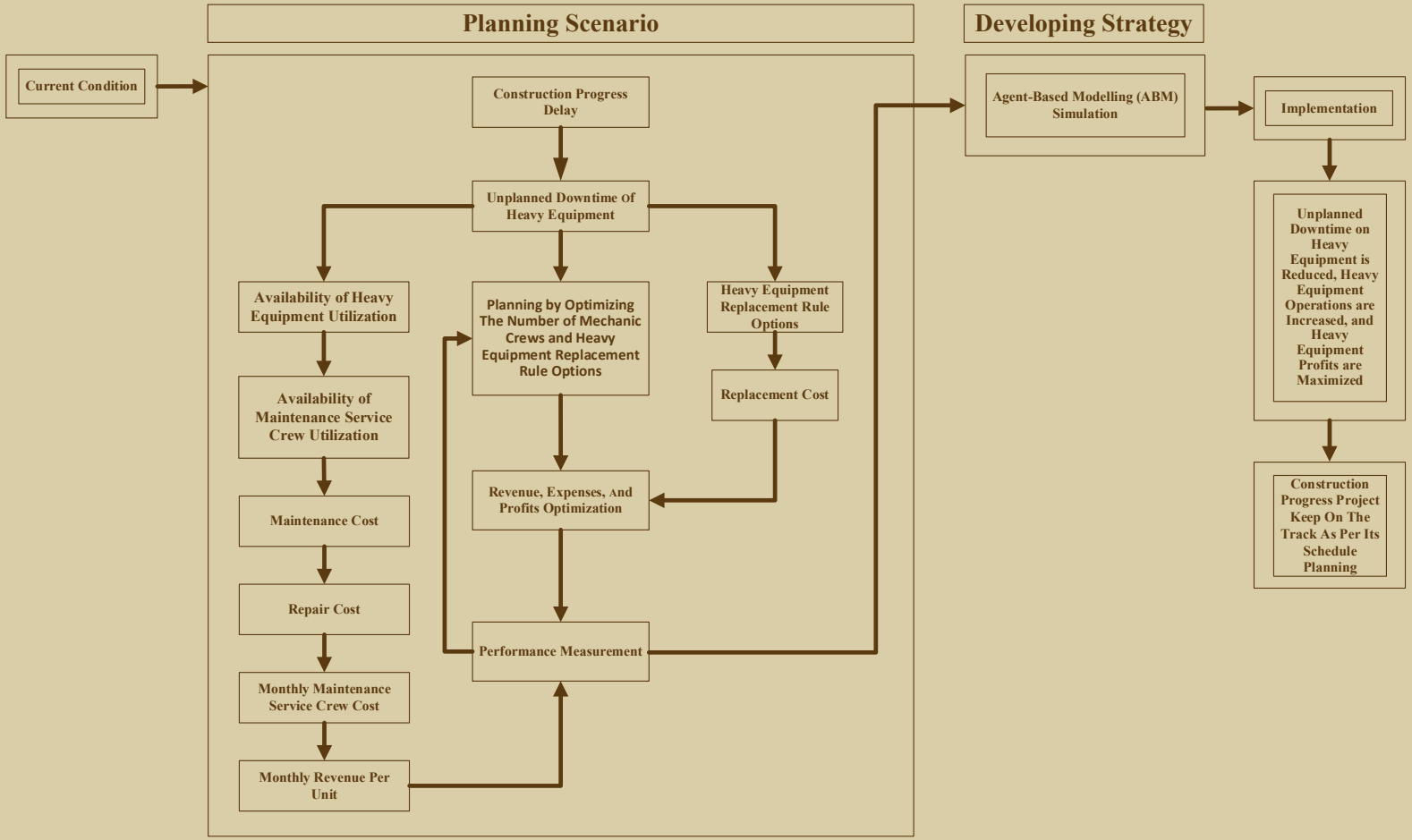
The Stakeholders

1. EPC Construction Engineer (Problem Owner)
2. Project Owner Construction & QAQC Manager (Client/Decision Maker)
3. Heavy Equipment Operator (Problem Owner)
4. Maintenance Service Crew (Problem Owner)
5. Construction Workforce (Problem Owner)

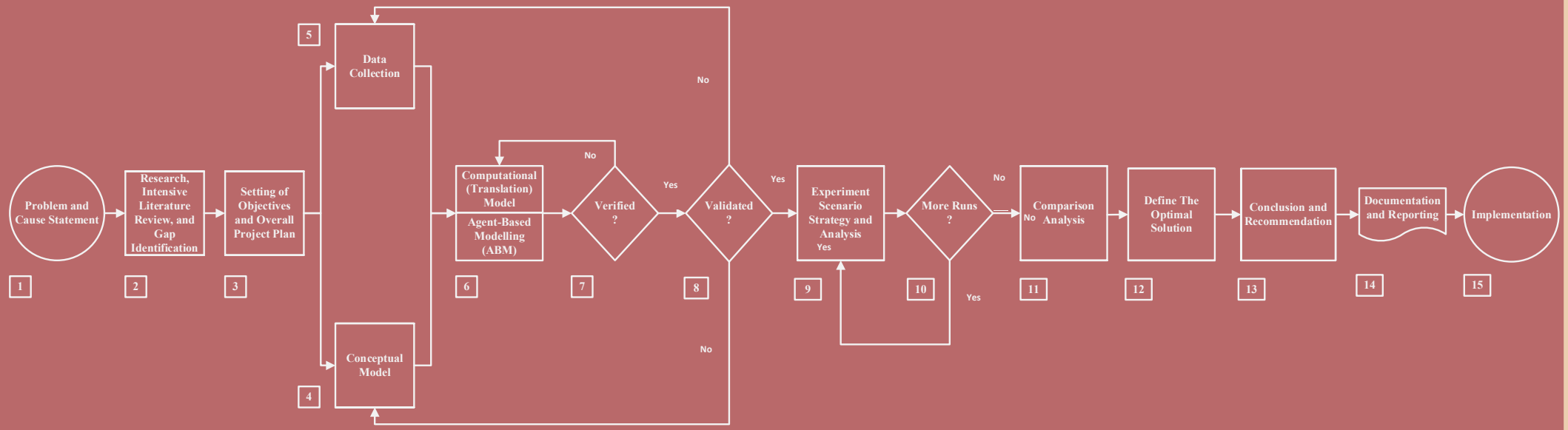


Stakeholder Power/Interest Map

Conceptual Framework



Research Design



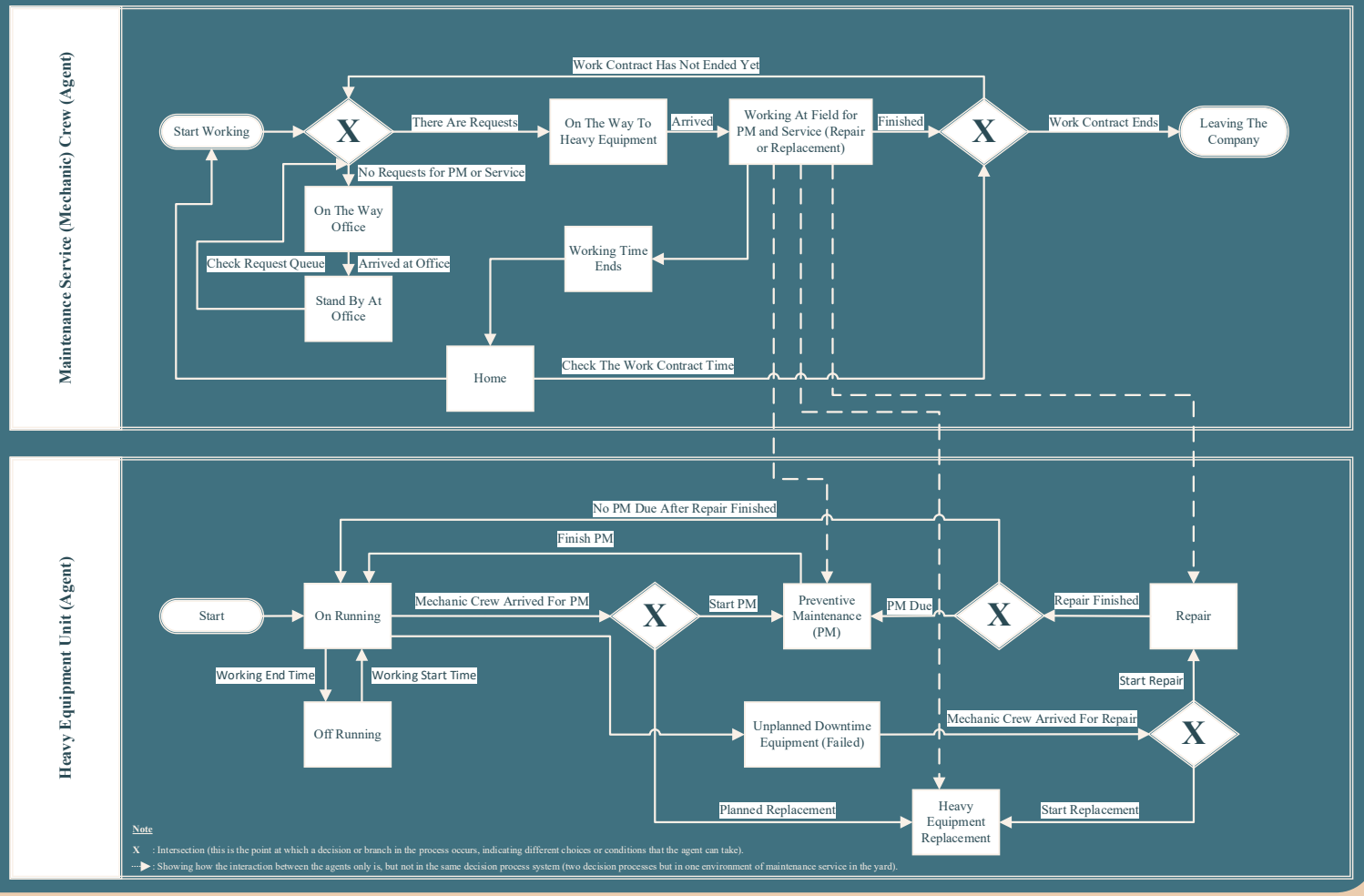
Source: Modified from discrete event system simulation (Banks, 2014)

Simulation Analysis

Simulation Analysis
Business Solution
Implementation Plan

1. Conceptual Model for Agent Decision Process (Agent Behaviors)

This conceptual model for agent decision process (agent behaviors) is divided in two because there are two agents in this modelling simulation. They are Maintenance Service (Mechanic) Crew and Heavy Equipment Unit.



Simulation Analysis

2. Agent Attribute and Definition

These attributes are defined by using AnyLogic version 8.9.4 software.

Maintenance Service (Mechanic) Crew Agent

No.	Attribute	Name	Type	Description
1	Parameter	office	Other: ShapePolyLine	As a place for the mechanic to stand by if there is no job task at the moment.
2	Variable	Heavyequipmentunit	HeavyEquipmentUnit	To interate with another agent (Heavy Equipment Unit)

Simulation Analysis

2. Agent Attribute and Definition

These attributes are defined by using AnyLogic version 8.9.4 software.

Heavy Equipment Unit Agent

No.	Attribute	Name	Type	Description
1	Parameter	PMPeriod	Time	The period of PM Schedule in daily basis.
2	Parameter	PMMeanTime	Time	The average time of PM Schedule that can be conducted in hour basis.
3	Parameter	RepairTypicalTime	Time	The typical time of repair that can be conducted in hour basis.
4	Parameter	NormalFailureRate	Rate	The number of Normal Failure Rate (NFR) which is allowed in unit per day basis.
5	Parameter	ProbabilityReplacementNeeded	Double	The precentage number of probability replacement which is needed.
6	Parameter	ReplacementMeanTime	Time	The average time of heavy equipment replacement that can be conducted in hour basis.
7	Variable	maintserviceCrew	MaintServiceCrew	To interate with another agent (Maintenance Service Crew)

Simulation Analysis

2. Agent Attribute and Definition

These attributes are defined by using AnyLogic version 8.9.4 software.

Heavy Equipment Unit Agent

No.	Attribute	Name	Type	Description
8	Variable	TimeLastPM	Double	To store the variable value of when the PM last time done.
9	Variable	TimeLastReplacement	Double	To store the variable value of when the heavy equipment last time done.
10	Function	Age	Double	To calculate the age of the heavy equipment utilization since it was replaced.
11	Function	TimeToFailure	Double	To calculate time to failure
12	Function	Color	Color	To calculate the change of color of the heavy equioment status.
13	Event	PMTimer	Trigger: TimeOut	When PM time is due, then request the PM.

Simulation Analysis

3. Data Collection (for Setting Parameter)

The researcher collected data to support the input data and conduct analyses. Yet, all the data but the data obtained mainly from internal company document reports.

Equation:

No.	Name	Equation
1	Amount of Monthly Average Revenue Per Unit	$\frac{Total\ Amount\ of\ Monthly\ Revenue\ Per\ Unit}{Total\ Number\ of\ Heavy\ Equipment}$
2	Amount of average PM Cost Per Unit	$\frac{Total\ Amount\ of\ Average\ PM\ Cost\ Per\ Unit}{Total\ Number\ of\ Heavy\ Equipment}$
3	Amount of Average Repair Cost Per Unit	$\frac{Total\ Amount\ of\ Repair\ Cost\ Per\ Unit}{Total\ Number\ of\ Heavy\ Equipment}$
4	Amount of Average Replacement Cost Per Unit	$\frac{Total\ Amount\ of\ Replacement\ Cost\ Per\ Unit}{Total\ Number\ of\ Heavy\ Equipment}$
5	Amount of Monthly Average Mechanics (MSC) Salary Cost Per Person	$\frac{Total\ Amount\ of\ Mechanic\ Salary\ Cost\ Per\ Person}{Total\ Number\ of\ Mechanic\ Crew}$

Simulation Analysis

3. Data Collection (for Setting Parameter)

The researcher collected data to support the input data and conduct analyses. Yet, all the data but the data obtained mainly from internal company document reports.

Equation:

No.	Name	Equation
6	Normal Failure Rate (NFR)	$\frac{Number\ of\ Normal\ Failures\ in\ a\ Given\ Period\ (Within\ A\ Certain\ Time)}{Total\ Number\ of\ Operating\ Time\ (Within\ A\ Certain\ Time)}$
7	Probability Replacement Needed	$\frac{Number\ of\ Replacements\ in\ a\ Given\ Period\ (Within\ A\ Certain\ Time)}{Total\ Number\ of\ Service\ (Repair\ +\ Replacement)\ in\ a\ Given\ Period}$
8	Yearly Average Heavy Equipment On Running	$\frac{\sum_{i=1}^{n}(Days\ of\ Heavy\ Equipment\ Running_i \times Number\ of\ Heavy\ Equipment\ Units\ Running_i)}{Total\ Days\ in\ A\ Year}$
9	Yearly Average Mechanic Crew Size	$\frac{\sum_{i=1}^{n}(Days\ of\ Mechanic\ Working_i \times Number\ of\ Mechanic\ Working_i)}{Total\ Days\ in\ A\ Year}$
10	Yearly Heavy Equipment Cost	$Yearly\ Total\ PM\ Cost + Yearly\ Total\ Repair\ Cost + Yearly\ Total\ Replacement\ Cost$

Simulation Analysis

3. Data Collection (for Setting Parameter)

The researcher collected data to support the input data and conduct analyses. Yet, all the data but the data obtained mainly from internal company document reports.

Equation:

No.	Name	Equation
11	Yearly Revenue from The Heavy Equipment Units	$Yearly\ Average\ Heavy\ Equipment\ Running \times (Monthly\ Revenue\ Per\ Unit \times 12\ Months)$
12	Yearly Expenses from The Heavy Equipment Units' Cost	$(Yearly\ Average\ Mechanic\ Crew\ Size \times (Monthly\ Mechanic\ Crew\ Salary \times 12\ Months)) + Heavy\ Equipment\ Cost$
13	Yearly Heavy Equipment's Profit	$Yearly\ Revenue - Yearly\ Expenses$

Simulation Analysis

3. Data Collection (for Setting Parameter)

The researcher collected data to support the input data and conduct analyses. Yet, all the data but the data obtained mainly from internal company document reports.

Data Collection:

No.	Description	As Data of	Unit
1	Number of Heavy Equipment Unit	Input	23 units
2	Number of Maintenance Service Crew	Input	2 persons
3	Amount of Monthly Average Revenue Per Unit	Input	Rp. 60,391,304.35
4	Amount of average PM Cost Per Unit	Input	Rp. 4,589,375.74
5	Amount of Average Repair Cost Per Unit	Input	Rp. 8,212,854.00
6	Amount of Average Replacement Cost Per Unit	Input	Rp. 42,332,124.00
7	Amount of Monthly Average Mechanics (MSC) Salary Cost Per Person	Input	Rp. 8,500,000.00
8	Replacement Equipment Options	Input	“If it cannot be repaired” or “After 5 times PM”

Simulation Analysis

3. Data Collection (for Setting Parameter)

The researcher collected data to support the input data and conduct analyses. Yet, all the data but the data obtained mainly from internal company document reports.

Data Collection:

No.	Description	As Data of	Unit
9	PM Schedule Period	Input	90 Days
10	PM Mean Time	Input	6 hours
11	Repair Typical Time	Input	18 hours
12	Normal Failure Rate (NFR)	Input	0.03 Failures Per Day
13	Probability Replacement Needed	Input	0.1429
14	Replacement Mean Time	Input	120 hours
15	Yearly Average Heavy Equipment On Running	Calculation	%
16	Yearly Average Mechanic Crew Size	Calculation	%

Simulation Analysis

3. Data Collection (for Setting Parameter)

The researcher collected data to support the input data and conduct analyses. Yet, all the data but the data obtained mainly from internal company document reports.

Data Collection:

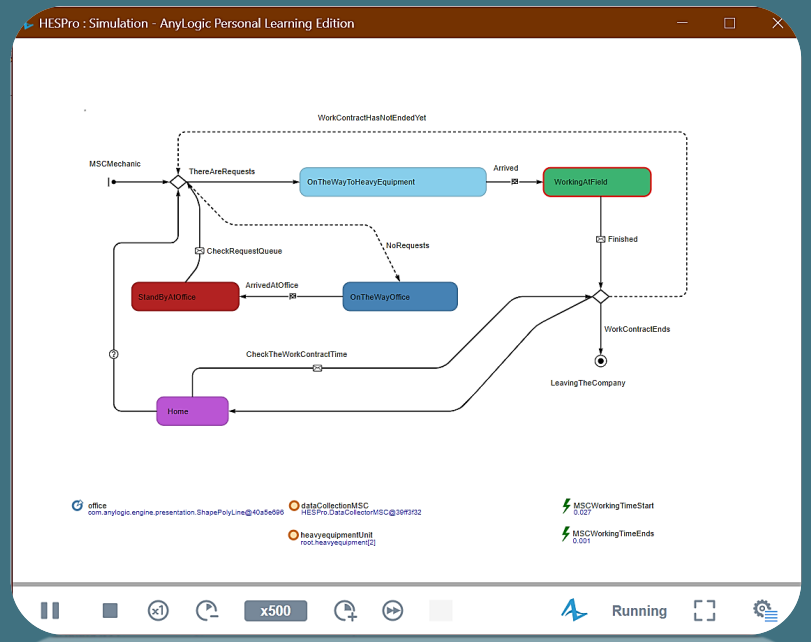
No.	Description	As Data of	Unit
17	Yearly Heavy Equipment Cost	Calculation	Rp.
18	Yearly Revenue from The Heavy Equipment Units	Output	Rp.
19	Yearly Expenses from The Heavy Equipment Units' Cost	Output	Rp.
20	Yearly Heavy Equipment's Profit	Output	Rp.

Simulation Analysis

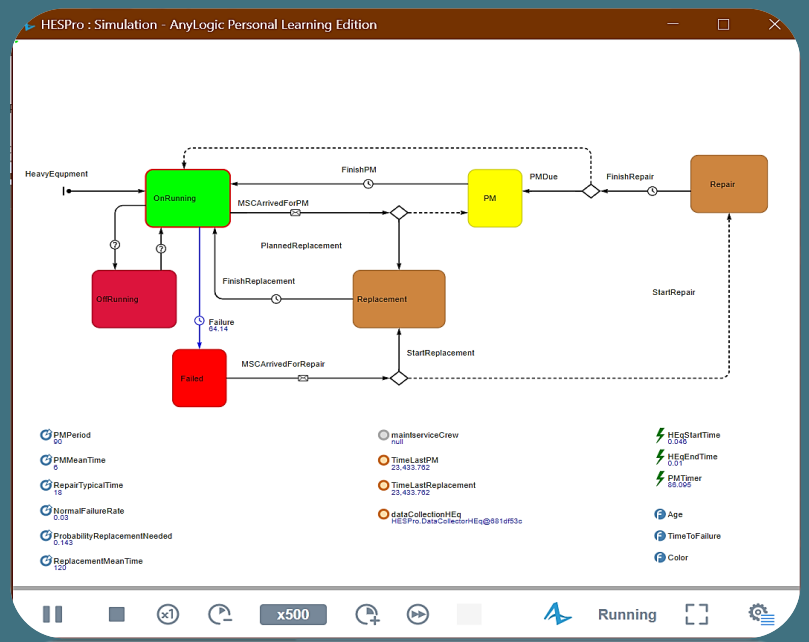
4. Computational Model (Logic Model Simulation Design)

The researcher developed an ABM simulation design using AnyLogic software version 8.9.4 from the components and model conceptualization grounded in real condition of heavy equipment availability and mechanic utilization. This computational model is divided into each agent.

Logic Model Design Simulation of MSC (Mechanic) Agent



Logic Model Design Simulation of Heavy Equipment Unit Agent



Simulation Analysis

5. Verification

The developed model in AnyLogic version 8.9.4 is subsequently verified to determine the occurrence of any errors or not. If a mistake arises in the current model, the logic of the simulation generated is not entirely accurate. Models that encounter faults or errors must recreate the original simulation model.

heavyequipment - HeavyEquipmentUnit

Statistics

Name:	OnRunning	
Type:	Count ○ Sum ○ Average ○ Min ○ Max	
Condition:	agent.inState(HeavyEquipmentUnit.OnRunning)	
Name:	OnPM	
Type:	Count ○ Sum ○ Average ○ Min ○ Max	
Condition:	agent.inState(HeavyEquipmentUnit.PM)	
Name:	OnService	
Type:	Count ○ Sum ○ Average ○ Min ○ Max	
Condition:	agent.inState(HeavyEquipmentUnit.Repair) || agent.inState(HeavyEquipmentUnit.Replacement)	
Name:	Failed	
Type:	Count ○ Sum ○ Average ○ Min ○ Max	
Condition:	agent.inState(HeavyEquipmentUnit.Failed)	

Function body

```
//if this unit already has asked for service - no need to leave request for mechanic
if( serviceRequests.contains( unit ) )
    return;
//if some service crew is already handling this unit - ignore request
for( MaintenanceServiceCrew msc : maintservice )
    if( msc.heavyequipmentUnit == unit )
        return;
//add PM request to the queue
pmRequests.addLast( unit );
//and make all service crews check the request queue
for( MaintenanceServiceCrew msc : maintservice )
    send("CHECK REQUEST QUEUE", msc);
```

endOfYear - Event

Action

```
//Record the year results
endYearHEqOnRunning.add( statsHEqOnRunning.mean() );
endYearHEqOnPM.add( statsHEqOnPM.mean() );
endYearHEqOnService.add( statsHEqOnService.mean() );
endYearHEqFailed.add( statsHEqFailed.mean() );

endYearMaintServStandByAtOffice.add( statsMaintServStandByAtOffice.mean() );
endYearMaintServOnTheWay.add( statsMaintServOnTheWay.mean() );
endYearMaintServWorkingAtField.add( statsMaintServWorkingAtField.mean() );

double yearrevenue = statsHEqOnRunning.mean() * (MonthlyRevenuePerUnit *12);
double yearexpenses = statsMaintServSize.mean() * ( MonthlyMSCSalaryCost *12 ) + HeavyEquipmentCost;
endYearRevenue.add( yearrevenue / 1000000 );
endYearExpenses.add( yearexpenses / 1000000);
endYearProfit.add(( yearrevenue - yearexpenses ) / 1000000);

//Reset the stats
statsHEqOnRunning.reset();
statsHEqOnPM.reset();
statsHEqOnService.reset();
statsHEqFailed.reset();

statsMaintServSize.reset();
statsMaintServStandByAtOffice.reset();
statsMaintServOnTheWay.reset();
statsMaintServWorkingAtField.reset();

HeavyEquipmentCost = 0;
```

maintservice - MaintenanceServiceCrew

Statistics

Name:	StandByAtOffice	
Type:	Count ○ Sum ○ Average ○ Min ○ Max	
Condition:	agent.inState(MaintenanceServiceCrew.StandByAtOffice)	
Name:	OnTheWay	
Type:	Count ○ Sum ○ Average ○ Min ○ Max	
Condition:	agent.inState(MaintenanceServiceCrew.OnTheWayToHeavyEquipment) || agent.inState(MaintenanceServiceCrew.OnTheWayOffice)	
Name:	WorkingAtField	
Type:	Count ○ Sum ○ Average ○ Min ○ Max	
Condition:	agent.inState(MaintenanceServiceCrew.WorkingAtField)	

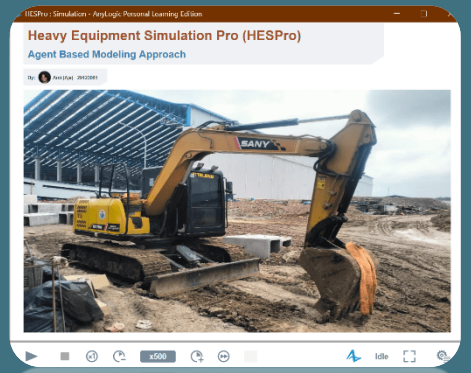
Function body

```
//if this unit already has asked for mantenance - remove that request as lower priority
if( pmRequests.contains( unit ) )
    pmRequests.remove( unit );
//if some service crew is already handling this unit - ignore request
for( MaintenanceServiceCrew msc : maintservice )
    if( msc.heavyequipmentUnit == unit )
        return;
//add service request to the queue
serviceRequests.addLast( unit );
//and make all service crews check the request queue
for( MaintenanceServiceCrew msc : maintservice )
    send("CHECK REQUEST QUEUE", msc);
```

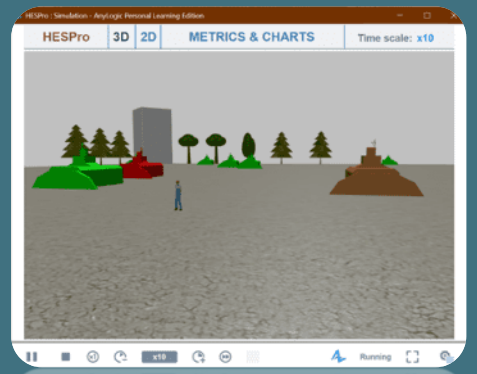
Simulation Analysis

5. Verification

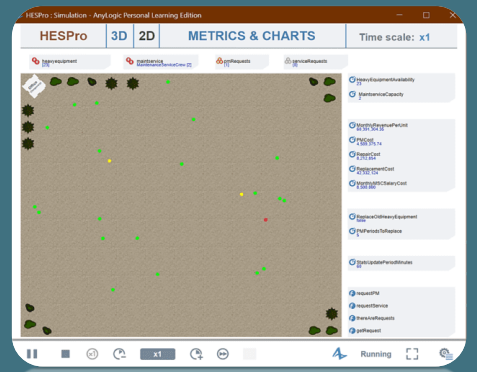
The developed model in AnyLogic version 8.9.4 is subsequently verified to determine the occurrence of any errors or not. If a mistake arises in the current model, the logic of the simulation generated is not entirely accurate. Models that encounter faults or errors must recreate the original simulation model.



Start-up Screen View



3D View



2D View

Metrics & Charts View

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time speed scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

In a two-sample independent t-test statistic method, researcher wanted to test the hypotheses:

- H_0 (Null hypothesis): There is no significant difference between the real data and the simulated data.
- H_1 (Alternative hypothesis): There is a significant difference between the real data and the simulated data.

To gain the validation result will be H_0 or either H_1, researcher will use the t-critical and P-value in order to be analyzed as the summary validation.

Heavy Equipment's Output	End Year	Real Condition Data	Simulation Data
Revenue	2023	Rp. 9,808,277,321.22	Rp. 13,353,545,402.23
	2024	Rp. 10,400,135,937.50	Rp. 13,101,117,961.98
Expenses	2023	Rp. 2,029,628,128.64	Rp. 3,227,738,260.92
	2024	Rp. 4,213,189,753.76	Rp. 3,125,492,695.70
Profit	2023	Rp. 7,778,649,192.58	Rp. 10,125,807,141.31
	2024	Rp. 6,186,946,183.74	Rp. 9,975,625,266.28

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

Equation:

No.	Name	Equation
1	Average ($\bar{X}$) :	$\frac{\sum X}{n}$
2	Standard Deviation (SD)	$\sqrt{\frac{(X_i - \bar{X})^2}{n-1}}$
3	Variation (SD^2)	$\frac{(X_i - \bar{X}_1)^2}{n_1 - 1}$
4	Two Independent Sample t-count (t_{count})	$\frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{{SD_1}^2}{n_1} + \frac{{SD_2}^2}{n_2}}}$

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

Equation:

No.	Name	Equation
5	Degrees of freedom (*df*) By using Welch–Satterthwaite's formula	$\frac{\left(\frac{SD_1{}^2}{n_1}+\frac{SD_2{}^2}{n_2}\right)^2}{\frac{\left(\frac{SD_1{}^2}{n_1}\right)^2}{n_1-1}+\frac{\left(\frac{SD_2{}^2}{n_2}\right)^2}{n_2-1}}$
6	t-critical ($t_{critical}$) due to a two-tailed test	$t_{\left(\frac{\alpha}{2},df\right)}$
7	Find P_{value} by using Linier Interpolation	$P_1+\frac{(t-t_1)}{(t_2-t_1)}\times(P_2-P_1)$
8	For two-tailed test, P_{value}	$2x\ P(T\ >\ \lvert t\rvert)$

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

Calculation Steps

- **Step 1 and 2:** Defining α, n_1, and n_2, where $n_1 = 6$; $n_1 = 6$; $\alpha = 0.05$ (due to the confidence level is 95%).
- **Step 3:** Calculating Average $(\bar{X})$ by using equation (1) for real data $(\bar{X}_1)$ and Simulation data
- **Step 4:** Standard Deviation (SD) by using equation (2) for real data (SD_1) and Simulation data (SD_2)
- **Step 5:** Calculating Variation (SD_2) by using equation (3) for real data (SD_1^2) and Simulation data (SD_2^2)
- **Step 6:** Calculating Two Independent Sample t-count (t_{count}) by using equation (4)
- **Step 7:** Calculating degrees of freedom (df) by using Welch–Satterthwaite's equation (5) due to difference SD and varian (unequal varians) between real data and simulation data.
- **Step 8:** Defining t-critical ($t_{critical}$) in the student's t-distribution table according to df and α from (Syihab, n.d.) and due to a two-tailed test by using equation (6)

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

Calculation Steps

- **Step 9, 10, 11, and 12:** Defining t_{A1}, t_{A2}, P_{A1} or (P_{A1} ($T_{A1} > t_{A1}$), and P_{A2} or (P_{A2} ($T_{A2} > t_{A2}$). Since the *t*-distribution is a symmetric distribution centered at 0, and also, the probability to the left of a negative t value (e.g. $P(T < -0.906)$) is equal to the probability to the right of a positive *t* value (e.g. $P(T > 0.906)$) due to the symmetric property, then, $P(T < -0.906) \rightarrow P(T > 0.906)$

  To find the closest *t*-value to -0.906 in the table *t*-distribution according to its *df* = 9, then from the table t-distribution:
  $t_1 = 0.883 \rightarrow P_1 = 0.20 \rightarrow P_1(T_1 > t_1) = 0.20$
  $t = 0.906$
  $t_2 = 1.100 \rightarrow P_2 = ? \rightarrow P_2(T_2 > t_2) = ?$ (due to it not being shown on the table, but it will be interpolated in the next step)
  To interpolate $t_2 = 1.100$ that is not explicitly in the table, researcher can use <u>Linear Interpolation (LI)</u> between the two closest known t-values from the table. So, let's estimate between for *t*-count = 1.100
  $t_{A1} = 0.883 \rightarrow P_{A1} = 0.20$
  $t_{count} = 1.100 \rightarrow P_A = ?$
  $t_{A2} = 1.383 \rightarrow P_{A2} = 0.10$

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

Calculation Steps

- **Step 13:** Calculating $P_{\text{value A}}$. Find $P(T > 1.100)$ using linear interpolation between these two points by using equation (7)
- **Step 14, 15, 16, and 17:** Defining t_1, t_2, P_1 or $(P_1(T_1 > t_1)$, and P_2 or $(P_2(T_2 > t_2)$. After getting $P_A(T_A > 1.100) = 0.1566$, then find $P(T > 0.906)$:
  $t_1 = 0.883 \rightarrow P_1 = 0.20$
  $t = 0.906 \rightarrow P = ?$ (due to it not being shown on the table, but it will be interpolated below)
  $t_2 = 1.100 \rightarrow P_2 = 0.1566 \rightarrow P(T > t_2) = 0.1566$
- **Step 18:** Calculating P_{value}. Since -0.906 is not available directly in the table t-distribution, then researcher will use linear interpolation to find the P-value by using equation (7)
- **Step 19:** Calculating two-tailed test, P_{value}. by using equation (8)

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

Result of The Calculation for Each Steps

Steps	Construct	Used Equation No.	General	Real Condition Data$_{(1)}$	Simulation Data$_{(2)}$	Note
1	α		0.05			
2	n			6	6	
3	$(\bar{X})$	1		Rp. 6,736,137,752.91	Rp. 8,818,221,121.40	
4	SD	2		Rp. 3,248,626,329.85	Rp. 4,596,137,351.64	
5	SD^2	3		Rp. 1.05536E+19	Rp. 2.11245E+19	
6	t_{count}	4	-0.906			
7	df	5	9			
8	$t_{critical}$	6	± 2.262			Find the $t_{critical}$ in the student's t-distribution table according to df and α
9	t_{A1}		0.883			
10	t_{A2}		1.383			

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

Result of The Calculation for Each Steps

Steps	Construct	Used Equation No.	General	Real Condition Data$_{(1)}$	Simulation Data$_{(2)}$	Note
11	P_{A1} or ($P_{A1}(T_{A1} > t_{A1})$		0.20			
12	P_{A2} or ($P_{A2}(T_{A2} > t_{A2})$		0.10			
13	$P_{value\ A}$	7	0.1566			
14	t_1		0.883			
15	t_2		1.100			
16	P_1 or ($P_1(T_1 > t_1)$		0.20			
17	P_2 or ($P_2(T_2 > t_2)$		0.157			
18	P_{value}	7	0.1954			
19	Two-tailed test, P_{value}	8	0.3908			

Simulation Analysis

6. Validation

The researcher ran the simulation model by the model time unit based on yearly as the real one from this business case, with the real time scale 1 to 500 as the execution mode by the stop at specified time during 2 calendar years (2023-2024). Based on (Banks, 2014), the researcher conducted the validation method by using historical data (historical data validation) – compare the output of the simulation model with real data. The theoretical basis used for this validation method is the two sample t-test distribution statistic.

Interpreted based on two-tailed t-test

|*t*-count| to *t*-critical:

The rule:
If $|t_{count}| \geq t_{critical}$, then reject H_0 (null hypothesis) → the model is invalid → H_1 (alternative hypothesis)
If $|t_{count}| < t_{critical}$, then accept H_0 (null hypothesis) → the model is valid.

$|t_{count}| = |-0.906| \approx 0.906$; $t_{critical} = 2.262$. Due to $|t_{count}| \approx 0.906 < t_{critical} = 2.262$, then accept H_0 (null hypothesis) → the model is valid because there is no significant difference between the real data and the simulated data.

P_{value} to α

The rule:
If $P_{value} \leq \alpha$, then reject H_0 (null hypothesis) → the model is invalid → H_1 (alternative hypothesis).
If $P_{value} > \alpha$, then accept H_0 (null hypothesis) → the model is valid.

Due to $P_{value} \approx 0.3908 > \alpha = 0.05$, then accept H_0 (null hypothesis) → the model is valid because there is no significant difference between the real data and the simulated data.

Summary of The Validation

Due to $t_{count} < t_{critical}$ and $P_{value} > \alpha$, then accept H_0 (null hypothesis). Thus, the simulation model can be considered valid because there is no significant evidence that the simulation results differ from the real data at the 0.05 (5%) significance level.

Simulation Analysis

7. Experiment Scenario Designs

This section states all the experiment scenario designs only. For output of the experiment scenario designs will be explained in the next section.

Real condition

The average monthly income per heavy equipment unit is Rp. 60,391,304.35, with periodic maintenance (PM) costing Rp. 4,588,521.74 and average repair costs at Rp. 8,212,000.00. If repair is not feasible, replacement costs Rp. 42,332,000.00. Two mechanics are paid Rp. 8,500,000.00 each monthly. The 23 units of equipment follow a 90-day PM schedule, with a 6-hour PM mean time, 18-hour repair time, and a 0.03 failure rate per day. The probability of needing replacement is 0.1429, with a 120-hour replacement mean time. Replacement occurs only if repair is impossible.

Simulation

The following experiment scenario will be divided into two parts according to the choice of the heavy equipment replacement rule options:

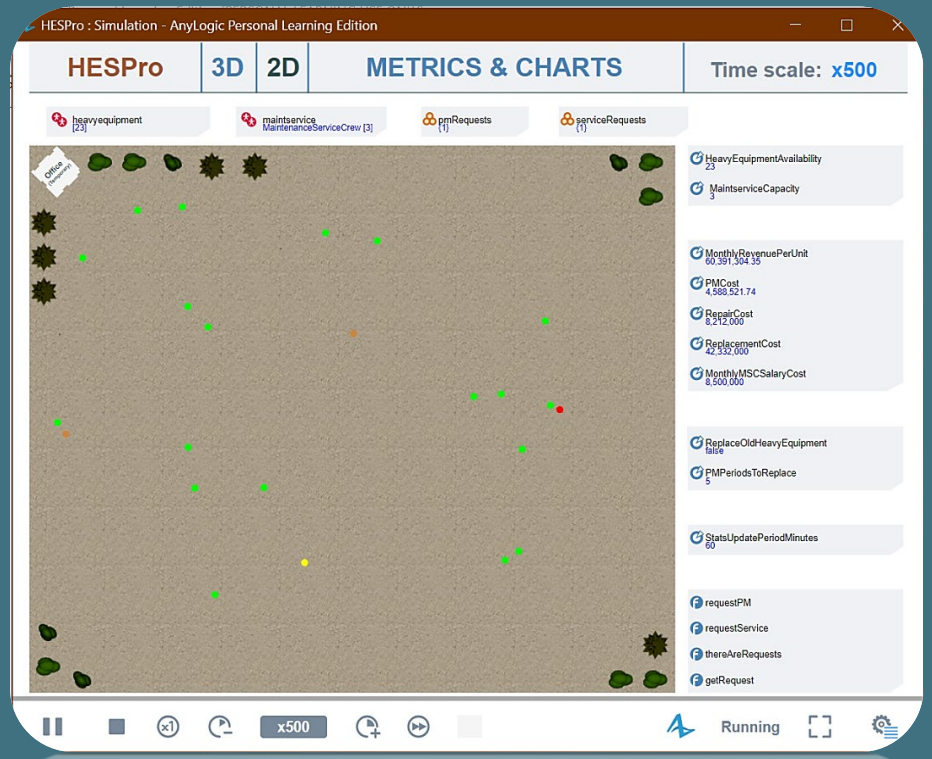
1. **Only if it cannot be repaired:** In this rule option, all the data input is the same as in real condition (remain unchanged). However, in the number of mechanics, there are differences in scenarios, namely in experiment #1 for 3 mechanics, experiment #2 for 4 mechanics, experiment #3 for 5 mechanics, experiment #4 for 6 mechanics, and experiment #5 for 7 mechanics.
2. **After 5 PM periods:** In this rule option, all the data input is the same as in real condition. However, in the number of mechanics, there are differences in scenarios, namely in experiment #6 for 2 mechanics, experiment #7 for 3 mechanics, experiment #8 for 4 mechanics, experiment #9 for 5 mechanics, experiment #10 for 6 mechanics, and experiment #11 for 7 mechanics.

Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: "Only If It Cannot Be Repaired"

Experiment #1

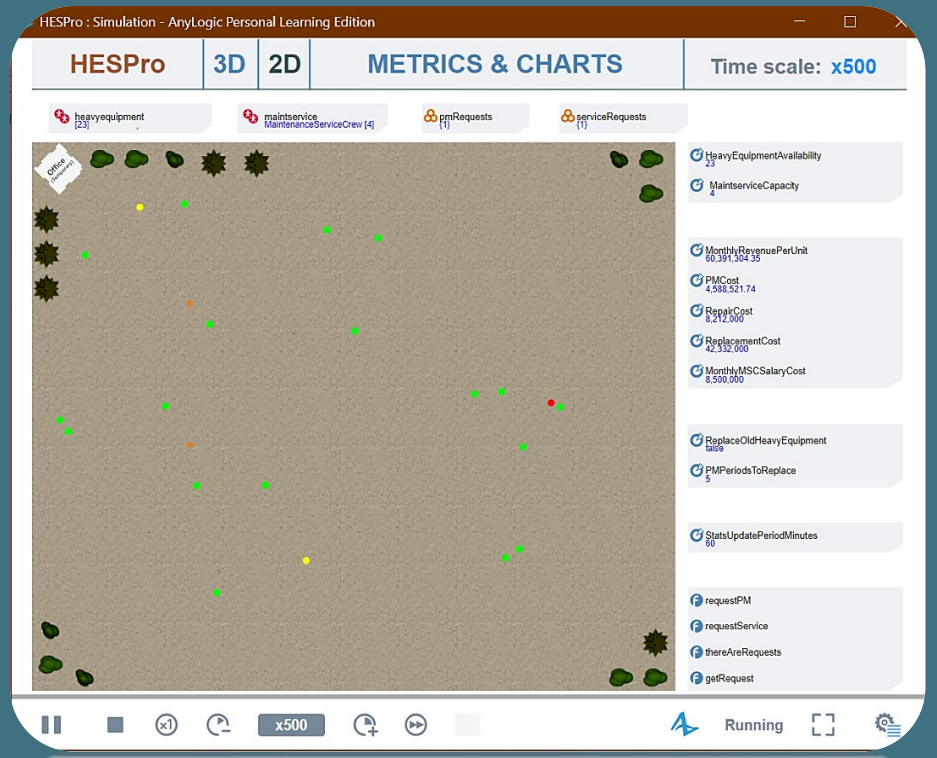


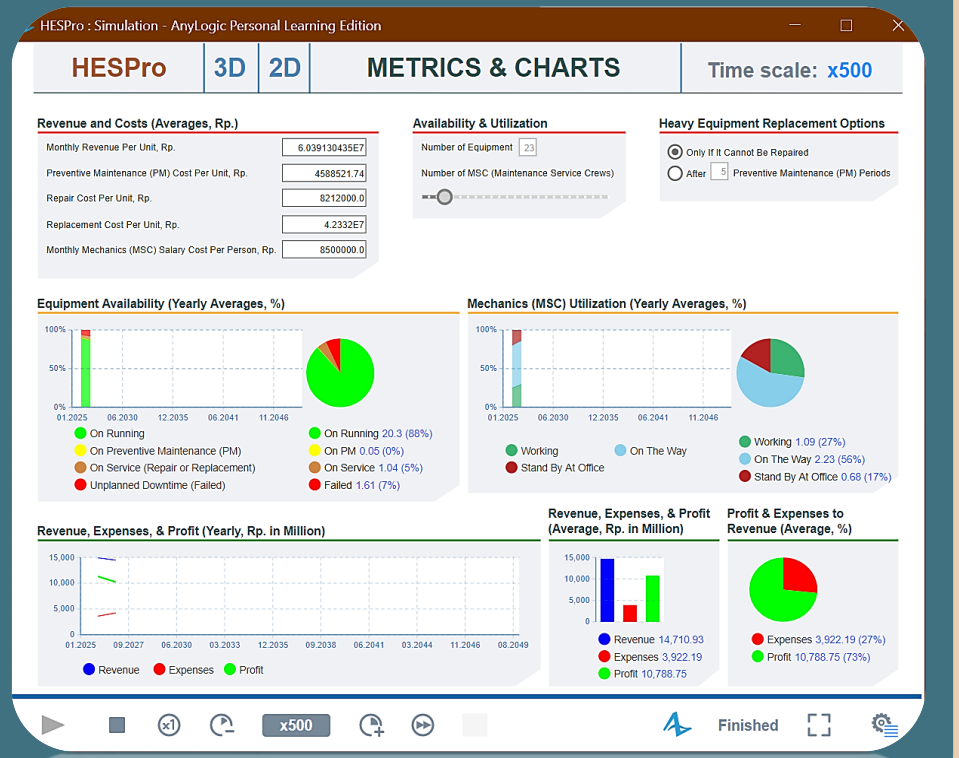
Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “Only If It Cannot Be Repaired”

Experiment #2



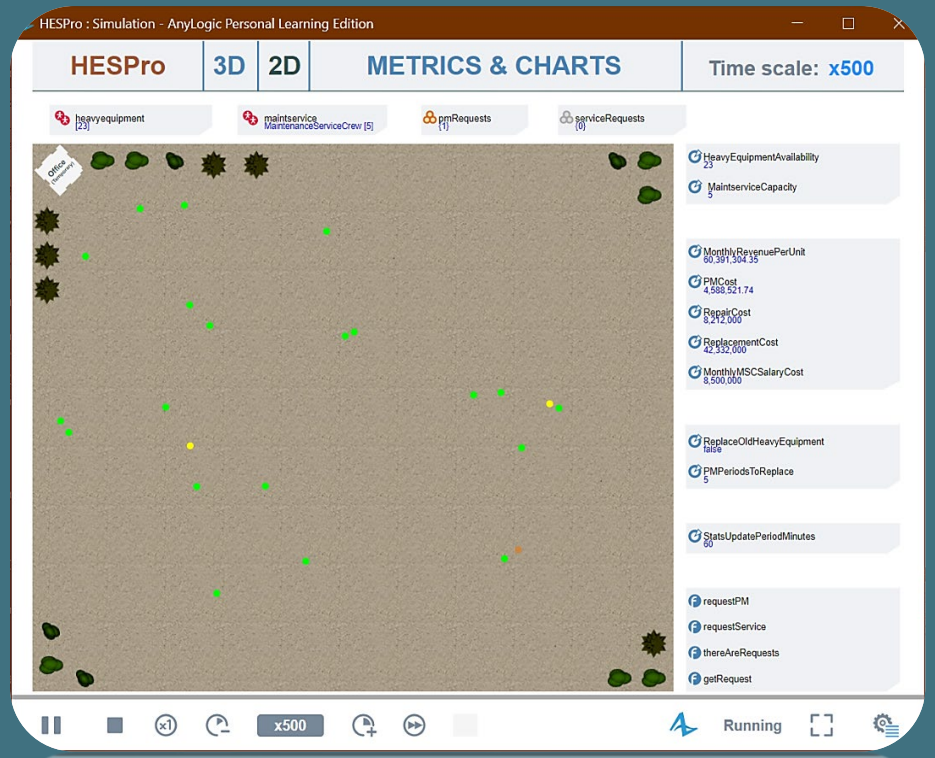


Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “Only If It Cannot Be Repaired”

Experiment #3

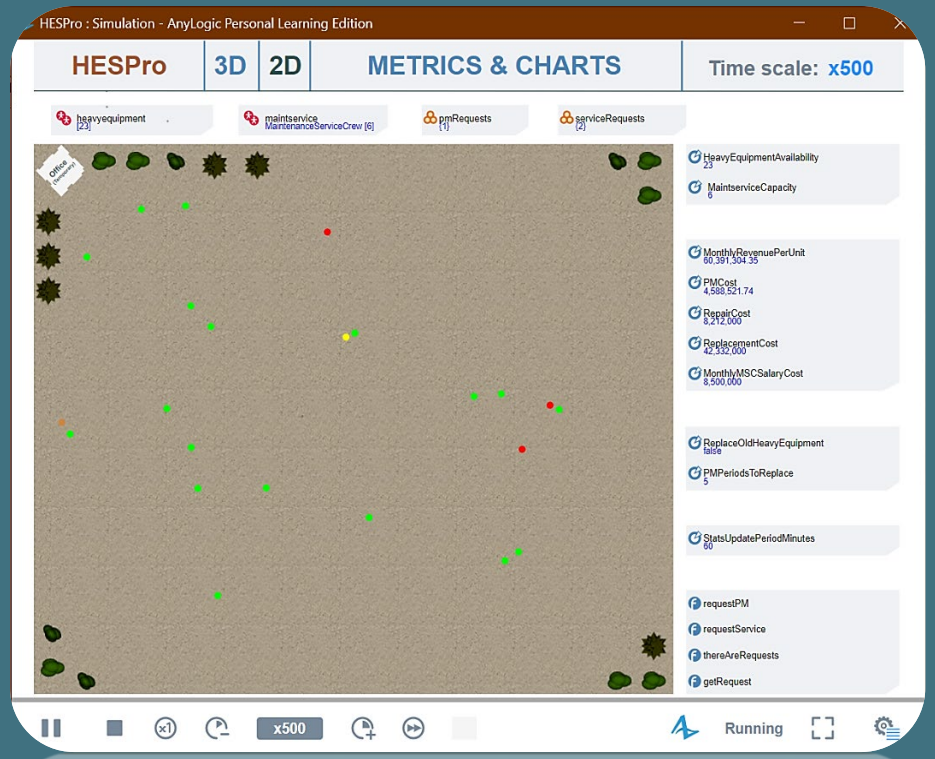


Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: "Only If It Cannot Be Repaired"

Experiment #4

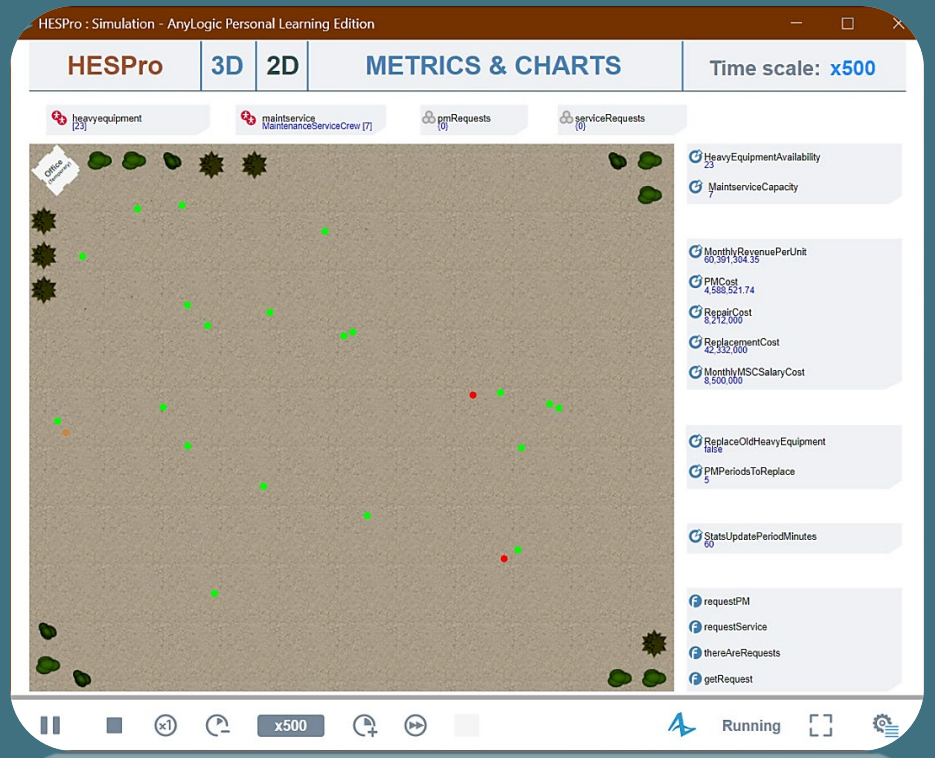


Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “Only If It Cannot Be Repaired”

Experiment #5

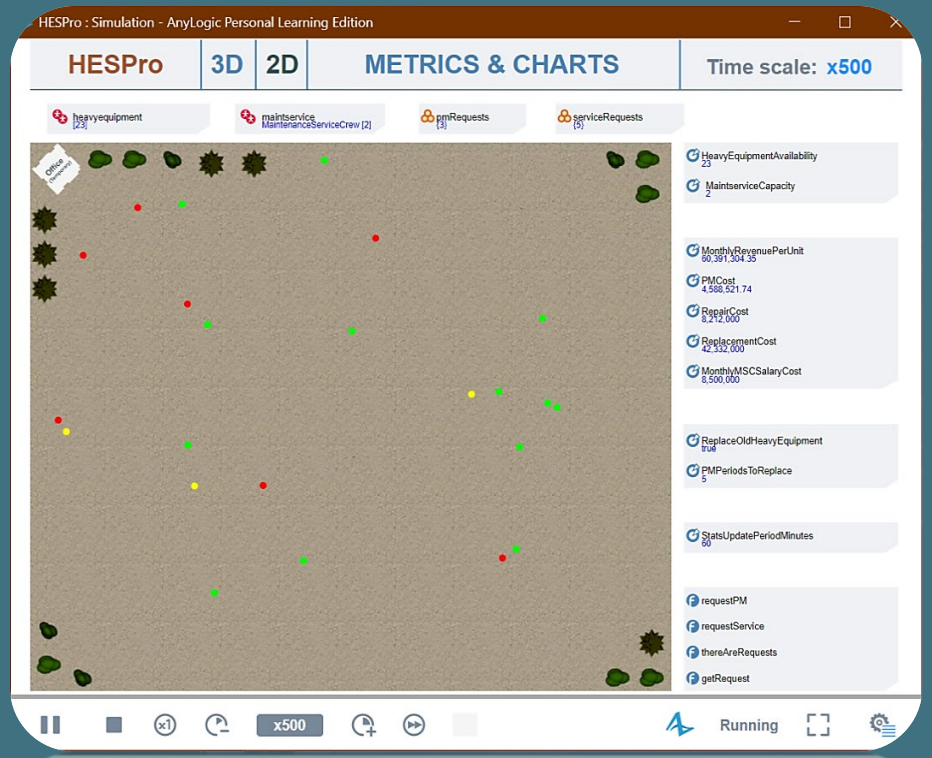


Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “After 5 PM Periods”

Experiment #6

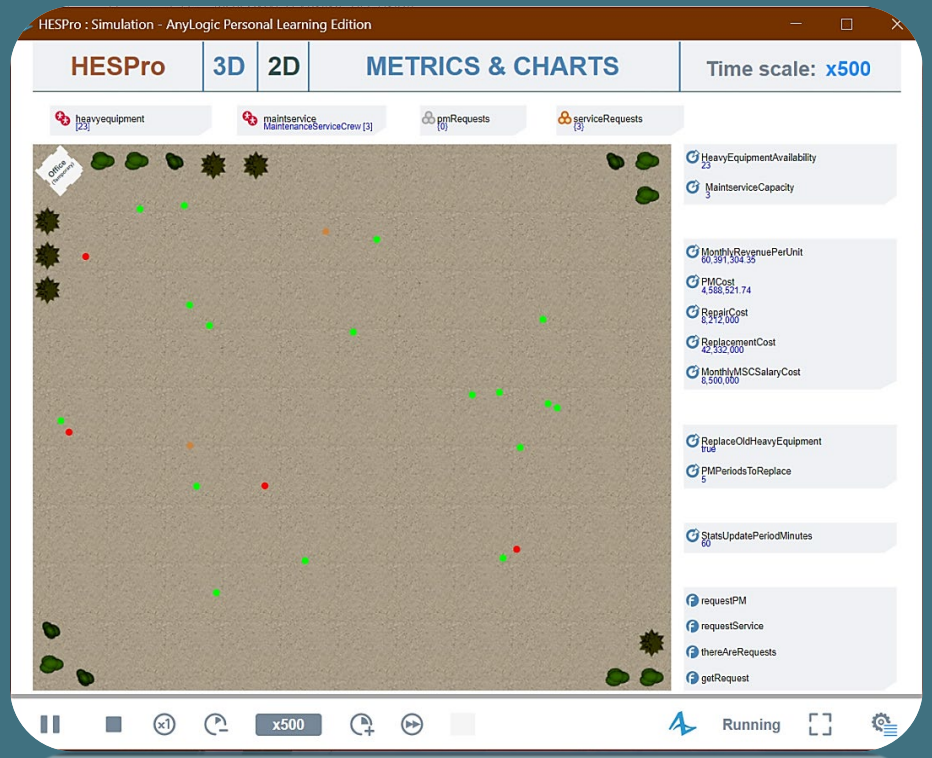


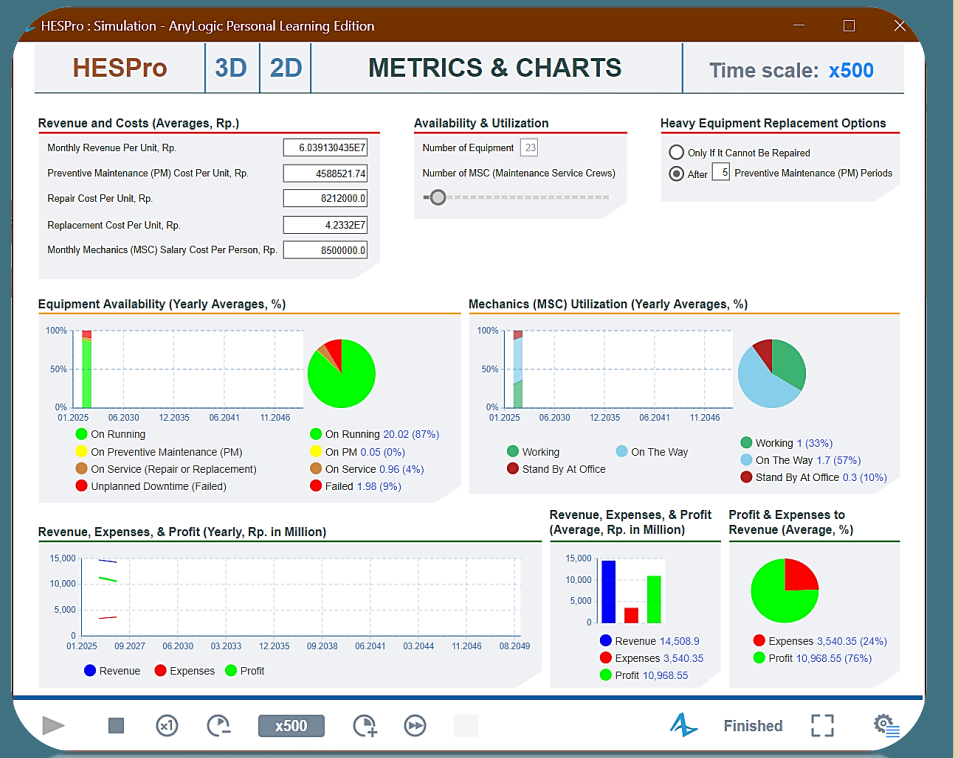
Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “After 5 PM Periods”

Experiment #7



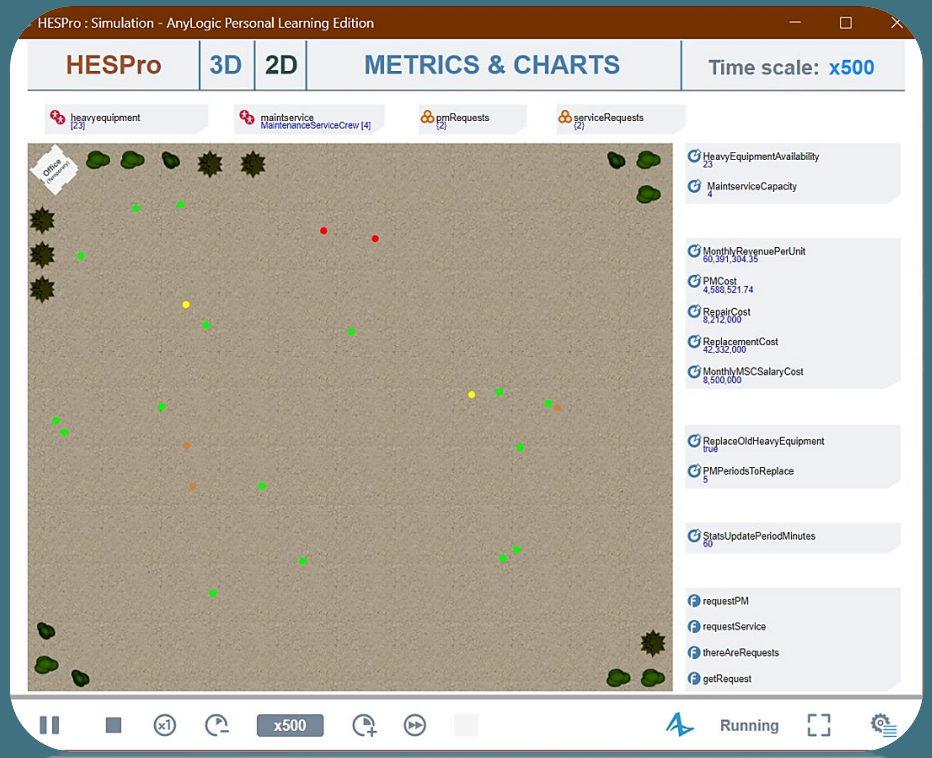


Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “After 5 PM Periods”

Experiment #8

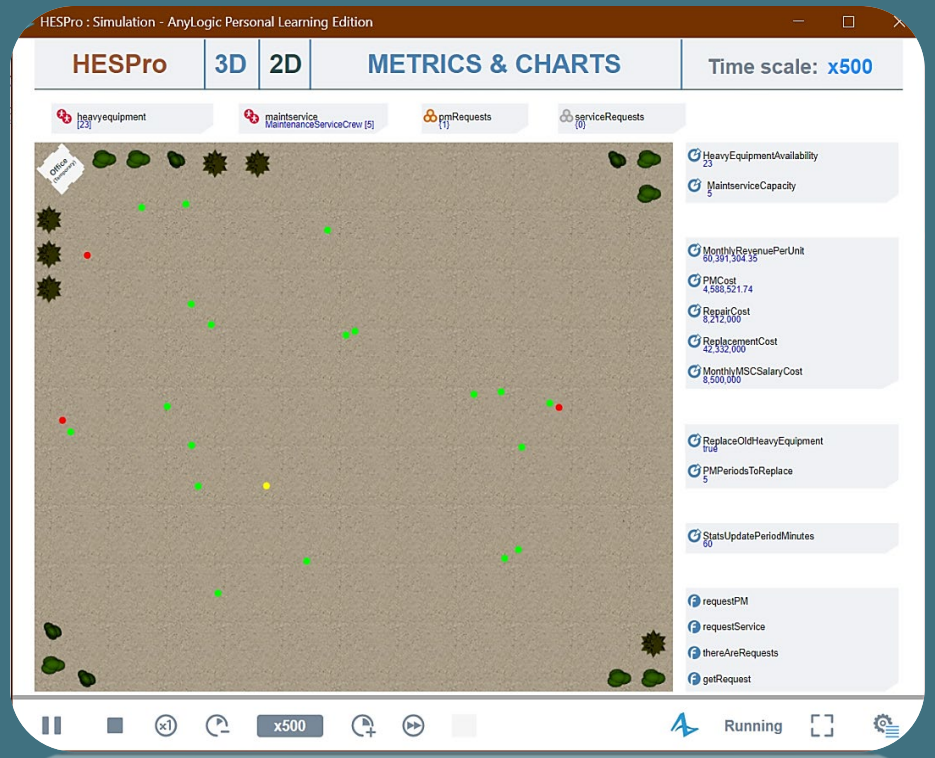


Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “After 5 PM Periods”

Experiment #9

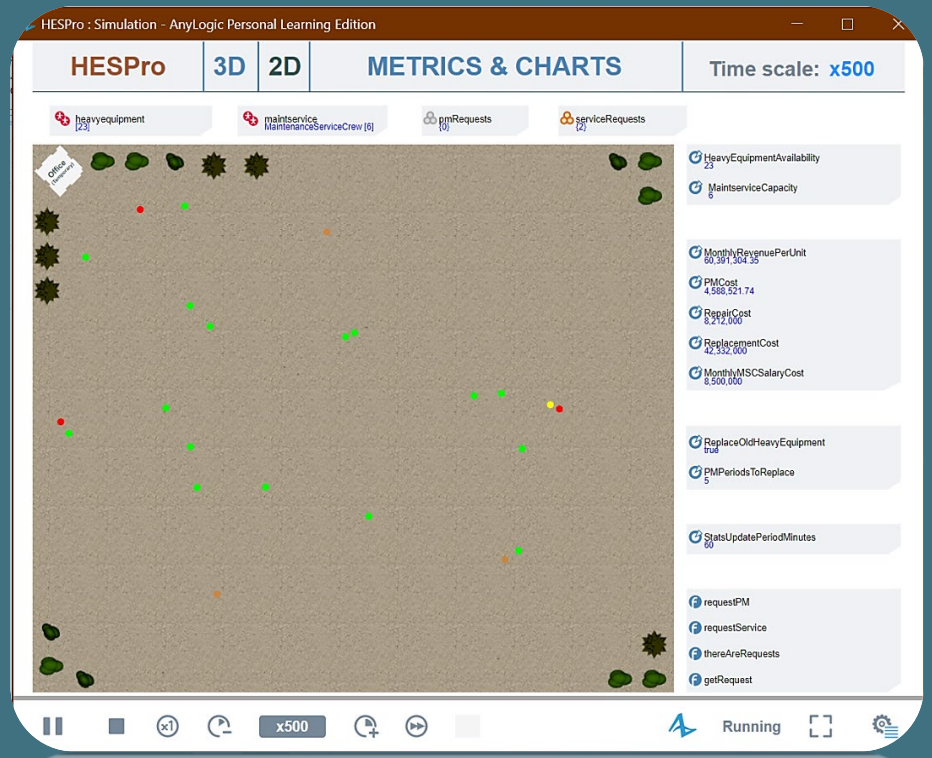


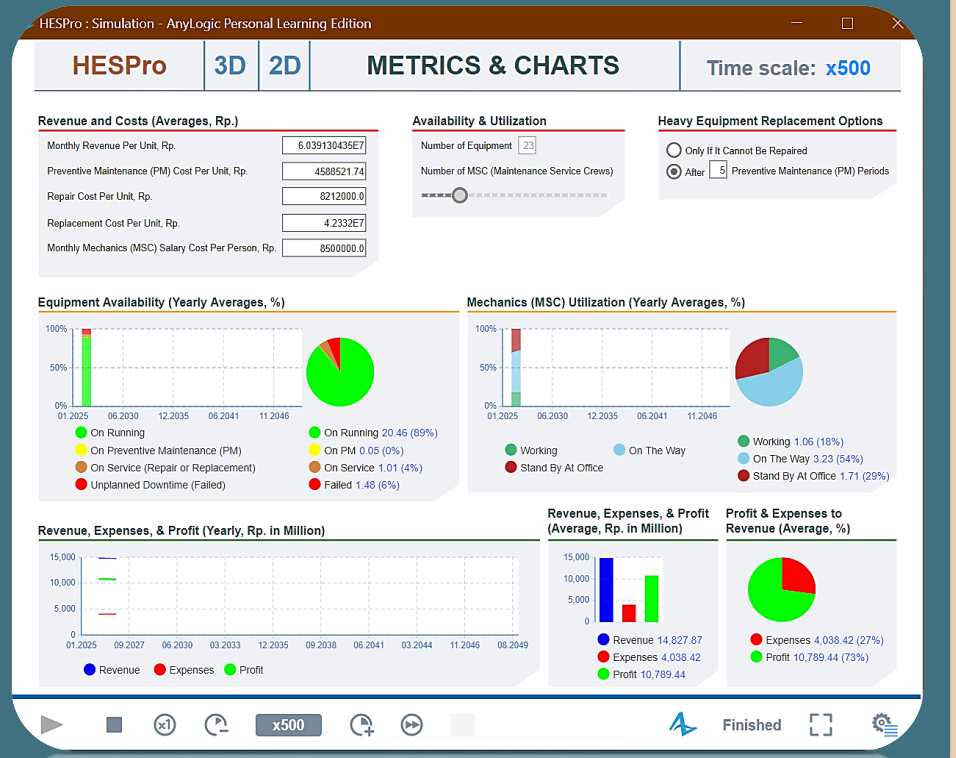
Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “After 5 PM Periods”

Experiment #10



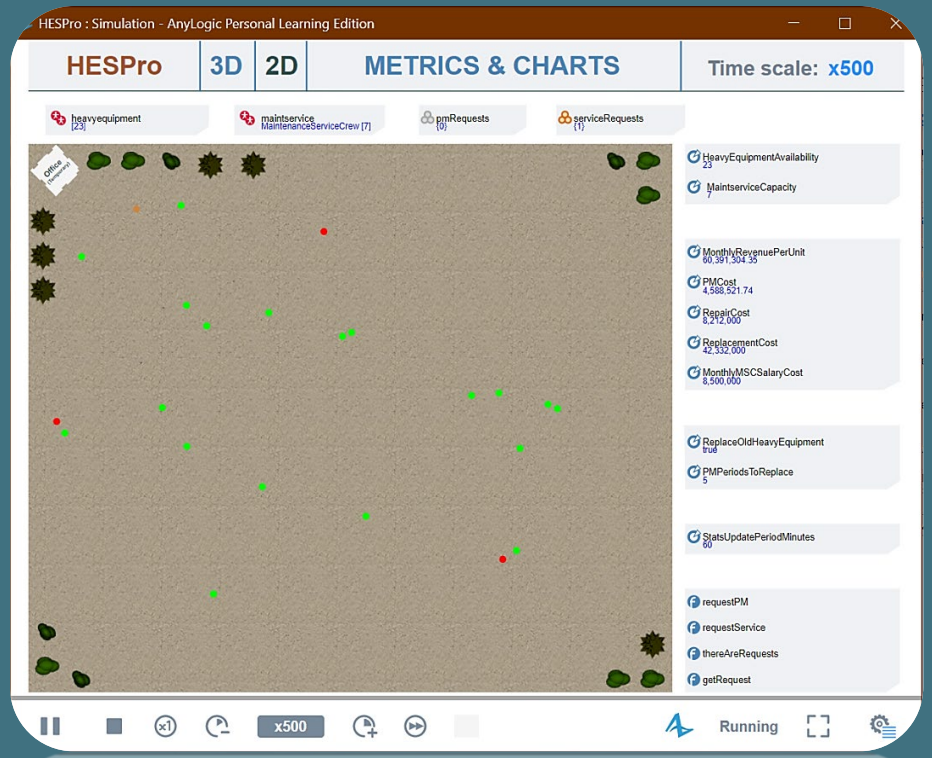


Simulation Analysis

8. Output from The AnyLogic Software Model

- Heavy Equipment Replacement Rule Options: “After 5 PM Periods”

Experiment #11



Simulation Analysis

9. Comparison of The Experiment Scenario Output

Because the construction project plan will finish at the end of 2026, the simulation takes the average forecast for the next two ends of the year: 2025 and 2026. Noted that the color of "Green" means the value gap is increasing, while the "Red" one means the value gap is decreasing.

Description	Heavy Equipment's Availability				Mechanics' Utilization			Revenue	Expenses	Profit
	On Running (Yearly Averages, %)	On Preventive Maintenance (PM) (Yearly Averages, %)	On Service (Repair or Replacement) (Yearly Averages, %)	Unplanned Downtime (Failed) (Yearly Averages, %)	Working (Yearly Averages, %)	On The Way (Yearly Averages, %)	Stand By At Office (Yearly Averages, %)	Heavy Equipment (Yearly Averages, Rp. in Million)	Heavy Equipment & Mechanics (Yearly Averages, Rp. in Million)	Heavy Equipment (Yearly Averages, Rp. in Million)
Heavy Equipment Replacement Rule Options: Only If It Cannot Be Repaired										
Real Condition (2 Persons)	60.62%	0.13%	2.91%	12.73%	34.95%	41.02%	0.42%	Rp 10,104.21	Rp 3,121.41	Rp 6,982.80
Experiment #1 (3 Persons)	86.93%	0.21%	4.19%	8.67%	33.73%	57.43%	8.87%	Rp 14,489.63	Rp 3,585.46	Rp 10,904.17
Gap to real condition	26.31%	0.08%	1.28%	4.06%	1.22%	16.41%	8.45%	Rp 4,385.42	Rp 464.05	Rp 3,921.37
Experiment #2 (4 Persons)	88.26%	0.21%	4.52%	7.02%	27.18%	55.85%	16.98%	Rp 14,710.93	Rp 3,922.19	Rp 10,788.75
Gap to real condition	27.64%	0.08%	1.61%	5.71%	7.77%	14.83%	16.56%	Rp 4,606.72	Rp 800.78	Rp 3,805.95
Experiment #3 (5 Persons)	88.66%	0.22%	4.37%	6.74%	21.14%	56.42%	22.42%	Rp 14,778.03	Rp 3,877.21	Rp 10,900.82
Gap to real condition	28.04%	0.09%	1.46%	5.99%	13.81%	15.40%	22.00%	Rp 4,873.82	Rp 755.80	Rp 4,018.02
Experiment #4 (6 Persons)	88.83%	0.23%	4.49%	6.45%	18.05%	54.27%	27.67%	Rp 14,807.31	Rp 4,072.33	Rp 10,734.97
Gap to real condition	28.21%	0.10%	1.58%	6.28%	16.90%	13.25%	27.25%	Rp 4,902.10	Rp 951.92	Rp 3,952.17
Experiment #5 (7 Persons)	89.10%	0.21%	4.35%	6.33%	15.00%	50.49%	34.51%	Rp 14,850.95	Rp 4,116.81	Rp 10,734.14
Gap to real condition	28.48%	0.08%	1.44%	6.46%	19.95%	9.43%	34.09%	Rp 4,746.74	Rp 995.40	Rp 3,751.34

Description	Heavy Equipment's Availability				Mechanics' Utilization			Revenue	Expenses	Profit
	On Running (Yearly Averages, %)	On Preventive Maintenance (PM) (Yearly Averages, %)	On Service (Repair or Replacement) (Yearly Averages, %)	Unplanned Downtime (Failed) (Yearly Averages, %)	Working (Yearly Averages, %)	On The Way (Yearly Averages, %)	Stand By At Office (Yearly Averages, %)	Heavy Equipment (Yearly Averages, Rp. in Million)	Heavy Equipment & Mechanics (Yearly Averages, Rp. in Million)	Heavy Equipment (Yearly Averages, Rp. in Million)
Heavy Equipment Replacement Rule Options: After 5 Preventive Maintenance (PM) Periods										
Experiment #6 (2 Persons)	78.93%	0.17%	3.90%	17.00%	46.85%	52.65%	0.50%	Rp 13,155.64	Rp 3,280.73	Rp 9,874.91
Gap to real condition	18.31%	0.04%	0.99%	4.27%	11.90%	11.63%	0.08%	Rp 3,051.43	Rp 159.32	Rp 2,892.11
Experiment #7 (3 Persons)	87.05%	0.20%	4.17%	8.59%	33.47%	56.63%	9.90%	Rp 14,508.90	Rp 3,540.35	Rp 10,968.55
Gap to real condition	26.43%	0.07%	1.26%	4.14%	1.48%	15.61%	9.48%	Rp 4,404.69	Rp 418.94	Rp 4,085.75
Experiment #8 (4 Persons)	88.17%	0.21%	4.62%	7.00%	27.80%	55.85%	16.35%	Rp 14,695.79	Rp 4,011.11	Rp 10,684.68
Gap to real condition	27.55%	0.08%	1.71%	5.73%	7.15%	14.83%	17.05%	Rp 4,591.58	Rp 800.70	Rp 3,793.88
Experiment #9 (5 Persons)	89.32%	0.21%	4.33%	6.13%	20.92%	53.28%	25.80%	Rp 14,888.18	Rp 3,836.14	Rp 11,052.04
Gap to real condition	28.70%	0.08%	1.42%	6.60%	14.03%	12.26%	23.38%	Rp 4,783.87	Rp 744.73	Rp 4,069.34
Experiment #10 (6 Persons)	88.96%	0.22%	4.40%	6.43%	17.68%	53.78%	28.53%	Rp 14,827.87	Rp 4,038.42	Rp 10,789.44
Gap to real condition	28.34%	0.09%	1.49%	6.30%	17.27%	12.76%	28.13%	Rp 4,723.66	Rp 917.01	Rp 3,806.65
Experiment #11 (7 Persons)	89.18%	0.20%	4.62%	6.00%	15.83%	48.43%	35.73%	Rp 14,864.23	Rp 4,244.67	Rp 10,619.56
Gap to real condition	28.56%	0.07%	1.71%	6.73%	19.12%	7.14%	27.21%	Rp 4,760.02	Rp 1,123.26	Rp 3,636.76

Business Solution

From the Front Group Discussion (FGD) with relevant stakeholders yielded numerous insights to address the business issue, specifically:

1. The lack of mechanics causes increased heavy equipment downtime. By optimizing the number of mechanics in the maintenance service division, the goal is to reduce downtime and increase equipment availability to support smooth project progress.

2. By adding a new heavy equipment replacement rule option "after 5 Preventive Maintenance (PM) periods" in addition to the "only if it cannot be repaired" option, it is expected to be a new and more efficient alternative to the heavy equipment replacement rule when comparing the two of them in simulation.

3. Focusing on reducing heavy equipment unplanned downtime

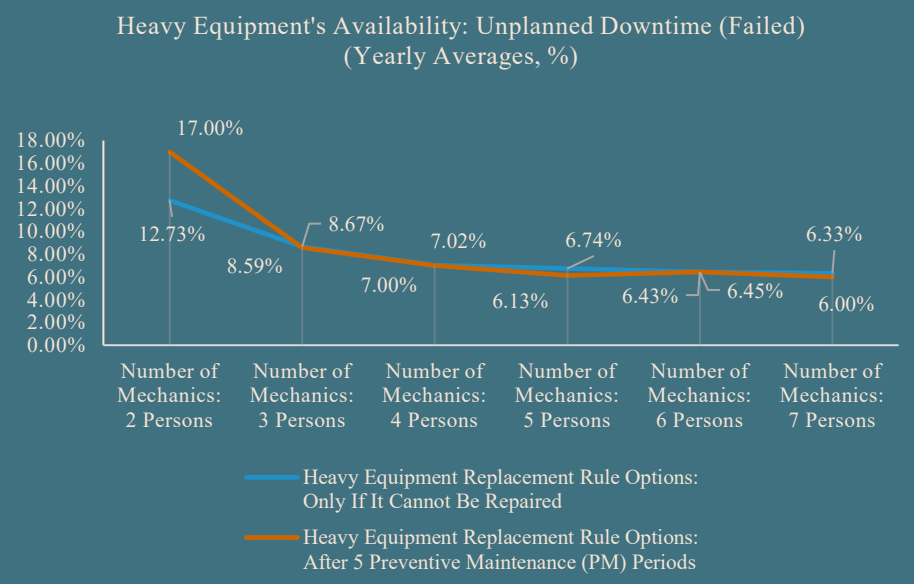
4. Focusing on enhancing heavy equipment running

5. Focusing on maximizing heavy equipment profits

Business Solution

From the simulation in AnyLogic and according to the business issue in chapter I, researcher will analysis the 3 key points from the previous comparison experiments table:

1. Reducing Heavy Equipment Unplanned Downtime (Failed)



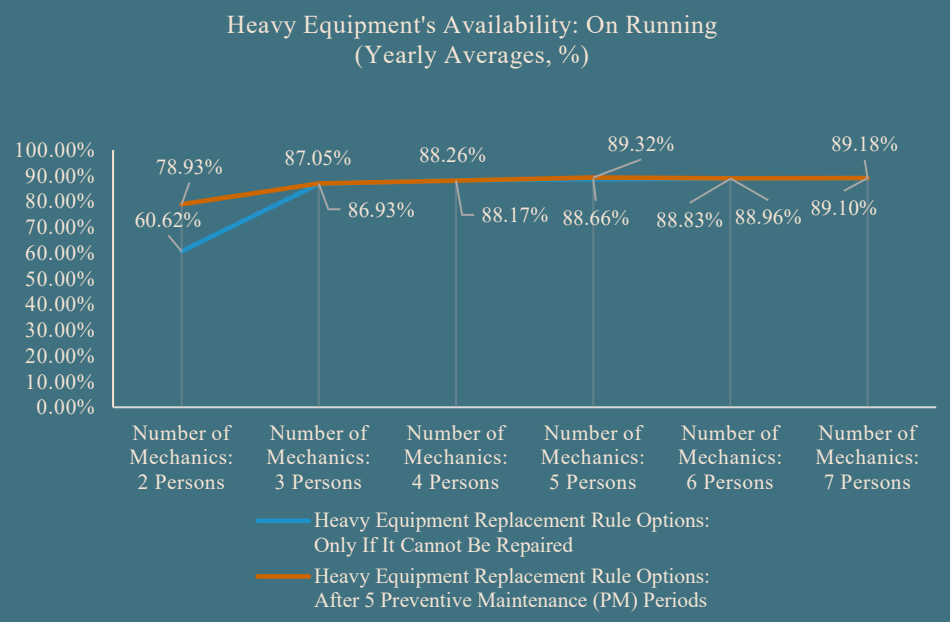
Experiment #9 (5 mechanics with equipment replacement after 5 Preventive Maintenance (PM) periods) showed the best performance with the lowest unplanned downtime of 6.13%, outperforming experiment #6 (2 mechanics) which had 17.00% downtime. This highlights the effectiveness of using five mechanics and timely equipment replacement in reducing downtime and improving equipment availability.

Although experiment #11 (7 mechanics) had slightly lower downtime (6.00%) than experiment #9 (6.13%), experiment #9 was more cost-efficient with fewer mechanics (5 mechanics), leading to lower operating costs and higher profitability. The small difference in downtime (0.13%) further supports the superior cost-performance balance in experiment #9.

Business Solution

From the simulation in AnyLogic and according to the business issue in chapter I, researcher will analysis the 3 key points from the previous comparison experiments table:

2. Enhancing Heavy Equipment On Running

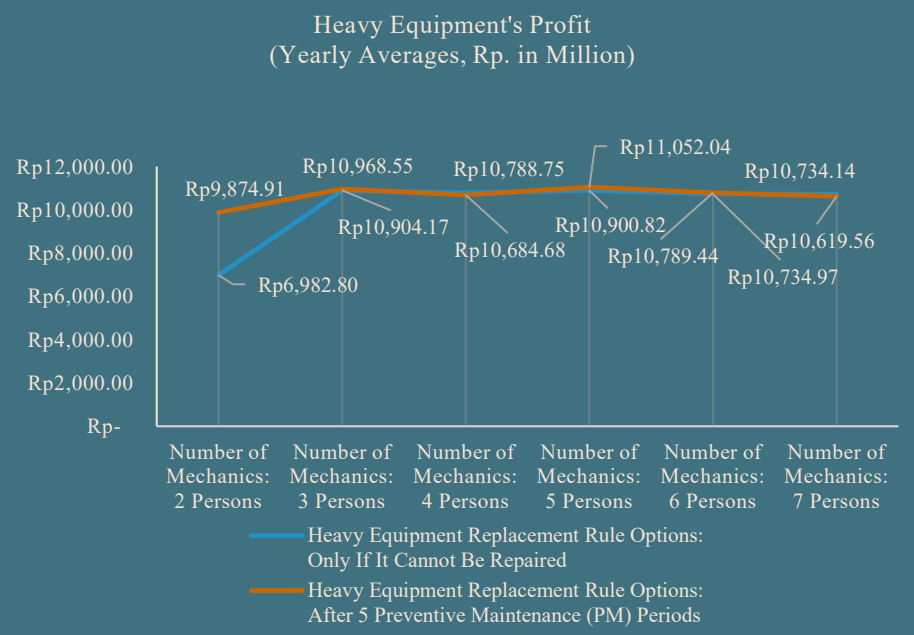


Experiment #9 (5 mechanics with equipment replacement after 5 Preventive Maintenance (PM) periods) achieved the highest heavy equipment availability at 89.32%, outperforming other experiments. While experiment #11 (7 mechanics) had 89.18%, experiment #9 used fewer mechanics, reducing operational costs without sacrificing equipment availability. This demonstrates better efficiency in resource utilization and preventive maintenance, making experiment #9 the optimal choice for long-term equipment availability.

Business Solution

From the simulation in AnyLogic and according to the business issue in chapter I, researcher will analysis the 3 key points from the previous comparison experiments table:

3. Maximizing Heavy Equipment Profits

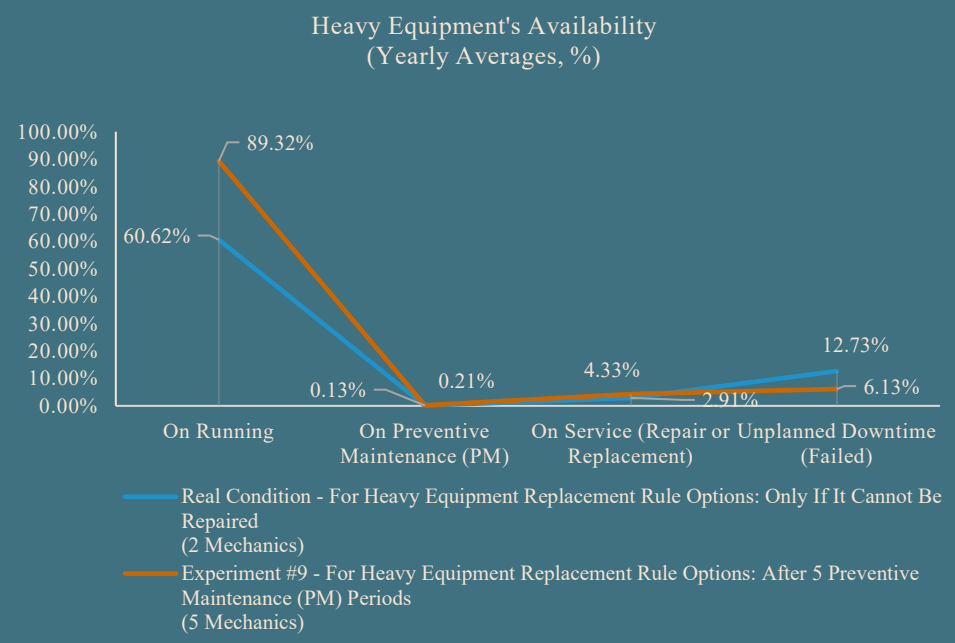


Experiment #9 (5 mechanics with equipment replacement after 5 Preventive Maintenance (PM) periods) achieved the highest profit of Rp. 11,052.04 million, outperforming other experiments. This experiment offers an efficient balance between operational costs and preventive maintenance, making it the most effective choice for maximizing heavy equipment profits.

Business Solution

In addition, the following are the outcomes of alternative experiment # 9 that have been simulated from each section compared to its real condition data:

1. Heavy Equipment's Availability Section

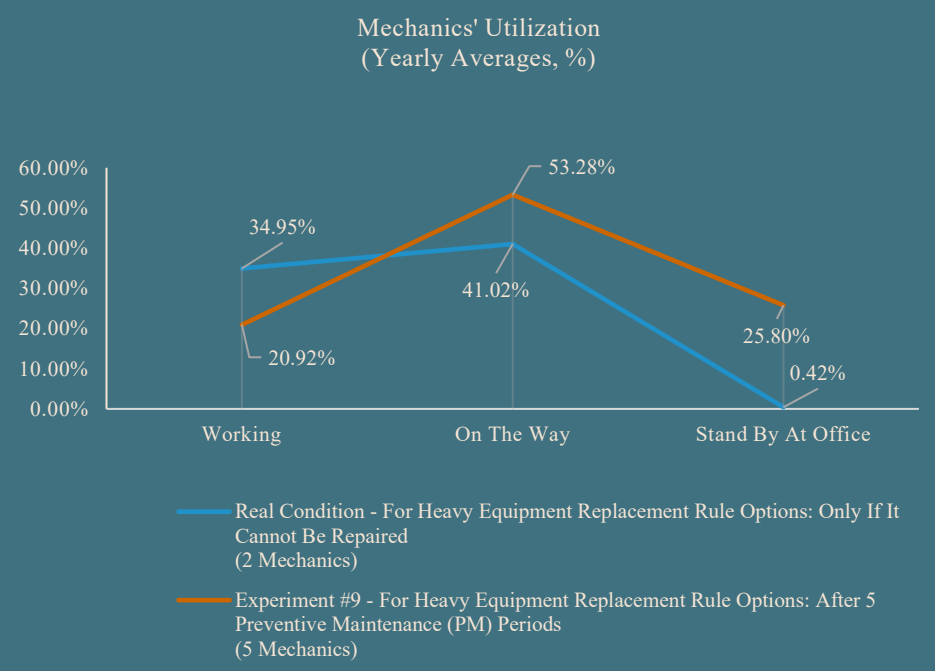


Experiment #9 also showed the highest equipment availability at 89.32% on running, significantly better than the real conditions, where availability was only 60.62%. By optimizing the number of mechanics and replacing equipment after 5 preventive maintenance periods, we achieved better resource utilization, ensuring that the equipment remained operational without overburdening the maintenance crew.

Business Solution

In addition, the following are the outcomes of alternative experiment # 9 that have been simulated from each section compared to its real condition data:

2. Mechanics' Utilization Section

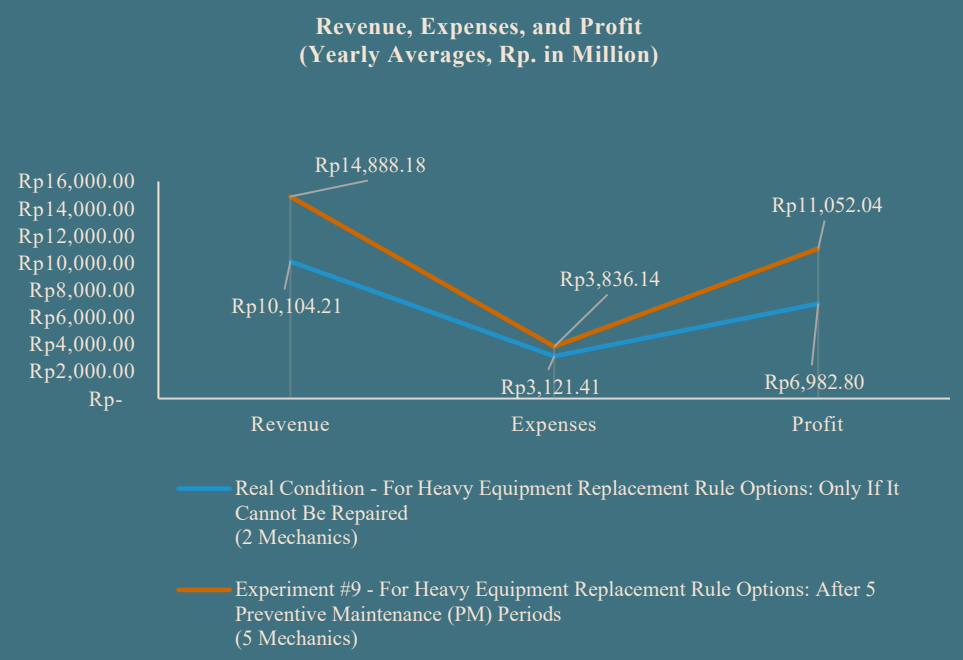


Experiment #9 optimized mechanic crew utilization, increasing standby time from 0.42% in real conditions to 25.80%. In real conditions, mechanics were overloaded with work, leaving little rest. However, with 5 mechanics in experiment #9, working time (20.92%), on the way (53.28%), and standby time (25.80%) were more balanced, indicating a healthier work system and better responsiveness to equipment damage.

Business Solution

In addition, the following are the outcomes of alternative experiment # 9 that have been simulated from each section compared to its real condition data:

3. Revenue, Expenses, and Profit Section



Experiment #9 increased profit from Rp. 6,982.80 million to Rp. 11,052.04 million, a 58% rise, driven by revenue growth from Rp. 10,104.21 million to Rp. 14,888.18 million. While costs rose from Rp. 3,121.41 million to Rp. 3,836.14 million, the increase in costs was much smaller than the revenue increase, highlighting improved cost efficiency and a larger profit margin.

Implementation Plan

In addition, the following are the outcomes of alternative experiment # 9 that have been simulated from each section compared to its real condition data:

EPC'S HEAVY EQUIPMENT FOR COAL FIRED STEAM POWER PLANT (CFSPP) PROJECT

Phase	Description	Key Tasks	PIC	Implementation Schedule Plan									
				Apr 2025		May 2025				Jun 2025			
				W4	W5	W1	W2	W3	W4	W1	W2	W3	W4
I.	Planning	Planning and discussing the implementation of experiment #9	Project Owner, EPC										
II.	Briefing and giving direction	Instructing the maintenance services (mechanics) crew involved	Project Owner, EPC										
III.	Conducting experiment #9	Executing the experiment in accordance with the changing made that implemented in the simulation process.	EPC										
		Observing the experiment's process	Project Owner, EPC										
		Calculating the heavy equipment availability, mechanic's utilization, revenue, expenses, and profit	EPC										
IV.	Analyzing	Processing the result of experiment	EPC										
		Analyzing the implementation results	Project Owner, EPC										
V.	Evaluation	Conducting the evaluation of the experiment results	Project Owner, EPC										
VI.	Submission	Presenting the outcome of the experiment test	EPC										

Conclusion

After researcher's investigation of the business issue and the proposed business solution, the after-research results are presented to answer the research questions:

1. **What is the best optimal solution that could be implemented to reduce heavy equipment unplanned downtime, enhance heavy equipment running, and maximize heavy equipment profits at PT. XYZ's construction project?**

By establishing these conditions into a design simulation, then according to the output issued, researcher obtained the best optimal results by experiment #9 compared to other experiment scenario designs. The following are the reasons:

a) Reducing Heavy Equipment Unplanned Downtime

The results from the simulation revealed that experiment #9, which involved 5 mechanics and the new equipment replacement rule after 5 preventive maintenance periods, reduced unplanned downtime to 6.13%. This was significantly lower than the real conditions, where downtime was 12.73%. Although experiment #11 (7 mechanics) had slightly lower unplanned downtime (6.00%), however, experiment #9 was still more optimal because it used fewer mechanics, leading to lower operating costs without sacrificing significant performance. The use of 5 mechanics in experiment #9 provided better cost efficiency compared to 7 mechanics in experiment #11, even though the difference in downtime was very small (0.13% difference only).

b) Enhancing Heavy Equipment Running

It also successfully increasing the percentage of heavy equipment that was on running from 60.62% to 89.32%. This improvement reflects the success of optimizing the combination of the number of mechanics (5 persons) and a more proactive heavy equipment replacement rule (replacing it after 5 PM periods).

Conclusion

After researcher's investigation of the business issue and the proposed business solution, the after-research results are presented to answer the research questions:

1. **What is the best optimal solution that could be implemented to reduce heavy equipment unplanned downtime, enhance heavy equipment running, and maximize heavy equipment profits at PT. XYZ's construction project?**

By establishing these conditions into a design simulation, then according to the output issued, researcher obtained the best optimal results by experiment #9 compared to other experiment scenario designs. The following are the reasons:

c) Maximizing Heavy Equipment Profits

The heavy equipment's profit increased from Rp. 6,982.80 million (real condition) to Rp. 11,052.04 million (experiment #9). The result is a profit jump of more than 58%, driven by an increase in revenue from Rp. 10,104.21 million to Rp. 14,888.18 million. Although there was an increase in costs (from Rp. 3,121.41 million to Rp. 3,836.14 million), these additional costs were much smaller than the increase in revenue. This means that experiment #9's strategy significantly improved cost efficiency per operating heavy equipment and contributed to the achievement of a much larger profit margin. In addition, experiment #9 showed higher profitability, thus providing a better balance between reduced downtime, operating costs, and overall financial performance.

Conclusion

After researcher's investigation of the business issue and the proposed business solution, the after-research results are presented to answer the research questions:

2. How to implement the solution?

Based on the results of the FGD and ABM simulation, the best solution is to increase the number of mechanics to 5 people and change the heavy equipment replacement rules to become after 5 Preventive Maintenance (PM) periods. This process requires in-depth analysis and challenging proposals for the company, including data validation that can prove that adding mechanics and changing heavy equipment replacement rules can reduce unexpected downtime, improve heavy equipment performance, and maximize heavy equipment profits in the PT. XYZ construction project. The criteria for the success of this implementation can be seen from the simulation results using Agent-Based Simulation in AnyLogic version 8.9.4, which can support stakeholders in proposing improvement solutions, as well as assisting EPC companies in planning the number of mechanics needed to reduce heavy equipment downtime and ensure that construction projects continue to run according to target.

Recommendation

Recommendation

1

Based on the findings of the research, researcher recommends PT. XYZ should consider adding 5 mechanics immediately to their maintenance service crew and adopt a new heavy equipment replacement rule after 5 Preventive Maintenance (PM) periods. This adjustment would help reduce unplanned downtime, improve heavy equipment availability, and maximize the overall profits of the construction project.

2

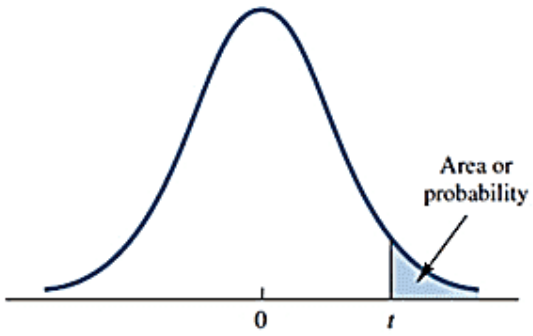
According to the analysis showing that the percentage of "on the way" for mechanics is quite high, especially in experiment #9 which used 5 mechanics with the equipment replacement rule after 5 Preventive Maintenance (PM) periods (53.28%), compared to the actual condition (41.02%), it is highly recommended by researcher that PT. XYZ consider providing off-road vehicles such as cross motorcycles for the mechanics. This is due to the large construction project area (around 300 hectare), which makes travel between heavy equipment locations time-consuming if done only by walking from the temporary office to the field.

Future Research Suggestions

- The model's scope can be expanded to include external factors like fuel price fluctuations, supplier involvement, and weather conditions.
- Additionally, integrating machine learning for real-time failure prediction could enhance the accuracy of the model.
- Testing the model in different kind of construction projects (not only for coal fired steam power plant project) could also assess its scalability and adaptability.

Table of Distribution *t* Based on *df* = 9

t DISTRIBUTION



Entries in the table give *t* values for an area or probability in the upper tail of the *t* distribution. For example, with 10 degrees of freedom and a .05 area in the upper tail, $t_{.05} = 1.812$.

Degrees of Freedom	Area in Upper Tail					
	.20	.10	.05	.025	.01	.005
1	1.376	3.078	6.314	12.706	31.821	63.656
2	1.061	1.886	2.920	4.303	6.965	9.925
3	.978	1.638	2.353	3.182	4.541	5.841
4	.941	1.533	2.132	2.776	3.747	4.604
5	.920	1.476	2.015	2.571	3.365	4.032
6	.906	1.440	1.943	2.447	3.143	3.707
7	.896	1.415	1.895	2.365	2.998	3.499
8	.889	1.397	1.860	2.306	2.896	3.355
9	.883	1.383	1.833	2.262	2.821	3.250
10	.879	1.372	1.812	2.228	2.764	3.169

Thank You