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A Comprehensive Approach to Minimize Inventory Costs Using RCM, RCS, and Economic Order Quantity Methods

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Abstract

Spare parts inventory differs from inventory of finished products and manufacturing materials in many aspects. Spare parts are crucial in maintaining efficient production processes, thus avoiding production losses and quality issues. This research aims to optimize the management of spare parts inventory by considering the level of component damage. To achieve this goal, Reliability Centered Maintenance (RCM), Reliability Centered Spares (RCS), and Economic Order Quantity (EOQ) methods are used. Based on the research results, maintenance intervals were found for each component calculated using the RCM method, and the required amount of spares for one repair period was calculated using the RCS method. The research also calculated the EOQ to determine each component's reorder point, safety stock, optimal order quantity, and total cost. The EOQ calculation results were compared with the total cost before the calculation, and it was found that by using the integration of RCM, RCS, and EOQ, the company can minimize costs of Rp. 2,390,119,- for the 5 analyzed components. Therefore, it can be concluded that the use of RCM, RCS, and EOQ methods can help companies optimize spare part inventory management.

Keywords: EOQ, reliability centered maintenance, reliability centered spares

Introduction

Spare parts inventory and preventive maintenance play a crucial role in ensuring the availability of operational spare parts for capital equipment (Shi et al., 2016), where it aims to minimize inventory costs while avoiding stockouts and overstock situations based on the maintenance interval schedule. With proper maintenance planning, maintenance costs can be easily controlled. Maintenance costs encompass labor and spare parts costs (Chen et al., 2015) and equipment downtime costs due to failures. Therefore, effective and efficient spare parts management is essential for maintenance management as it impacts equipment downtime schedules (Teixeira et al., 2018). According to Kennedy et al. (2002), spare parts inventory differs from the inventory of finished products and manufacturing materials in many aspects. Spare parts are characterized by their high cost, intermittent and highly uncertain demand, and inventory determined by demand (Hu et al., 2018), triggered by preventive and corrective maintenance interventions (Teixeira et al., 2018). Uneven distribution of maintenance tasks over time is a primary cause of intermittent demand for spare parts, which can complicate spare parts inventory control (Zhu et al., 2020).

The availability of spare parts should be directly related to maintenance to reduce failure time and high downtime costs (Shi et al., 2016). Therefore, inventory management and maintenance should be seen as interconnected parts to optimize company operations (Van Horenbeek et al., 2013). In inventory control, there are several functions, namely to keep inventory levels from being too high to avoid excessive costs (Heizer & Render, 2017), to ensure that the company does not run out of inventory to prevent disruptions in production or sales activities, and to prevent repetitive purchasing during production activities to avoid high ordering costs (Hoswari et al., 2020). Several studies related to spare parts inventory have been conducted previously, such as the research conducted by Teixeira et al. (2018), which presented a multi-criteria classification methodology that combines maintenance and logistics perspectives aimed at distinguishing and grouping spare parts to determine the most appropriate stock management policies for each group. Riskianto et al. (2021) believed that the use of the periodic review (R, S) system approach and Monte Carlo simulation can control spare parts inventory. Additionally, the Reliability Centered Spares method can be used to determine the required amount of spares in machine repairs, while Probabilistic Inventory can be used to determine inventory policies such as re-order point and re-order quantity, as demonstrated in the research conducted by Fadil et al. (2018). Another study was conducted by Imran & Vanany (2021), where the ADI-CV matrix method and continuous review (s, S) method were used to determine order quantity (Q), reorder point (ROP), and total inventory costs, while Monte Carlo simulation was used to analyze inventory performance such as inventory cost and service level.

Unlike general inventory control, spare parts management poses a critical issue as maintaining high spare parts inventory (overstock) ties up capital and often consumes a significant portion of capital investment (Teixeira et al., 2018). On the other hand, stockouts can disrupt the maintenance process of the power transmission system, leading to power outages (Riskianto et al., 2021). Therefore, this research aims to determine the required quantity of spare parts based on the maintenance interval schedule of the machines and minimize inventory costs while avoiding stockouts and overstock situations.

To achieve this objective, the first step is to determine the quantity of spare parts required during a maintenance period. Reliability Centered Spares is one of the methods for analyzing spare parts management that considers various aspects such as the maintenance needs of the machines, the consequences of spare parts unavailability, the anticipation of spare parts requirements, and the necessary stock holding quantity of spare parts during maintenance/ repair based on the machine maintenance schedule obtained through Reliability Centered Maintenance (Gustian & Nurhidayat, 2022). Then, to determine the order quantity of inventory that minimizes storage and ordering costs, the Economic Order Quantity model will be used (Rachmawati et al., 2014). This will undoubtedly result in operational efficiency, reduced inventory costs, increased equipment availability, and improved overall system reliability.

Materials and Method

This research utilizes several data in its analysis, including work order data, inventory data, and machine Bill of Material (BOM) data. The stages of this research are as follows :

Time Failure Calculation

The machine failure data (work orders) obtained will be used for the calculation of the Reliability Centered Maintenance method, where the first calculation involves determining the values of TBF (Time Between Failure) and TTR (Time To Repair). TBF is calculated by determining the time difference between the completion of the first repair and the occurrence of the subsequent failure, while TTR is calculated by determining the duration of the repair process, which is the time difference between the completion of the repair and the occurrence of the failure (Mutiara et al., 2014).

TTR and TBF are then categorized into MTTR and MTBF (Junaedi et al., 2022). Mean Time To Repair (MTTR) is the average time required to perform a repair on a component, while Mean Time Between Failure (MTBF) is the average interval of time between the completion of a repair and the occurrence of the next failure of the machine or component (Fatma et al., 2020). MTTR and MTBF can be calculated using Excel functions as follows (Hermanto, 2016).

$$\text{MTBF} \quad = \theta \; x \; EXP\left(GAMMALN\left(1 + \left(\frac{1}{\beta}\right)\right)\right) \qquad (1)$$

Reliability Function Determination

The reliability function is a function that represents the relationship between reliability and time, which is the duration that a system performs its task (Hermanto, 2016). The reliability function can be calculated using the following formula.

$$R(t) = e^{-\left(\frac{t}{\theta}\right)^{m}} \qquad (2)$$

Determination of Component Maintenance Interval

The determination of the maintenance interval can be done after calculating MTTR and MTBF. The maintenance interval is obtained by calculating the average repair time, average inspection time, average failure rate, and optimal inspection frequency (Farisa, 2020). The formula used is as follows.

Average repair time:
Average inspection time :
Average failure rate :
Optimal inspection frequency :

$$1/\mu = \frac{\text{MTTR}}{\text{average working hours per month}} \qquad (3)$$

$$\mu = \frac{1}{1/\mu} \qquad (4)$$

$$1/i = \frac{\text{an average of one inspection}}{\text{average working hours per month}} \qquad (5)$$

$$i = \frac{1}{1/i} \qquad (6)$$

$$k = \frac{\text{amount of damage}}{i} \qquad (7)$$

$$n = \sqrt{\frac{k\,x\,i}{\mu}} \qquad (8)$$

$$ti = \frac{\text{average working hours per month}}{n} \qquad (9)$$

Calculation of Spares Requirements

The spare requirements can be calculated using the Poisson process formula in the Reliability Centered Spares (RCS) method, with classification based on repairable and non-repairable components (Sarashvati et al., 2018). The formula for non-repairable components is as follows (Rachmawati et al., 2014).

$$\lambda t = \frac{1}{\text{MTBF}} t = \frac{\text{AxNxMxT}}{\text{MTBF}} \qquad (10)$$

$$P \leq \sum_{x=0}^{n} \frac{(\lambda t)^x e^{-\lambda t}}{x!} = e^{-\lambda t}\left[1 + \lambda t + \cdots + \frac{(\lambda t)^n}{n!}\right] \qquad (11)$$

The formula for non-repairable components is as follows

$$\lambda 1t = \frac{\text{AxNxMxRxT}}{\text{MTBF}} \qquad (12)$$

$$\lambda 2 = \frac{\text{AxNxMxMTTR}}{\text{MTBF}} \qquad (13)$$

$$P \leq \sum_{x=0}^{n} \frac{(\lambda t)^x e^{-\lambda t}}{x!} = e^{-\lambda t}\left[1 + \lambda t + \cdots + \frac{(\lambda t)^{n-1}}{(n-1)!}\right] \qquad (14)$$

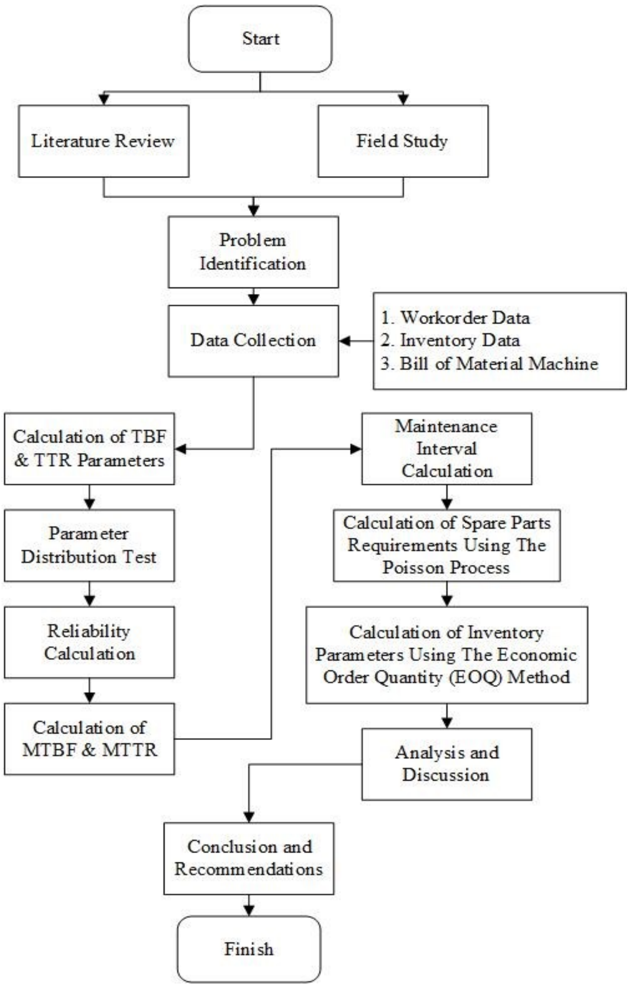

Figure 1. Research Flowchart

Calculation of Inventory Parameters

The calculation of inventory parameters such as optimal order quantity, reorder point, etc. is done using the economic order quantity (EOQ) method with the assistance of POM-QM software. The general formula for the EOQ model is as follows.

$$\text{EOQ} = Q^* = \sqrt{\frac{2xDxS}{IxC}} \qquad (15)$$

Meanwhile, safety stock and reorder points can be calculated using the following formulas.

$$SS = \left(\frac{D}{\text{number of working days a year}}\right) xL \qquad (16)$$

$$ROP = 2x\left(\frac{D}{\text{number of working days a year}}\right) xL \qquad (17)$$

Research Flowchart

On the Figure 1 is the flowchart of this research.

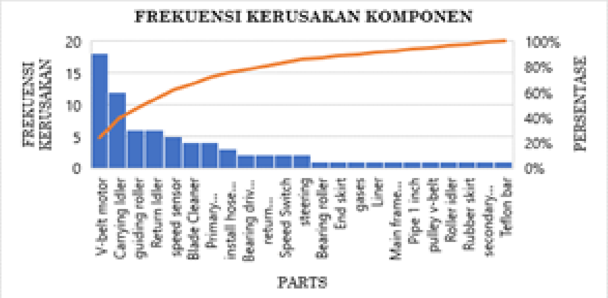

Figure 2. Pareto Diagram of Component 7BA-CNVR-**200**

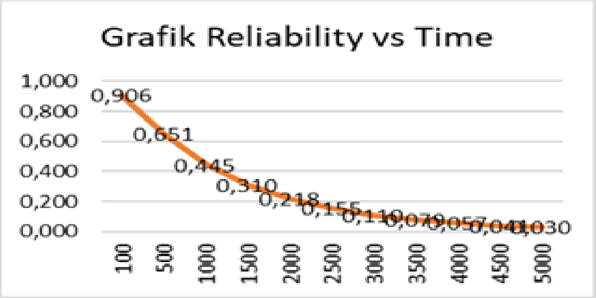

Figure 3. Reliability vs Time Graph

Table 1. TTR and TBF Results for Carrying Idler Component

WONUM	Damaged Material	ACTSTART	ACTFINISH	TTR	TBF
2103251075	Carrying Idler	26/3/21 16:00	29/3/21 16:00	72	-
2105231381	Carrying Idler	25/5/21 8:00	25/5/21 19:00	11	1360
2106301704	Carrying Idler	30/6/21 17:00	3/7/21 16:00	71	862
2107161006	Carrying Idler	16/7/21 8:00	17/7/21 16:00	32	304
2108151012	Carrying Idler	15/8/21 8:00	17/8/21 15:00	55	688
2110011024	Carrying Idler	5/10/21 8:00	7/10/21 15:00	55	1169
2110131165	Carrying Idler	19/10/21 12:26	23/10/21 16:00	99,55	285,45
2112101062	Carrying Idler	14/1/22 7:08	14/1/22 16:00	8,85	1983,15
2112171009	Carrying Idler	17/1/22 7:34	17/1/22 16:00	8,42	63,58
2201211057	Carrying Idler	27/1/22 8:00	27/1/22 16:00	8	232
2207201054	Carrying Idler	21/7/22 7:30	22/7/22 15:30	32	4191,50
2210131024	Carrying Idler	24/10/22 11:58	25/10/22 16:00	28,02	2252,48

Table 2. TTR and TBF Results for Carrying Idler Component

Components	Distribution and TBF Parameters				
	Distribution	Beta	Eta	Gamma	Lambda
V-Belt Motor	Weibull 2	0,6017	644,9	-	-
Carrying Idler	Weibull 2	0,9127	1262	-	-
Guiding Roller	Weibull 2	0,8908	2630	-	-
Return Idler	Weibull 2	0,4646	1833	-	-
Speed Sensor	Weibull 2	5,76	1487	-	-
Components	**Distribution and TTR Parameters**				
	Distribution	**Beta**	**Eta**	**Gamma**	**Lambda**
V-Belt Motor	Weibull 2	0,9094	15,45	-	-
Carrying Idler	Weibull 2	1,151	45,19	-	-
Guiding Roller	Weibull 2	1,752	30,75	-	-
Return Idler	Weibull 2	1,504	25,7	-	-
Speed Sensor	Weibull 2	1,155	14,26	-	-

Results and Discussion

Determination of Critical Components

The determination of critical components is done using a Pareto Diagram, taking into consideration the frequency of component failures. Based on the data processing conducted, the following results were obtained.

Based on Figure 2, we identified 5 critical components that are of primary importance in this study, namely V-Belt Motor, Carrying Idler, Guiding Roller, Return Idler, and Speed Sensor.

Table 3. Calculation Results of Maintenance Interval

Components	Component Maintenance Interval
V-Belt Motor	1133
Carrying Idler	851
Guiding Roller	1507
Return Idler	1638
Speed Sensor	2347

Table 4. Calculation Results of Poisson Process for Carrying Idler

n	fact(n)	Exp (-λt)	(λt)^n/n!	1+λt+…+(λt)^n/n!	p	p%
0	1	0,00	1		0,000	0%
1	1	0,00	25,815	1	0,000	0%
2	2	0,00	333,209	27	0,000	0%
3	6	0,00	2867,267	360	0,000	0%
4	24	0,00	18504,664	3.227	0,000	0%
5	120	0,00	95539,795	21.732	0,000	0%
6	720	0,00	411060,894	117.272	0,000	0%
7	5040	0,00	1515937,278	528.333	0,000	0%
8	40320	0,00	4891751,147	2.044.270	0,000	0%
9	362880	0,00	14031204,550	6.936.021	0,000	0%
10	3628800	0,00	36221636,322	20.967.226	0,000	0%
11	39916800	0,00	85005786,610	57.188.862	0,001	0%
12	479001600	0,00	182869111,298	142.194.649	0,002	0%
13	6227020800	0,00	363136674,306	325.063.760	0,004	0%
14	8,7178E+10	0,00	669599600,806	688.200.434	0,008	1%
15	1,3077E+12	0,00	1152383514,659	1.357.800.035	0,015	2%
16	2,0923E+13	0,00	1859302974,579	2.510.183.550	0,027	3%
17	3,5569E+14	0,00	2823412626,544	4.369.486.524	0,044	4%
18	6,4024E+15	0,00	4049253417,012	7.192.899.151	0,069	7%
19	1,2165E+17	0,00	5501669102,931	11.242.152.568	0,103	10%
20	2,4329E+18	0,00	7101295426,813	16.743.821.671	0,147	15%
21	5,1091E+19	0,00	8729540729,308	23.845.117.097	0,200	20%
22	1,124E+21	0,00	10243345577,070	32.574.657.827	0,263	26%
23	2,5852E+22	0,00	11497067959,432	42.818.003.404	0,334	33%
24	6,2045E+23	0,00	12366561643,171	54.315.071.363	0,410	41%
25	1,5511E+25	0,00	12769740382,280	66.681.633.006	0,488	49%
26	4,0329E+26	0,00	12678907392,495	79.451.373.389	0,566	57%
27	1,0889E+28	0,00	12122471602,952	92.130.280.781	0,641	64%
28	3,0489E+29	0,00	11176511105,102	104.252.752.384	0,710	71%
29	8,8418E+30	0,00	9949044329,626	115.429.263.489	0,771	77%
30	2,6525E+32	0,00	8561171973,731	125.378.307.819	0,823	82%
31	8,2228E+33	0,00	7129263014,760	133.939.479.793	0,867	87%
32	2,6313E+35	0,00	5751323132,135	141.068.742.807	0,903	90%
33	8,6833E+36	0,00	4499113389,403	146.820.065.940	0,930	93%
34	2,9523E+38	0,00	3416025716,510	151.319.179.329	0,951	95%

n	fact(n)	Exp (-λt)	(λt)^n/n!	1+λt+…+(λt)^n/n!	p	p%
35	1,0333E+40	0,00	2519568656,055	154.735.205.045	0,967	97%
36	3,7199E+41	0,00	1806744769,435	157.254.773.702	0,978	98%
37	1,3764E+43	0,00	1260573554,656	159.061.518.471	0,985	99%
38	5,2302E+44	0,00	856362625,822	160.322.092.026	0,991	99%
39	2,0398E+46	0,00	566847463,986	161.178.454.651	0,994	99%
40	8,1592E+47	0,00	365830007,985	161.745.302.115	0,996	100%
41	3,3453E+49	0,00	230339584,809	162.111.132.123	0,998	100%

Table 5. Calculation Result of EOQ

Parameter	Value	Parameter	Results using EOQ	Results using 2
Demand rate(D)	4	Optimal order quantity (Q*)	5,16	
Setup/Ordering cost(S)	1512000	Maximum Inventory Level (Imax)	5,16	2
Holding cost(H)	453600	Average inventory	2,58	1
Unit cost	1512000	Orders per period(year)	0,77	2
Days per year (D/d)	365	Annual Setup cost	1171190	3024000
Daily demand rate	0,01	Annual Holding cost	1171190	453600
Lead time (in days)	14	Annual Holding (safety stock)	453600	453600
Safety stock	1	Unit costs (PD)	6048000	6048000
		Total Cost	8843980	9979200
		Reorder point	1,15 units	-

Determination of Time Failure

In Table 1, the calculation results for Time to Repair (TTR) and Time Between Failures (TBF) for the carrying ider component were obtained.

Distribution Testing

The TBF and TTR data of critical components were processed using Isograph Reliability Workbench software. This processing was performed based on the 2-Parameter Weibull distribution. The results of the processing for each critical component can be seen in Table 2.

Reliability Function

The reliability function R(t) is calculated according to the 2-Parameter Weibull distribution used with the assistance of Microsoft Excel. The parameters used to calculate the reliability function are the time between failure parameters and the result for the Carrying Idler can be seen in Figure 3.

Calculation of Mean Time Between Failure (MTBF)

Here are the results of the MTBF calculation for the Carrying Idler component. The MTBF value is calculated using the Excel function.

MTBF = $\theta\ x\ EXP\ (GAMMALN\ (1 + \left(\frac{1}{\beta}\right)$

MTBF = $1262\ x\ EXP\ (GAMMALN\ (1 + \left(\frac{1}{0{,}9127}\right)$

MTBF = 1317,888

Calculation of Mean Time To Repair (MTTR)

Here are the results of the MTTR calculation for the Carrying Idler component.

MTTR = $\theta\ x\ EXP\ (GAMMALN\ (1 + \left(\frac{1}{\beta}\right)$

MTTR = $45{,}19\ x\ EXP\ (GAMMALN\ (1 + \left(\frac{1}{1{,}151}\right)$

MTTR = 42,997

Determination of Critical Component Maintenance Interval

The maintenance interval is calculated using the previously provided formula. Based on the calculations conducted, the results of the component maintenance intervals were obtained, as shown in Table 3.

Calculation of Spare Parts Requirement

The calculation of spare parts requirement is done using the Poisson process formula using Microsoft Excel. The following are the calculation results to determine the requirement for the Carrying Idler component can be seen in Table 4.

From the calculation iterations, it can be determined that to achieve 100% availability of the Carrying Idler component within one maintenance period, a total of 40 spare parts for the Carrying Idler component are required.

Calculation Result of Economic Order Quantity

The calculation of EOQ is based on the results of the previous RCS calculation, where the demand used is the result of the RCS calculation. This is because calculating EOQ for spare parts requires considering MTBF. This calculation is done with the assistance of POM-QM software. The following is the calculation results for the Speed Sensor component.

From Table 5, it can be observed that the total cost for the speed sensor component, calculated using the integration of RCM, RCS, and EOQ, amounts to Rp. 8.843.980, whereas before the integration, the total cost was Rp. 9.979.200. Additionally, through these calculations, the optimal order quantity and reorder point for the component were determined.

Conclusion

The conclusion of this research is as follows: Based on the calculations using the Reliability Centered Maintenance (RCM) method, the maintenance intervals for 5 critical components were determined to establish the machine maintenance schedule and calculate the required number of spares for each component in one maintenance period. The Poisson process formula in the RCS method was used to calculate the number of spares needed. Consequently, the V-Belt requires 5 pieces, the Carrying Idler needs 40 pieces, the Guiding Roller necessitates 10 pieces, the Return Idler calls for 14 pieces, and the Speed Sensor requires 4 pieces in one maintenance period. By integrating RCM, RCS, and EOQ, companies can effectively reduce inventory costs by considering the level of machine damage in spare part management policies. This integration aids in determining reorder points, optimal order quantities, and total costs for each component. The research findings showed that the integration resulted in a total cost of Rp. 52,375,189,-, while the actual total cost was Rp. 49,985,069,-, thereby enabling the company to minimize inventory costs by Rp. 2,390,119,-.

Suggestion

The suggestions from this research are as follows: Firstly, to ensure the validity of RCM calculations, it is recommended to use time failure data that accurately reflects the occurrence of damage. Utilizing appropriate software and undergoing additional training can enhance the accuracy and reliability of these calculations. Secondly, in RCS calculations, it is advisable to determine whether each component belongs to the repairable or non-repairable category. This distinction will enable the utilization of more effective calculation formulas tailored to the specific characteristics of each category. By implementing these suggestions, companies can enhance the robustness and efficiency of their maintenance strategies, leading to improved overall equipment reliability and cost optimization.

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