Preventive Maintenance Scheduling with Age Replacement Method at CNG Station

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Abstract

CNG Mother Station focused to distribute Compressed Natural Gas for various industries. In the period from December 2020 to November 2021, there were 40 breakdowns in the distribution process machine causing delays in distribution of CNG. Company has to pay attention to the maintenance scheduling for vulnerabl components. This study aims to determine Preventive Maintenance scheduling and calculating maintenance costs using Age Replacement method for the critical components. The results showed that the critical components are Air Supply's Hose (ASH) and Double Nipple Stage 4 (DNS-4). The proposed optimal replacement time interval for the ASH is 20 days where 19 component replacements are scheduled in 1 year with a cost reduction up to 4.8% compared to existing. The optimal replacement time interval for DNS-4 components is 24 days, which is scheduled for 16 component replacements in 1 year with cost reduction up to 29.1% compared to existing.

Keywords: *Preventive Maintenance, Mean Time to Failure, Mean Time to Repair, Age Replacement, Cost saving.*

1. Introduction

PT Pertamina Gas is a company that operates between the upstream and downstream sectors (middle stream) which handles gas trading, gas transportation and gas processing and other businesses related to natural gas and its derivative products. In an effort to provide an environmentally friendly energy source at an affordable price, PT Pertamina Gas built a new facility, namely the Bitung CNG Mother Station in Tangerang. This company is engaged in the distribution of gas fuel, especially Compressed Natural Gas for various industries.

In 2021 CNG Mother Station Bitung distributed 38,669,001 MSCF (million standard cubic foot) of Compressed Natural Gas (CNG) which was a decrease compared to 2020 as much as 53,138,9023 MSCF. This decrease was due to breakdown of the distribution process machine, causing delays in the distribution process of CNG to consumers. In the period from December 2020 up to November 2021, there have been 40 breakdowns to the distribution process machine where were 26 breakdowns occurred on the gas compressor, 7 breakdowns occurred on the generator set, 5 breakdowns occurred on the gas dryer and 2 breakdowns occurred on the air compressor. Gas Compressors play an important role in the distribution of CNG to consumers, if Gas Compressor has any problem, the distribution process will stop until the problem is resolved. Every occurrences of breakdown will issue additional costs for repairs.

Study on determining the schedule of preventive maintenance using the Age Replacement method has been carried out by previous researchers. The Age Replacement method had applied to determine the tools replacement schedule with the least down time at diesel engine Company [1]. The said method also applied to determine maintenance interval with preventive downtime maintenance at air separation plant and the result showed the plant can save up to 69,23% [2]. Preventive maintenance on die casting machines with age replacement method had increased machine reliability and saving preventive maintenance cost up to 8,72% [3].

The aims of this study are to define the critical components of the CNG Mother Station in Bitung, finding the distribution pattern of the time between break down and the length of time for repairing the critical components and determine the optimum replacement time interval for these critical components. Furthermore, by using the Age Replacement method, this study will calculate the cost comparison before and after carrying out preventive maintenance. At the end, the study will propose the schedule of preventive maintenance for the critical components.

2. Research Method

This study was started by observation the object, collecting data of gas compressor breakdowns that occurred in the period of December 2020 up to November 2021, list of gas compressor's components, breakdown time interval, cost of damage prevention and replacement. This study used the Pareto Diagram to determine the critical components and continued by identification distribution pattern of the interval data between breakdown to the machine or component and the length of time to repair the breakdown.

Based on the distribution pattern, we calculate the Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR) followed by calculating cost of preventive (Cp) and cost of failure (Cf). An analysis is carried out to obtain the most optimal replacement time interval for the critical components and comparing to the initial costs to find out the savings that can be achieved. As the final result, this study will propose the optimal replacement time interval for the critical components in a year as a preventive maintenance.

2.1. Literature Review

2.1.1. Maintenance

Maintenance is the process of keeping equipment in a functional state, either by preventing it from failing or by restoring it to a functional state once it has failed [4]. Preventive maintenance, is the activities carried out to prevent the emergence of unexpected damages [5]. Maintenance can divide into Corrective Maintenance (CM) and Preventive Maintenance (PM). PM is carried out at predetermined interims or agreeing to endorsed criteria and is expecting to decrease the likelihood of disappointment or the degradation of things [6]. Prevention Cost define as an action taken to prevent or reduce the risk of a machine failure. Any cost involved in repairing or replacing assets before a failure occurs or in maintaining its condition to a determined level [7]. In analyzing problems related to engine maintenance, several types of distribution of break down and repairs can be used to approach the pattern of engine breakdown and repairs. The common type of distribution used to determine the pattern of the data formed, namely: Weibull distribution, exponential distribution, normal distribution and lognormal distribution.

2.1.2. Reliability

Reliability can be defined as the probability that the system will perform according to the functions required in a given time period. Reliability also shows how long a component can work properly as its purposed [8].

2.1.3. Mean Time to Failure and Mean Time to Repair

According to Kurniawan [9], Mean time to failure (MTTF) is the average time interval for damage that occurs when the machine or component has been repaired until the machine or component is breakdown again. Mean Time to Repair (MTTR) is the average time to repair any breakdown of a machine or component. The formula used to calculate the MTTF and MTTR are as follows:

$$\text{MTTF} = \frac{Total\ Time - Downtime - idle\ time}{Total\ Breakdown}$$

$$\text{MTTR} = \frac{Total\ Downtime\ (unscheduled)}{Total\ Breakdown}$$

2.1.4. Age Replacement

Age replacement is preventive replacement performed depending on the service life of the component. So preventive replacement will be done by re-determining the next replacement time according to a predetermined interval [10]. The Age Replacement model can be used to reduce downtime, reduce machine maintenance costs and increase machine reliability. The following is the formula for the Age Replacement model:

$$C(tp) = \frac{Cp\ x\ R(tp) + Cf(1 - R(tp))}{(tp + Tp)x\ R(tp) + M(tp) + TF\ x\ (1 - R(tp))}$$

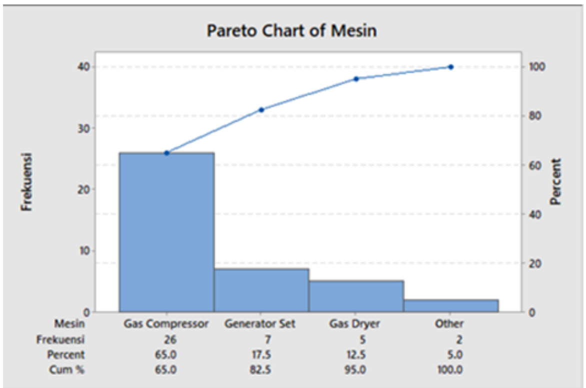
Whereas:
tp = preventive replacement time interval
Tp = time to do preventive replacement
Tf = time to replace the breakdown
Cp = preventive replacement cost
Cf = breakdown replacement cost
R(tp) = probability of occurrence of prevention cycle
F(t) = probability density function that occurs when t
Tp+tp = prevention cycle length
M(tp)+TF = expected damage cycle length

3. Findings

This study begins with determining critical engine by using the Pareto Diagram. There are 4 engines used in the CNG distribution process namely Gas Compressor, Generator Set, Gas Dryer and Air Compressor Instrument. Data of the occurrence of breakdown is shown in Table 1 where it finds that Gas Compressor is the critical engines with the highest frequency of the breakdown. Data from Table 1 is processed and presented in a Pareto diagram as shown in Picture 1.

Table 1. Engine Breakdown Data

Engine	Breakdown Frequency	Percentage	Cumulative Percentage
Gas Compressor	26	65%	65%
Generator set	7	17,5%	82,5%
Gas Dryer	5	12,5%	95%
Air Compressor Instrument	2	5%	100%
Total	40	100%	

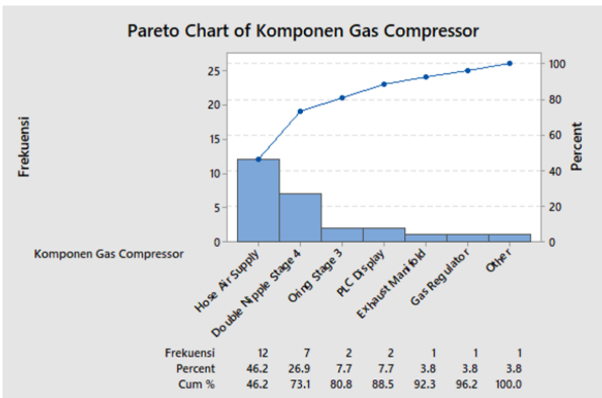


Picture 1. The Pareto Diagram of The Engines

The data on the components that cause the most frequent breakdown on the gas compressor are investigated to find the critical components. There are 6 components on Gas Compressor namely Air Supply's Hose, Double Nipple Stage 4, Oring Stage 3, PLC Display, Exhaust Manifold and Gas Regulator. Table 2 present the frequency of breakdown of every component that occurred during the process. The Pareto Diagram is used to determine the critical components where it turns out that the Air Supply's Hose and Double Nipple Stage 4 are the critical components as presented on Picture 2.

Table 2. Data of Gas Compressor Component Damage

Components	**Frequency of Breakdown**	**Percentage**	**Cumulative Percentage**
Air Supply' Hose	12	46,2%	46,2%
Double Nipple Stage 4	7	26,9%	73,1%
Oring Stage 3	2	7,7%	80.8%
PLC Display	2	7,7%	88,5%
Exhaust Manifold	1	3,8%	92,3%
Gas Regulator	1	3,8%	96,2%
Magneto	1	3,8%	100%
Total	26	100%	



Picture 2. The Pareto Diagram of Critical Component of Gas Compressor

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After the critical components are detected, the next step is to calculate the time between damage (Time To Failure) and the length of time to repair (Time To Repair) for Air Supply's Hose and Double Nipple Stage 4 as shown on Table 3.

Table 3. Time to Failure and Time to Repair for Critical Components

	Air Supply's Hoses		***Double Nipple Stage 4***	
No	***Time To Failure***	***Time To Repair***	***Time To Failure***	***Time To Repair***
1	0	3	0	3
2	36	2	39	4
3	29	3	50	3,5
4	27	3	31	3,5
5	25	3	42	2,5
6	33	3	45	2,5
7	23	2	47	3,5
8	20	4	35	2
9	30	3		
10	41	3		
11	35	3		
12	31	3		
13	34	3		

There are 4 patterns of distributions namely the Weibull, exponential, normal and lognormal distribution were tested to get the index of fit (r) value for Air Supply's Hose and Double Nipple Stage 4. Selection of the best distribution based on the highest r value and the result is shown on Table 4 for Air Supply's Hose and Table 5 for Double Nipple Stage 4.

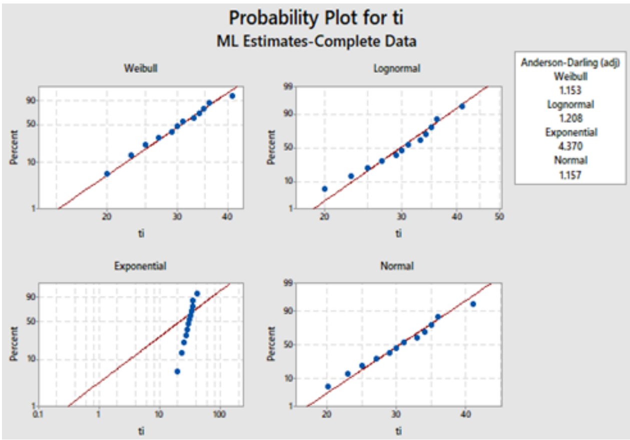
Table 4. Identification of TTF Distribution Pattern on Critical Components

Components	**Distribution**	***Index of Fit***	**Best Distribution**
Air Supply's Hose	Weibull	0,99639	**Weibull**
	Exponential	0,9322	
	Normal	0,9953	
	Lognormal	0,9876	
Double Nipple Stage 4	Weibull	0,9971	**Weibull**
	Exponential	0,9205	
	Normal	0,9927	
	Lognormal	0,9848	

Table 5. Identification of TTR Distribution Pattern on Critical Components

Components	Distribution	Index of Fit	Best Distribution
Air Supply's Hose	Weibull	**0,8230**	**Weibull**
	Exponential	0,7350	
	Normal	0,8006	
	Lognormal	0,7928	
Double Nipple Stage 4	Weibull	**0,9740**	**Weibull**
	Exponential	0,8922	
	Normal	0,9676	
	Lognormal	0,9590	

To ensure that the selected distribution for the critical component is correct, calculations are carried out using Minitab software where the smallest Anderson-Darling's value is selected [5]. The smallest Anderson-Darling TTF value for Air Supply's Hose is 1.153 obtained on the Weibull distribution as shown on Picture 3.



Picture 3. Anderson-Darling TTF value for air supply's hose

The smallest Anderson-Darling TTF value for Double Nipple Stage 4 is 1.839 obtained on the Weibull distribution as shown on Picture 4.

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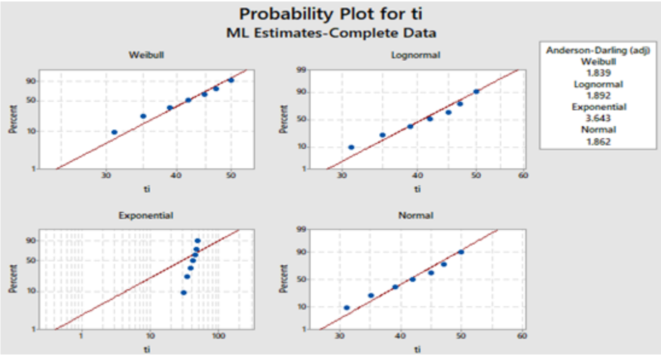
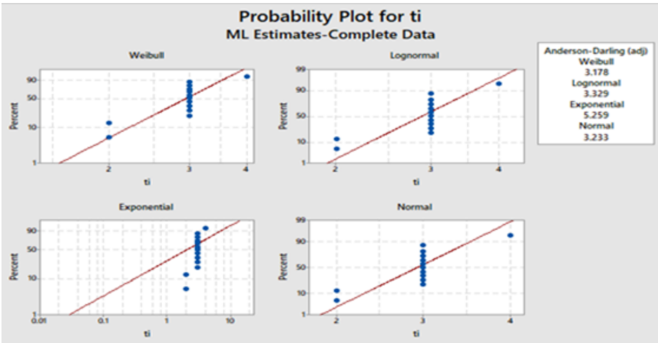
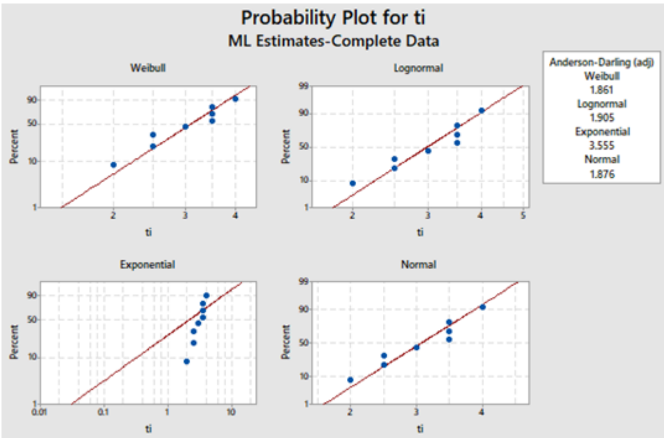


Figure 4. Anderson-Darling TTF value for Double Nipple Stage 4

The smallest Anderson-Darling TTR value for Air Supply's Hose is 3.178 obtained on the Weibull distribution as shown on Picture 5.



Picture 5. Anderson-Darling TTR Value for Air Supply's Hose



Picture 6. Anderson-Darling TTR value for Double Nipple Stage 4

Hypothesis testing is needed to prove that the breakdown time data of critical component follows the Weibull distribution. The goodness of fit test for the Weibull distribution uses the Mann's test. Table 6 shows the goodness of fit for Air Supply's Hose and Double Nipple Stage 4.

Table 6. Goodness of Fit for Critical Components

Data	Components	*M*count	*Mtabl*e	Remark
Time To Failure	Air Supply's Hose	0,085	4,95	H_0 Accepted
	Double Nipple Stage 4	3,9227	19,16	H_0Accepted
Time To Repair	Air Supply's Hose	1,2311	4,95	H_0 Accepted
	Double Nipple Stage 4	1,3062	9,12	H_0 Accepted

MTTF shows the average time the damage occurred (the average time the tool has finished being replaced until the tool breaks again). MTTR shows the average time needed to repair. MTTF and MTTR calculations are performed using predetermined parameters. MTTF for the critical components show on Table 7 and MTTR shows on Table 8.

Table 7. Parameter and MTTF Value for Critical Components

Critical Component	Q	α	MTTF (days)
Air Supply' Hose	5,5536	32,7537	30,256
Double Nipple Stage 4	6,3702	44,179	41,0774

Table 8 Parameter and MTTR Value for Critical Components

Critical Component	Q	α	MTTR (hours)
Air Supply' Hose	7,6703	3,0887	2,9032
Double Nipple Stage 4	4,7835	3,332	3,051

Historical data from company shows there is overtime cost for the operator in the cost of failure (Cf). Overtime cost arise due to urgent factors to replace critical components breakdown, to speed up repairs to make sure the Gas Compressor can operate soon. Time to replace the breakdown (Tf) mostly is longer than preventive replacement time (Tp) due to unexpected critical component breakdown, so some preparations are needed before replacing critical components, such as waiting time for Gas Compressor cooling down and increasing time for purchasing critical components. because no stock in the warehouse. Cost of failure for Air Supply's Hose is shown on Table 9 and for Double Nipple Stage 4 is shown on Table 10.

Table 9. Cost of replacing the Breakdown for Air Supply's Hose

No	Description	As per Breakdown
1	Overtime cost	IDR. 50.000
2	Maintenance Labor Cost for 3 people	IDR. 66.000
3	Component Cost for 10 meters	IDR. 160.000
4	Breakdown replacement time (Tf)	3 hours

The total cost of failure for Air Supply's Hose is obtained by the following calculation:

Cf = ((IDR 50.000 + IDR 66.000) x 3) + IDR 160.000
Cf = IDR 348.000 + IDR 160.000
Cf = IDR. 508.000/breakdown

Table 10. Cost of replacing the Breakdown for Double Nipple Stage 4

No	Description	As Per Breakdown
1	Overtime cost	IDR. 50.000
2	Maintenance Labor Cost for 3 people	IDR. 66.000
3	Component Cost	IDR. 35.000
4	Breakdown replacement time (Tf)	3,5 hours

The total cost of failure for Double Nipple Stage 4 is obtained by the following calculation:

Cf = ((IDR 50.000 + IDR 66.000) x 3,5) + IDR 49.000
Cf = IDR 417.600 + IDR 35.000
Cf = IDR 452.600/breakdown

Preventive cost calculation is based on data from table 11 for Air Supply's Hose and using data from Table 12 to calculate cost of preventive for Double Nipple Stage 4.

Table 11. Replacement Cost for Preventive Action for Hose Air Supply

No	Description	As Per Replacement
1	Maintenance Labor Cost for 3 people	IDR 66.000
2	Component Cost for 10 meters	IDR. 160.000
3	Preventive Action replacement time (Tp)	2 hours

The total cost of preventive action for Air Supply's Hose as follows:

Cp = (IDR 66.000 x 2) + IDR 160.000
Cp = IDR 132.000 + IDR 160.000
Cp = IDR 292.000/replacement

Table 12. Replacement Cost for Preventive Action for Double Nipple Stage 4

No	Description	As Per Replacement
1	Maintenance Labor Cost for 3 people	IDR 66.000
2	Component Cost 1 pcs	IDR 35.000
3	Preventive Action replacement time (Tp)	1,5 hours

The total cost of preventive action for Double Nipple Stage 4 as follows:

Cp = (IDR 66.000 x 1,5) + IDR 35.000
Cp = IDR 99.000 + IDR 35.000
Cp = IDR 134.000/replacement

The preventive replacement interval is determined by doing a trial-and-error calculation to get the minimum cost value. It can be seen in Table 13 that the value of C(tp) continued to decrease until day 20 and start to increase from day 21, so that the most optimum preventive replacement interval is at day 20 with the smallest C(tp) value of IDR 6,201.72/day and with a reliability level of 0.9374 or 93.74%.

Table 13. Replacement Intervals for Preventive Action of Air Supply Hose

Tp	R(tp)	F(tp)	M(tp)	C(tp)
19	0.953	0.047	637.95	6217.63
20	**0.937**	**0.063**	**483.63**	**6201.72**
21	0.919	0.081	372.52	6214.42
22	0.896	0.104	291.26	6259.51
23	0.869	0.131	230.99	6341.19
24	0.969	0.031	741.09	7912.28

Table 14. Replacement Intervals for Preventive Action of Double Nipple Stage 4

Tp	R(tp)	F(tp)	M(tp)	C(tp)
22	0.988	0.011	3507.61	2185.86
23	0.985	0.016	2647.70	2173.98
24	**0.979**	**0.020**	**2023.86**	**2168.27**
25	0.974	0.026	1565.17	2169.64
26	0.967	0.034	1223.73	2179.12
27	0.958	0.043	966.67	2197.86

It can be seen in Table 14 that the value of C(tp) continues to decrease until day 24 and start to increase at day 25, so that the most optimum preventive replacement interval is at day 24 with the smallest C(tp) value of Rp. 2,168.27/day and with reliability level is 0.9797 or 97.97%.

Final step is to determine the cost of proposed replacement and compared to the existing to get percentage of cost reduction. The result is shown on Table 15.

Table 15. Comparison of Proposed Replacement Cost with Existing Replacement Cost

Critical Components	Proposed Replacement Cost (IDR)	Existing Replacement Cost (IDR)	Cost Reduction (IDR)	Cost Reduction (%)
Air Supply Hose	5.804.746,7	6.096.000	291.253,3	4,78
Double Nipple Stage 4	2.247.464	3.168.200	920.736	29,06

4. Conclusion

The results of this study indicate that the engine that often experiences breakdown is the gas compressor, with the critical components being the Air Supply Hose and Double Nipple Stage 4. The breakdown that occurs to the two critical components causes problems in the distribution of compressed natural gas to consumers. The calculations performed show that the distribution pattern of time to failure and time to repair on critical components follows the Weibull distribution pattern based on the highest index of fit value which has been validated with the Minitab software.

Based on the optimization calculation of component replacement, the replacement time for the Air Supply's Hose component is 20 days and the Double Nipple Stage 4 is 24 days. Applied preventive maintenance in gas compressor engine will make sure the

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critical components will perform in its best. The critical components have been replaced before wear. By using the Age Replacement method, maintenance costs are reduced by 4.78% for Air Supply's Hose and 29.06% for Double Nipple Stage 4. The final results of this study support previous research conducted by [1], [2], [3], [8] that shown the implementation of preventive maintenance methods can reduce costs.

The results of this study cannot be generalized, so that it is necessary to carry out further research on different types of manufacturing. The application of other scheduling methods will greatly help in getting the most optimal scheduling at the lowest cost.

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