Maintenance Of Raw Mill Machines Using Monte Carlo Simulation: A Case Study at Cement Company in Indonesia

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Abstract

PT. Semen Padang is the first cement company in Indonesia, established on March 18, 1910. To produce raw materials into finished materials, PT. Semen Padang uses three main machines: raw mill, kiln mill, and cement mill. To achieve the production target, PT. Semen Padang must have a machine that is qualified in operation. Therefore, proper maintenance of critical machinery in PT. Semen Padang. One of the critical machines that need maintenance is the raw mill machine. If the raw mill machine is damaged and causes the termination of the operating process, other machines will also not be able to operate. Therefore, maintenance is carried out on the critical components of the raw mill 4R1 indarung IV machine. To solve the problem with PT. Semen Padang planned treatment scheduling using Monte Carlo simulation, where this method is simulated by random number generation. The strategy proposed in the Monte Carlo simulation uses two scenarios, namely corrective maintenance and MTTF. The study results are the right maintenance strategies for raw mill machines and separators are preventive maintenance, and for boom side reclaimer machines that are corrective maintenance.

Keywords: Preventive Maintenance, Corrective Maintenance, Monte Carlo

1. Introduction

The fast expansion of the industrial world requires a business to be more competent to compete effectively and efficiently. There are several methods for companies to improve their effectiveness and efficiency, one of which is through efforts to optimize facility operations and minimize losses due to equipment damage. Damage to equipment can result in the stop of production, resulting in the company's production losing track of the objective. To achieve maximum output, it is necessary to have equipment that operates at optimum efficiency. As a result, a well-planned schedule of equipment maintenance is essential.

In general, equipment deterioration does not occur uniformly. As a result, each piece of equipment receives a unique level of care. There are three types of damaged equipment: mistreated, old equipment, and equipment that is affected by people. As a result, each piece of equipment requires specific treatment to increase performance, expand its life, and optimize its operation. It is the probability of a system running normally under certain operating conditions for a specified period (Suhendra et al. 2020). There are three basic forms of machine maintenance: breakdown, preventative, and corrective.

PT. Semen Padang is one of Indonesia's leading cement companies. PT. Semen Padang was established on March 18, 1910, as Indonesia's first cement company. PT. Semen Padang covers a large area of over 630 acres and has six facilities with an annual production capacity of 8,900,000 tons. PT. Semen Padang operates six plants, each employing three pieces of equipment in the manufacturing process. These machines include raw mill machines (tube mill and vertical mill), kiln machines, and cement mill machines. This machine operates continuously to generate products that fulfil the company's target. A raw mill machine is the first step in the production of cement. A raw mill machine is a machine that is used to smooth out cement forming ingredients. Raw mixes are materials that have been mashed in a raw mill. Raw mill machines have a significant impact on the manufacturing process since if the raw mill machine stops producing raw mix, the stage of cement manufacture will also stop. Raw mill 4R1 is the raw mill with the lowest OEE and performance rate of the six facilities that create raw mix. Low-performance rate values equate to ineffective engines. High downtime and frequent breakdowns contribute to a low-performance rate.

In 2019, the raw mill 4R1 engine was shut down 80 times, resulting in a total downtime of 293.63 hours, or approximately 13 days. PT. Semen Padang has performed preventive maintenance on existing equipment, but the damage frequency is not related to the frequency of PMC (Preventive Maintenance Control) at PT. Semen Padang, with a high enough frequency of breakdowns and downtime in the raw mill, the raw mix manufacturing process is inefficient. The resulting damage might result in a variety of different types of losses. One of them is the inability to meet the required level of raw mix production.

In relation to the issues found at PT. Semen Padang, preventive maintenance can be used to treat critical components of raw mill 4R1 engines indarung IV. As Asprilla and Agustiar (2020) state, preventive maintenance can reduce component damage frequency, minimize the frequency of component product failure, and increase production capacity while also reducing repair costs. As a result, the Monte Carlo approach will be used to calculate preventive maintenance scheduling on essential components of the Raw Mill 4R1 Indarung IV engine. This approach is applied because it can simulate and test quantitative issues in advance, hence predicting problems. Monte Carlo is based on the idea of random number generation. The Monte Carlo technique results in more optimum preventative scheduling, increasing reliability, performance and minimizing downtime. This study uses the Monte Carlo approach to design the recommended schedule of preventive maintenance for raw mill machine 4R1 Indarung 4.

2. Literature Review

According to Safytri et al. (2020), maintenance is a collection of all actions performed to maintain an item, piece of equipment, or machine and improve it to obtain a better and more acceptable condition. According to Coder's description, maintenance is a concept that covers all operations required to maintain or maintain the quality of items or equipment to work effectively (Ma,Z et al. 2020)

Siregar and Munthe (2019) said the treatment aims to help solve all problems related to the sustainability of manufacturing activities, including extending the lifetime of industrial equipment and facilities, minimizing downtime, increasing reliability, efficiency, and production resources, increasing the expertise of industrial care department personnel, increasing product added value, allowing businesses to compete on the global market, and assisting decision-makers in making informed choices.

Reliability enhancement is one of the objectives of maintenance. According to (Daely and Rahardjo, 2019), the idea of maintenance (reliability) is also well understood for the numerous distributions and parameters. The distribution patterns discovered provide insight into the machinery or equipment damage rate. Weibull distributions, lognormal distributions, exponential distributions, and normal distributions are the four types of distributions (Riantama 2020)

Kumar (2018) studied a comprehensive examination of the different aspects that affect the overall availability of a manufacturing facility. Additionally, it explains the many RAM tools, techniques, and procedures, including qualitative, quantitative, and commercially available software(s) for supporting RAM research and integrating contemporary approaches in conceptual process design. Numerous studies have worked over the previous few decades to examine various issues, including reliability-availability analysis methodologies. The final portion of the study tries to provide a directive model for conducting research in a certain field using the most reliable instruments possible while adhering to specified resource limits.

The reliability distribution is used to determine the mean time to failure (MTTF) and mean time to repair (MTTR) (Yadavalli 2018). According to (Daely and Rahardjo, 2019), the mean time to failure (MTTF) is the average value of the time required for a system to fail (spare part components). While mean time to repair (MTTR) is the average time between when a machine or component is fixed and when it is damaged again.

Monte Carlo simulation was employed in this study. According to (Manurung and Santony, 2019) and (Robas et al. 2021). Monte Carlo is a highly effective numerical method for simulating complex systems in various domains, ranging from economics to physics (Srivastava 2020), (Sakib 2018). This method is based on probability and uses random numbers to characterize the relevant system's parameters. Monte Carlo simulation was also used to develop the model that coordinates preventive maintenance minimizing the risk of loss of load probability in the Power System (Duarte et al. 2020). It also can estimate the maintenance budget. Another study was used the Monte Carlo simulation for forecasting demand in the SMEs industry (Jufriyanto 2020)

3. Methods

The data in this study is collected from original data such as direct observation and includes secondary sources such as journals and books. This study contains data processing processes that begin with identifying important components via Pareto diagrams. The distribution and parameter tests will be performed utilizing the Minitab 16 application. Following that, MTTF and MTTR calculations are performed. And the final one was performed using Monte Carlo simulations and random number generation to determine the proper treatment for important components and maintenance intervals.

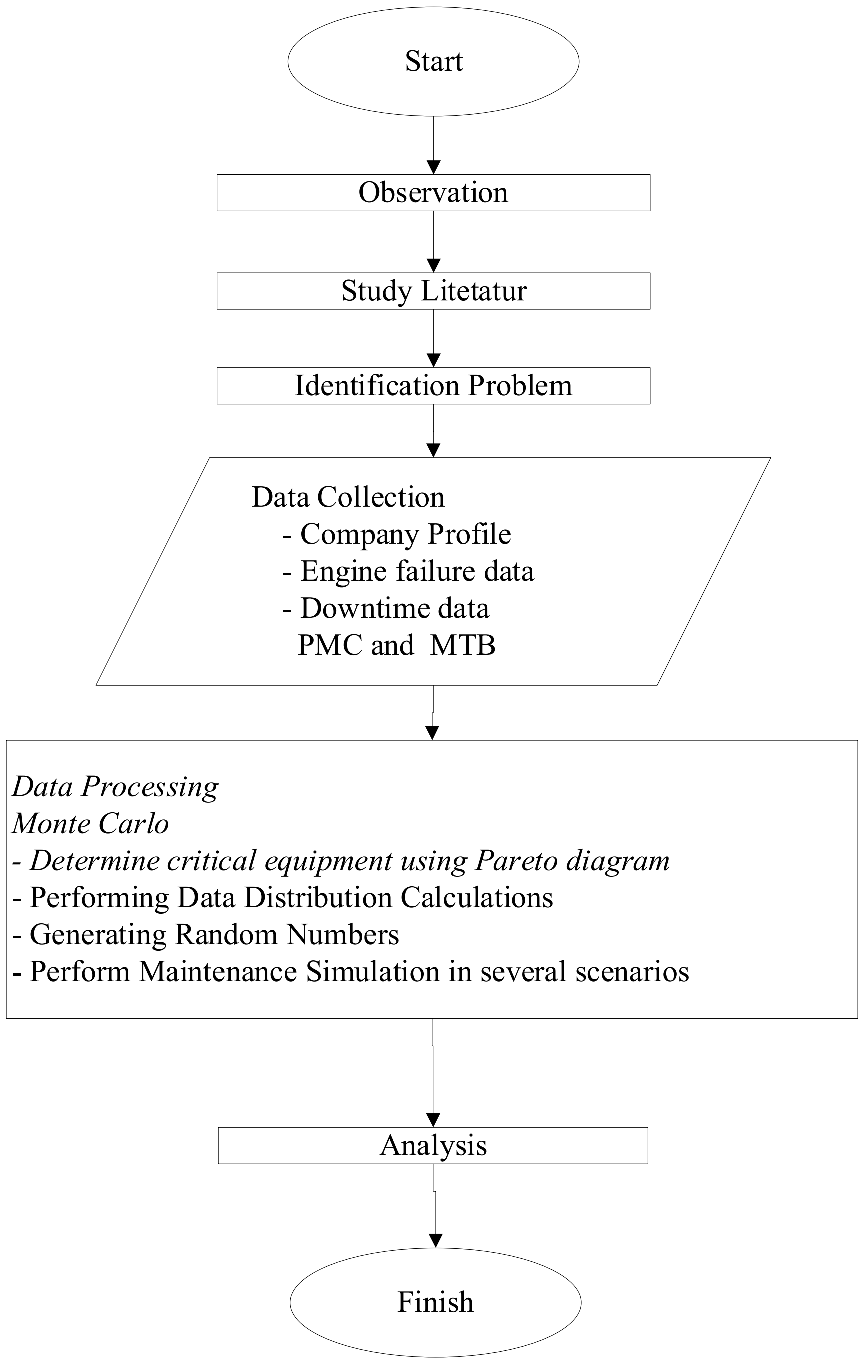

Figure 1. Flowchart Research

4. Data Collection

OEE Raw Mill Machine PT. Semen Padang

OEE determines a machine's effectiveness based on three main ratios: availability, performance rate, and quality. PT. Semen Padang provided OEE data for its Raw Mill equipment in 2019, as shown in Table 1.

Table 1. OEE Machine Raw Mill PT. Semen Padang

	Availability	Performance Rate	Quality	OEE
INDARUNG III - 3R2	90%	80%	100%	72%
INDARUNG IV - 4R1	85%	80%	100%	68%
INDARUNG IV - 4R2	84%	83%	100%	70%
INDARUNG V - 5R1	87%	86%	100%	75%
INDARUNG V - 5R2	89%	88%	100%	78%
INDARUNG VI - 6R1	86%	92%	100%	79%
AVERAGE - PTSP	89%	72%	100%	62%

Raw Mill 4R1 Indarung IV Engine Damage Data

PT. Semen Padang's Raw Mill 4R1 engine has the lowest OEE in 2019. Table 2 contains information about the damage frequency, the duration of downtime, and the PMC performed on raw mill 4R1 engines indarung IV.

Table 2. Frequency Breakdown, Downtime and PMC Raw Mill 4R1 Engine 2019

Month	Breakdown Frequency	Downtime (Hours)	PMC Raw Mill 4R1 PT. Semen Padang
January	14	64,8	1
February	1	0,4	Overhaul
March	16	50,4	3
April	5	26,4	2
May	6	21,6	-
June	6	38,4	-
July	5	19,2	1
August	7	12	2
September	10	43,3	-
October	1	0,33	1
November	4	16,8	1
December	5	7.2	1
Total	80	293,63	12

Frequency of Damage Components Machine Raw Mill 4R1 Indarung IV

The Raw Mill 4R1 Indarung IV machine is composed of various components. Table 3 shows engine damage to Raw Mill 4R1 engine components indarung IV in 2019.

Table 3. Frequency of Damage to Raw Mill Machine Components 4R1 Indarung IV

Components	Frequency of Damage
Raw Mill 3B	43
Boom Side Reclaimer	10
Separator	6
Silica Dosimat Feeder	5
Belt Conveyor	4
Bucket Excavator	2
Fluxo Slide System	2

Mill Fan	2
Side Reclaimer	2
Limestone Dosimat Feeder	1
Cyclone	1
Motor Utara	1
Raw Mill Fan	1
Total	**80**

Time Data Between Damages
Based on the data obtained, the time between the specifics of each component in the clock is as follows table 4 and table 5,

Table 4. Raw Mill 3B (4R1M01)

NO	Raw Mill 3B	NO	Raw Mill 3B	NO	Raw Mill 3B	NO	Raw Mill 3B	NO	Raw Mill 3B
1	148,4	11	107,5	21	110,9	31	29,9	41	322,9
2	159,8	12	543,0	22	86,9	32	33,1	42	110,6
3	6,3	13	96,7	23	4,0	33	18,2		
4	226,0	14	303,2	24	130,1	34	22,2		
5	383,8	15	286,3	25	439,5	35	328,2		
6	193,2	16	59,5	26	1,1	36	159,5		
7	57,5	17	361,3	27	577,3	37	17,1		
8	212,4	18	54,7	28	66,7	38	176,1		
9	8,0	19	668,0	29	41,1	39	297,7		
10	129,2	20	10,0	30	27,4	40	72,1		

Table 5. Boom Side Reclaimer (4R1J11) and Separator (4R1S01)

NO	Boom Side Reclaimer	NO	Separator
1	5,4	1	134,1
2	20,6	2	215,9
3	26,8	3	360,2
4	110,5	4	5,3
5	21,5	5	151,3
6	47,1		
7	204,9		
8	18,7		
9	1,4		

Repair Time
Based on the data obtained, the repair time of each component in the following hours in table 6 and table 7.

Table. 6. Raw Mill 3B (4R1M01)

NO	Raw Mill 3B	NO	Raw Mill 3B	NO	Raw Mill 3B	NO	Raw Mill 3B	NO	Raw Mill 3B
1	5,90	11	0,25	21	7,28	31	3,33	41	1,65
2	3,87	12	0,35	22	0,57	32	0,60	42	2,77
3	1,75	13	1,70	23	4,73	33	1,18	43	1,87
4	7,92	14	0,58	24	5,62	34	3,62		
5	26,47	15	3,07	25	0,90	35	0,85		
6	2,78	16	7,22	26	0,08	36	0,33		

7	10,75	17	5,47	27	0,08	37	10,38		
8	0,93	18	0,13	28	11,62	38	2,57		
9	0,38	19	10,60	29	19,28	39	2,15		
10	13,68	20	0,38	30	1,08	40	0,62		

Table 7. Boom Side Reclaimer Repair Time (4R1J11) and Separator(4R1S01)

NO	Boom Side Reclaimer	NO	Separator
1	0,30	1	1,85
2	0,63	2	1,03
3	0,27	3	0,40
4	0,38	4	0,95
5	1,95	5	1,27
6	1,48	6	16,38
7	1,33		
8	0,08		
9	0,12		
10	0,50		

5. Results and Discussion

5.1 Numerical Results

A raw mill is a machine that smooths cement before moving on to the next stage. Raw Mill features continuous components that drive the machine and allow it to work on smoothing cement. The identification of important components is carried out to establish the severity of the damage and the need for additional therapy. A Pareto diagram is used to figure out what this crucial component is. Table 8 shows the raw mill engine components and the incidence of damage.

Table 8. Frequency of Damage, Percentage and Cumulative *Of Raw Mill* Machine Components 4R1 Indarung IV

Component	Frequency of Damage	Percentage	Cumulative
Raw Mill 3B	43	54%	54%
Boom Side Reclaimer	10	13%	66%
Separator	6	8%	74%
Silica Dosimat Feeder	5	6%	80%
Belt Conveyor	4	5%	85%
Bucket Excavator	2	3%	88%
Fluxo Slide System	2	3%	90%
Mill Fan	2	3%	93%
Side Reclaimer	2	3%	95%
Limestone Dosimat Feeder	1	1%	96%
Cyclone	1	1%	98%
North Motor	1	1%	99%
Raw Mill Fan	1	1%	100%
Total	**80**		

Table 4.8 indicates that the Raw Mill 3B, Boom Side Reclaimer, and Separator machines suffer from a high damage rate, allowing for the proper scheduling of the three important components.

Distribution tests and parameters against TTF and TTR

The Minitab 16 Software is used to perform distribution and parameter tests. Then, against TTF and TTR, the following recapitulation of distribution tests and parameters was obtained (Table 9),

Table 9. Distribution recapitulation and parameters against TTR and TTF

No	Machine	TTF Distribution	Parameters	TTR Distribution	Parameters
1	Raw Mill 3B (4R1M01)	Weibull	β=0,79 θ =157,43	Lognormal	α=1,45 μ=0,64
2	Boom Side Reclaimer (4R1J11)	Weibull	β = 0,70 θ =34,77	Lognormal	α=1,01 μ=0,79
3	Separator (4R1S01)	Normal	α=129,41 μ=173,36	Lognormal	α=1,15 μ=0,45

Parameters that have been obtained for each critical component, needed for random number generation

Determination of *Mean Time to Failure* (MTTF) and *Mean Time to Repair* (MTTR)
Based on the distribution that has been obtained, calculations are carried out on the average time of damage and repair time. Examples of MTTF calculations are as follows:
1. MTTF Raw Mill 3B

$$\text{MTTF} = \theta.\Gamma\left(1 + \frac{1}{\beta}\right)$$
$$= 157{,}43 \,.\, \Gamma\left(1+\frac{1}{0{,}78}\right)$$
$$= 157{,}43 \,.\, \Gamma(2{,}26)$$
$$= 157{,}43 \,.\, 1{,}139$$
$$= 179{,}31$$

$$\text{MTTR}= e^{\mu+\frac{1}{2}(\alpha)^2}$$
$$= e^{0{,}79+\frac{1}{2}(1{,}01)^2}$$
$$= 2{,}72^{1{,}3}$$
$$= 3{,}67$$

Recapitulation of MTTF and MTTR can be seen in Table 10.

Table 10. Recapitulation OF MTTF and MTTR

NO	Machine Name	MTTF(Jam)	MTTR (Jam)
1	Raw Mill 3B (4R1M01)	179,4	5,4
2	Boom Side Reclaimer (4R1J11)	43,7	3,6
3	Separator (4R1S01)	173,36	3,0

5.2 Graphical Results

Critical components of the 4R1 Indarung IV raw mill machine were obtained using Pareto diagrams. Where the Pareto diagram can show what problems must first be solved to eliminate damage and repair the operation. A Pareto diagram to terminate critical components can be seen in Figure 1.

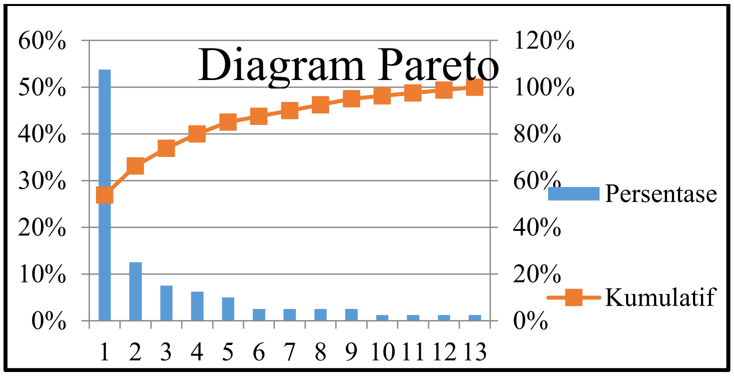

Figure 1. Pareto Diagram of Raw Mill Machine Damage Frequency 4R1 Indarung IV

5.3 Proposed Improvements

Monte Carlo Simulation

The first step in the Monte Carlo simulation is determining the scenario. The determination of this scenario is done to determine the type of treatment and the exact change time interval for each critical component. The treatment scenario is 2 of them:

Table 11. Proposed Critical Component Care Scenario

No	Machine Name	Scenario 1	Scenario 2
1	Raw Mill 3B (4R1M01)	Corrective Mantenance	MTTF = 179,4
2	Boom Side Reclaimer (4R1J11)	Corrective Mantenance	MTTF = 43,7
3	Separator (4R1S01)	Corrective Mantenance	MTTF = 173,36

Scenario 1, critical components are replaced when they suffer sudden damage (Corrective Maintenance). While Scenario 2, critical components are replaced according to the MTTF value of the engine's critical components.

After determining the scenario, random number generation is carried out as many as 250 samples. The purpose of generating random numbers is to produce values that have the same distribution as the TTF data population and TTR critical components of raw mill 4R1 machines. For the development of random numbers of critical parts of raw mill machine 4R1 can be seen in Table 12.

Table 12. TTF and TTR random number generation

No	TTF			TTR		
	4R1M01	4R1J11	4R1S01	4R1M01	4R1J11	4R1S01
1	669,25	13,.04619	207,6252	2,458973	2,834378	5,245552
2	229,93	103,938	226,3742	9,132961	1,822828	3,498259
3	140,77	5,661325	63,43961	5,135195	12,24609	1,023492
4	333,16	1,377146	362,3312	4,748966	2,608174	3,481378
5	111,92	40,9038	369,5356	7,594956	1,230607	9,804185
. . .	. . .	. . .	. . .	. . .	. . .	. . .
249	23,32262	175,2212	10,06279	1,76433	1,083038	1,083038
250	45,90032	172,8521	4,719166	0,419683	2,865571	2,865571

Next, do the scheduling maintenance using Monte Carlo simulations. The maintenance simulation on the critical components of the Raw Mill 4R1 Indarung IV engine based on the maintenance scenario aims to determine the amount of damage, total downtime, which will be used as a basis for consideration of the selection of the type of treatment and the appropriate replacement time interval for each critical component. The simulation was conducted over one year of 6000 hours for each critical component treatment scenario. The recapitulation of Monte Carlo simulation results can be seen in Table 13

Table 13. Recapitulation of Monte Carlo Machine Raw Mill 4R1 Indarung IV Simulation Results

Critical Machine	Scenario	TP (Frekquency)		Dt (Clock)	
		CM	PM	CM	PM
Raw Mill 3B (4R1M01)	Scenario 1	31	-	157,61	-
	Scenario 2	28	18	156,27	83,26
Boom Side Reclaimer (4R1J11)	Scenario 1	131	-	462,48	-
	Scenario 2	158	65	462,95	301,316
Separator (4R1S01)	Scenario 1	32	-	107,07	-
	Scenario 2	22	23	73,26	78,40

Table 13 describes the results of Monte Carlo simulations. It can be concluded that preventive maintenance can be used on Raw Mill 3B machines and Separator machines because preventive maintenance can reduce the frequency of breakdown in the engine components. In contrast, the Boom Side Reclaimer engine is more suitable for corrective maintenance because if preventive maintenance is done, the frequency of breakdown on this machine remains high.

5.4 Validation

One of the requirements for performing a Monte Carlo simulation is to ensure that the random numbers of TTF and TTR describe the actual situation. Therefore, a two-average comparison test is conducted between real TTF and TTR data with random number TTF and TTR data. The similarity test of these two averages is carried out for each critical component. The first two averages are done to the time between damages (TTF) for the similarity test.

1. Raw Mill 3B (4R1M01)
   a. Hypothetical formula:
      H0 : Average TTF Raw Mill value 3B real system = average TTF value Raw Mill 3B is the result of random number generation.
      H1: Average TTF Raw Mill 3B real system value ≠ average TTF value Raw Mill 3B is the result of random number generation.
   b. Determination of α (real level) of the t_{Table}
      $\alpha = 0{,}05$
      $df = 290$
      $t_{Tabel} = t_{\alpha,}$ df-2
      $= t_{0,05}$, 288
      $= 1{,}65016$
   c. Testing Criteria
      H0 is accepted if $-t_{Table} \leq t_{test} < t_{Table}$
      H0 is rejected if $t_{test} < -t_{Table}$ or $t_{test} > t_{Table}$
   d. Statistical test
      Statistical testing of the equation of two averages is done using SPSS Software 20. Test results can be seen in Table 14.

Table 14. Group Statistics TTF Raw Mill 3B (4R1M01)

condition	N	Mean	Std. Deviation	Std. Error Mean	t	df
Real	42	168.7571	169.16157	26.10238	-0.214	290
Random	250	16.0768	210.86531	13.33629		

   e. Withdrawal of Conclusions
      From the SPSS 20 Test Results, the results of the $\leq t_{test} < t_{Table}$ (-1.65016≤ -0.214 < 1.65016). Therefore, it can be noted that $_{H0}$ is accepted, i.e. The average value of TTF Raw Mill 3B real system = the average value of TTF Raw Mill 3B resulting from random number generation.

The recapitulation of the two average equality tests of random and real number TTF data using SPSS 20 is shown in table 15 and the recapitulation of the average similarity test of random and real number TTR data can be seen in table 16.

Table 15. Recapitulation test validity of real TTF data and random numbers

No.	Critical Components	T_{test}	T_{Table}	Result
1	*Raw Mill* 3B (4R1M01)	-0,214	1,65016	Accept H_0
2	*Boom Side Reclaimer* (4R1J11)	0,268	1,6509	Accept H_0
3	*Separator* (4R1S01)	-0,111	1,651	Accept H_0

Table 16. Recapitulation Test validity of real TTR data and random numbers

No	Critical Components	T_{test}	T_{Table}	Result
1	*Raw Mill* 3B (4R1M01)	-1,546	1,65004	Accept H_0
2	*Boom Side Reclaimer* (4R1J11)	-1,1635	1,65083	Accept H_0
3	*Separator* (4R1S01)	0,232	1,65092	Accept H_0

Based on Table 15 and Table 16, TTF and TTR data random number conditions reflect the same data form as real TTF and TTR.

6. Conclusion

In determining critical components using pareto diagram obtained 3 engine components that entered into 80% of the cause of damage, namely Raw Mill 3B with a frequency of damage of 43 times and a percentage of damage as much as 53%. The second is Boom Side Reclaimer, with a frequency of damage as much as 10 times and a percentage of damage of 13%. And the third is a separator with a frequency of damage as much as 6 times with a percentage of damage of 8%. Based on the results of Monte Carlo simulations, the right treatment for raw mill 3B (4R1M01) machine is preventive care by doing as many as 18 *preventive maintenance* measures with a maintenance time of 83.26 hours. The proper maintenance for *the Boom side reclaimer* (4R1J11) engine is corrective maintenance with 158 corrective maintenance activities for 158 hours. While the right treatment for the separator machine is preventive maintenance with preventive treatment as many as 23 times the action with a treatment time of 78.40 hours

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