The Proposed Maintenance Task for Plastic Injection Machine Using Reliability and Risk Centered Maintenance (RRCM) Method in Manufacturing Industry

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***Abstract* -** The objective of this research was to determine the optimal maintenance time interval for the selected critical components and the total cost of maintenance of a plastic injection machine. In determining the critical components, a risk matrix was used, and three components were selected, namely, hydraulic hose, barrel, and motor. Using the Reliability and Risk Centered Maintenance (RRCM) method, the researchers got a proposed maintenance policy and the total maintenance cost. Based on the result, it shows that there are seven proposed maintenance tasks with three scheduled on-condition tasks and four scheduled restoration tasks with an average maintenance interval of two months. The total maintenance cost proposed is IDR91.595.318. The cost is smaller compared to the actual maintenance costs of the company.

Keywords: maintenance task, plastic injection machine, Reliability and Risk Centered Maintenance (RRCM)

I. INTRODUCTION

Current technological developments occur very rapidly over time. With the rapid technological change, it triggers the increasing need and use of technology. So, it also increases the need for maintenance. The condition of the machine must always be monitored during the production process. It can be ascertained that this machine is in line with its function, and no damage causes the production process to be disrupted (Atmaji & Alhilman, 2018).

Maintenance is an activity carried out to restore the function of a machine or a system to its initial function (Dhamayanti, Alhilman, & Athari, 2016). According to Gupta and Mishra (2018), maintenance is a long-term strategic proposal that covers all product life cycle phases, namely the changes in environmental conditions, economics, and social trends. Maintenance activities carried out on production facilities or machines generally receive less attention from related stakeholders, especially in small to medium scale companies. Maintenance activities also have an important role, especially in the condition of the machine working for 24 hours without stopping. Therefore, engine maintenance must be considered to ensure the continuity and smoothness of the production process (Alhilman, Atmaji, & Athari, 2017).

Awad and As'ad (2016) stated that productivity increased and the total maintenance costs incurred if the maintenance strategy was carried out properly. Moreover, maintenance systems are generally divided into two major parts, namely, preventive maintenance and corrective maintenance (Atmaji & Ngurah, 2018).

There are several methods for determining optimal maintenance policies, one of which is the Reliability Centered Maintenance (RCM) method. Sainz and Sebastián (2013) stated that the RCM method was the optimal method because it could be used to determine what should be done to ensure the machine or system to work according to its functions. Along with increasingly rapid technological developments, it makes it possible to ensure that physical elements can continue to preserve their reliability in terms of design, manufacture, and testing. It also makes improvements at the right time to minimize the risk of small to large failures.

Atmaji, Noviyanti, and Juliani (2018), in their research about RCM analysis in the airline engine, showed the effects of maintenance costs arising from machine failures. While the engine was operating, it was important to analyze the risk of engine failure by knowing the probability of failure and the risk of lost system performance. Yssaad, Khiat, and Chaker (2014) stated that the RCM has its main focus on reducing maintenance costs by increasing engine performance to achieve optimal productivity.

Similarly, Sabouhi, Fotuhi-Firuzabad, and Dehghanian (2016) mentioned that RCM was a maintenance process aiming to minimize costs incurred by controlling the failed components and systems. RCM could help to prevent those components from failing. The losses could be prevented beforehand.

Mkandawire, Ijumba, and Saha (2015) agreed that to develop RCM by adding risk assessment models and probabilistic capabilities, which was, in general, the value of RCM effectiveness, was difficult to determine at an early stage. Specifically, the data were insufficient, and most assets were small in the distribution system. Tang, Liu, Jing, Yang, and Zou (2017) stated that identification of Maintenance Significant Items (MSI) was the main phase of RCM. They explained how the framework functioned to determine and identify MSI by using a combination of quantitative and qualitative analysis.

Sinha and Mukhopadhyay (2015) and Vishnu and Regikumar (2016) stated that maintenance has an increasing function because it had an important role in terms of the increasing availability, product quality, operator safety, and operating costs. Therefore, the selection strategy was one of the important things for continuous review.

RCM can be done to improve the overall reliability of the process in identifying and determining potential failures. Then, it can be used as an analysis of the failure. Afzali, Keynia, and Rashidinejad (2019) mentioned that RCM was the selection of an appropriate method of strategy to carry out maintenance based on the priority of preventive maintenance of system components. It was to minimize costs incurred when an asset was damaged or repaired.

The RCM has experienced several developments by adding risk factors as one of the reference analyzes. The uncertainty and frequency of failure result in a new method, Reliability and Risk Centered Maintenance (RRCM). It is an extension of the conventional RCM method (Selvik & Aven, 2011).

The problem related to the reliability and maintenance of the machine also happens in the automotive sector, especially in the spare parts for vehicles. It is one of the companies that provide jigs, dies, molds, and spare parts services. The plastic injection machine is one of the machines used by the company for production. It operates for 24 hours continuously. Therefore, the reliability of the engine will decrease as time goes, which causes the engine to break. To ensure that the performance of a plastic injection machine works according to its function, the company can carry out maintenance activities. In the production process, the company has four plastic injection machines used by the following specifications of the product to be made. Figure 1 shows the data downtime for the four plastic injection machines owned by the company.

Figure 1 shows the total damages for four plastic injection machines over the past three years. Then, it can be known that the relatively large amount of damage can cause the machine not to reach the desired production target for each month, especially on plastic injection machines with a capacity of 105 tons. Moreover, the high frequency of damage to the plastic injection machine 2 greatly affects the production process. It is because injection machine 2 is the machine that most often works to meet production demands. It is following the requested product specifications. Taking into account the frequency of damage, the plastic injection machine 2 with a capacity of 105 tons will be the focus of this research.
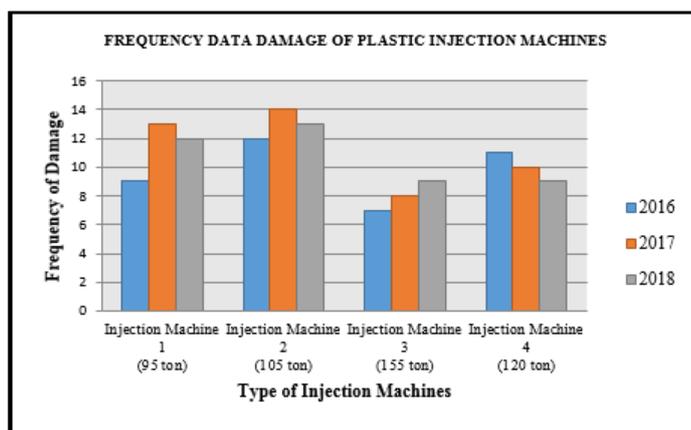

Figure 1 Total Damage of Plastic Injection Machine

In this study, the researchers propose a maintenance policy analysis for the selected critical components in a plastic injection machine using the RRCM. It is to determine the accuracy, focus, and optimal maintenance methods in achieving optimal facility reliability. It is done by considering the risks as a reference analysis that the uncertainty is one of the main components of risk other than the possibility of events occurring and associated consequences (Selvik & Aven, 2011). The RRCM can conclude the effective maintenance time intervals and the total maintenance costs required by the company.

II. METHODS

This research only focuses on plastic injection machines, especially on its critical components. The damage data used are from 2016–2018. The flow of research methodology is shown in Figure 2.

From Figure 2, after obtaining a critical system, the researchers use quantitative measurement, namely Functional Failure (FF). The first calculation is done by calculating the previously performed Time to Failure (TTF) and Time to Repair (TTR). After doing the calculation, it proceeds to Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR). MTTF and MTTR data are needed to determine the maintenance time intervals of each critical component. The maintenance tasks and time intervals will be proposed to the company in determining its maintenance policy.

MTTF is the average time from the time interval between the first component damage and the subsequent damage (Atmaji, 2015). Meanwhile, MTTR is the time needed to repair the damaged component until the component functions again. The following equations show the types of distribution.

Normal Distribution:
$$MTTF = \eta \tag{1}$$

Exponential Distribution:
$$MTTF = \frac{1}{\lambda} \tag{2}$$

Weibull Distribution:
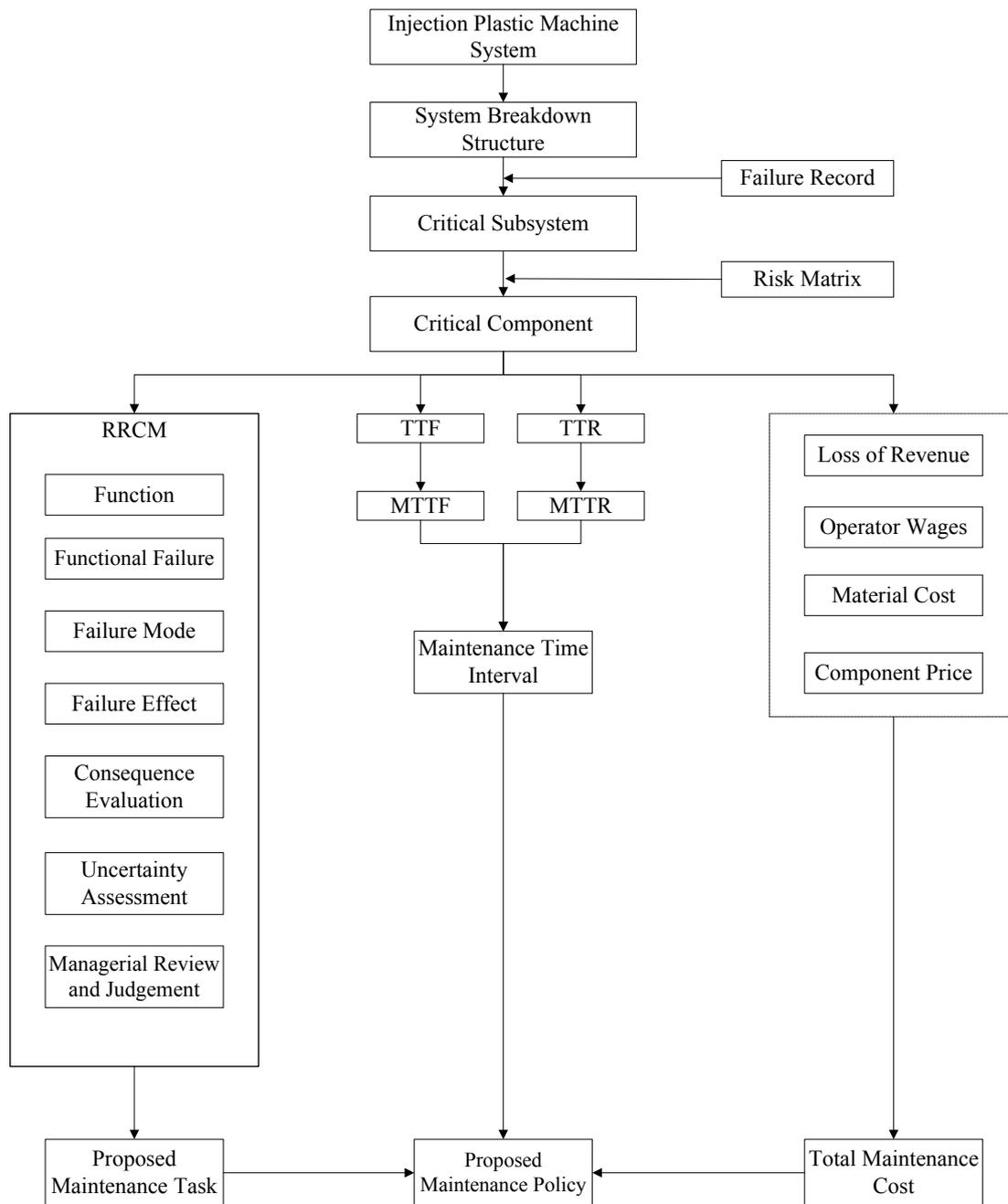$$MTTF = \eta \times \Gamma \left(1 + \frac{1}{\beta}\right) \tag{3}$$

Figure 2 Research Methodology

Where:

η = Distribution form parameters

λ = Failure rate

Γ = Gamma

β = Distribution form parameters

After knowing the result of MTTF and MTTR, the next step is to determine the functional failure and interval time of maintenance using the RRCM. It can use proactive, reactive, and preventive maintenance methods in an integrated manner to increase machine productivity to run according to its function and produce minimum maintenance costs (Igba, Alemzadeh, Anyanwu-Ebo, Gibbons, & Friis, 2013). Moreover, predictive maintenance is more effective in optimizing maintenance time compared to corrective and preventive maintenance. It can reduce maintenance costs and increase inventory availability (Jiang, Duan, Tian, & Wei, 2015).

Based on Figure 3, the initial step of working on the RRCM refers to the conventional RCM, namely using the RCM decision worksheet. To integrate the scores that have been assessed into task assessment and preventive maintenance intervals, it can expand the RCM worksheet to include all the results of the RCM decision worksheet. The first four steps are part of the traditional RCM. Then, the fifth step is to integrate specific uncertainty assessments into the RRCM framework. This uncertainty assessment is included as an integrated part of task evaluation and preventive maintenance intervals. It also adds to the uncertainty assessment carried out as part of the integration of the conventional RCM.
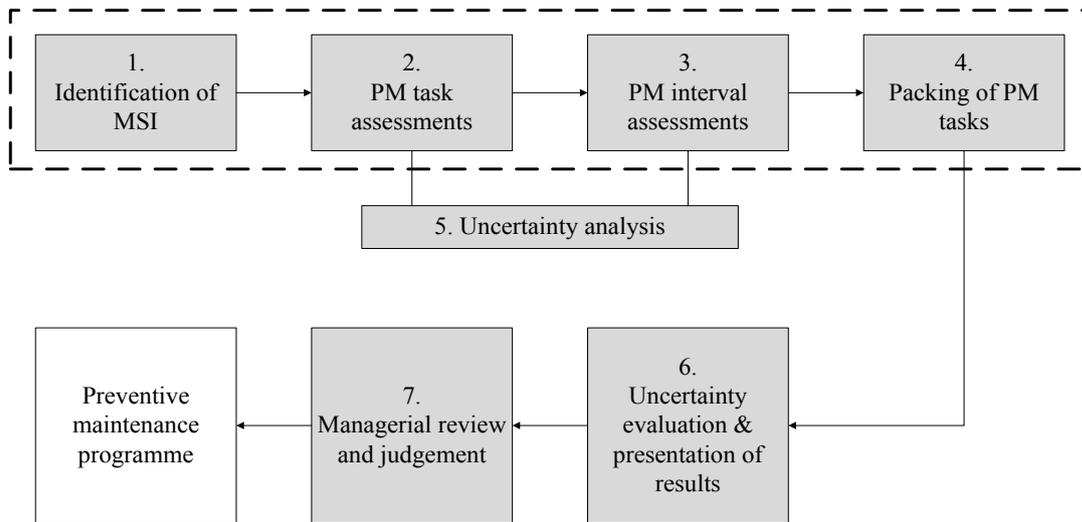
Figure 3 Framework of RRCM Method
(Source: Selvik & Aven, 2011)

In the fifth step, it specifically discusses the factors of uncertainty. Uncertainty analysis includes the main tasks, namely identifying uncertainty factors, assessment, and categorization of uncertainty concerning sensitivity level, and a summary of the importance of uncertainty factors.

According to Márquez (2007), RRCM divides the proposed maintenance task into three categories. The first one is scheduled on-condition task. The scheduled on-condition task is a maintenance activity carried out by observing or measuring the performance of components. It is when the machine is operating, and there are signs of damage to the component or system. The P-F interval is defined as the interval between potential failures and failure functions. The second one is the scheduled restoration task. It is a maintenance activity by fixing the system on a specific schedule before the age limit, regardless of the condition of the system at that time. So, for the implementation of this activity, the system needs to be temporarily paused. The third one is a scheduled discard task. It is a maintenance activity done by replacing certain parts or components of a system before the age limit regardless of the condition of the parts or components of the system. Determining of scheduled restoration and discard task intervals can be obtained by using the following equations.

$$TM = \eta \times \left[\frac{Cm}{Cf(\beta-1)} \right]^{\frac{1}{\beta}} \tag{4}$$

$$Cm = PM\ Cost + Downtime\ Cost + Cw \tag{5}$$

$$Cf = Cr + MTTR\ (Co + Cw) \tag{6}$$

Where,
  TM: Maintenance time interval in hours
  CM: Total costs incurred for maintenance
  Cf: The cost of repairing the system or replacing components of a system
  Cw: Wage engineer
  Cr: The cost of replacing or repairing damaged parts
  Co: Production loss costs

III. RESULTS AND DISCUSSIONS

There are several steps in analyzing the proposed maintenance task of the plastic injection machine. First, it is to determine the System Breakdown Structure (SBS). SBS machines are carried out to simplify the identification of systems, subsystems, and components contained in the engine (Atmaji & Ngurah, 2018). The SBS in the plastic injection machine can be seen in Figure 4.

Second, it is to determine the risk matrix. Risk matrix results are based on the calculation of the severity and likelihood value. The subsystem, which has the highest critically level, will require particular attention and maintenance priority. This risk matrix is divided into four parts, which are identified by colors. Those are green, yellow, orange, and red. Green indicates that if there are components in this zone, the component is in a safe condition. Thus, the damage will not have a significant impact on the company. In the yellow color, the component in the moderate zone will have an impact on the company, but it is not too significant. In the orange and red colors, if the component in these zone has a malfunction, it will significantly affect the losses in the company. Table 1 is the calculation result of the risk matrix. Based on Table 1, it can be seen that the plastic injection machine components in the critical category are components in the red and orange zones. Those components include motor, hydraulic hoses, and barrels.

Third, it is calculating MTTF and MTTR. After the critical component is selected, the researchers determine MTTF and MTTR. There are several types of failure distribution functions based on reliability. Those are often used to analyze maintenance problems such as Exponential, Normal, and Weibull distribution. Failure data from the critical components are analyzed using Minitab 17 and AvSim 9.0+ software. It is to determine the type of distribution that represents the failure in critical components of the machine. Tables 2 and 3 shows the results of the MTTF and MTTR calculations. Table 2 shows the result of average time for time to failure each component. It is 1819,18 for hydraullic hose, 2284,50 for barrel, and 2251,07 for motor. Moreover, Table 3 shows the result of average time for time to repair each component. It is 2,39 for hydraullic hose, 5,40 for barrel, and 85,25 for motor.

Injection Machine
→ Electrical System
  → Monitor Control
  → Inverter
  → Panel
→ Mechanical System
  → Injection
    → Heater
    → Hopper
    → Barrel
    → Hydraulic Hose
    → Motor
    → Pump
  → Clamping
    → Bed Molding
    → Mold
    → T-Bar
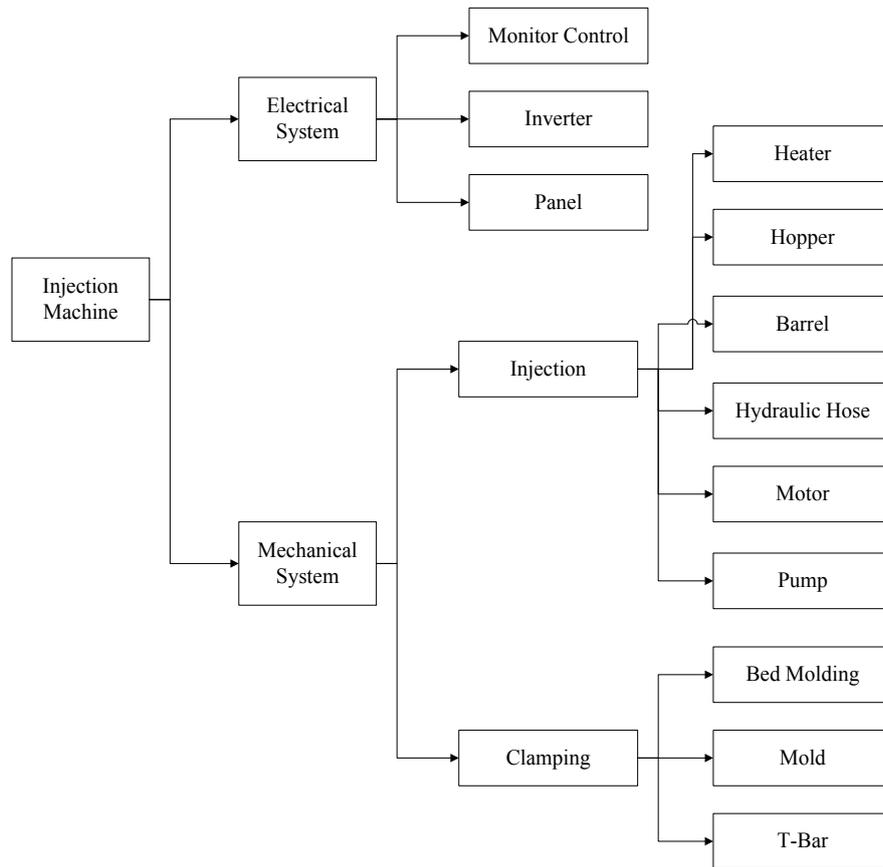
Figure 4 System Breakdown Structure (SBS) of Plastic Injection Machine

Table 1 The Risk Matrix

Likelihood	Severity				
	Insignificant (-1)	Minor (-2)	Moderate (-3)	Major (-4)	Catastrophic (-5)
Almost Certain (5)					
Likely (4)				Barrel	
Possible (3)					
Unlikely (2)	Hopper			Motor, Hydraulic Hose	
Rare (1)	Heater		Pump		

Table 2 The Result of MTTF Calculation

Component	Distribution	1+(1/β)	Γ	MTTF (Hour)
Hydraulic Hose	Weibull	1,0912	0,9550	1819,18
Barrel	Weibull	1,2095	0,9157	2284,50
Motor	Weibull	1,1679	0,9273	2251,07

Table 3 The Result of MTTR Calculation

Component	Distribution	Parameter		MTTR (Hour)
Hydraulic Hose	Normal	μ	2,38917	2,39
		σ	0,465738	
Barrel	Normal	μ	5,395	5,40
		σ	1,09157	
Motor	Normal	μ	85,25	85,25
		σ	12,562	

Fourth, it is calculation and data analysis using the RRCM method. The application of the RRCM method starts by making the RCM information worksheet. It contains functions, functional failure, failure mode, and the failure effect of each critical component that has been selected. RCM information is determined to find out the failure mode and the impact caused by the failure of the critical component of the injection plastic machine. Then, it determines the RCM decision worksheet to classify the consequences of the failure mode. It also chooses the appropriate preventive task for each component through the RCM decision diagram. After the RCM information worksheet is done,

the researchers compare it using uncertainty assessment factors for risk factor decision making. This risk factor will influence the final decision-making results in the proposed maintenance task. To integrate the results of this uncertainty assessment into the decision of the proposed maintenance task, the researchers expand the RCM worksheet by including all the results of the assessments.

In the application of the RRCM method, data are needed by experts judgment in uncertain assessment and historical data of the company. In determining the evaluation of the consequences using an extended RRCM decision diagram, it can determine the maintenance task that fits the real conditions the best in the field. There are two types of preventive maintenance scenarios. Those are scheduled on-condition tasks and scheduled restoration tasks. Scheduled on-condition tasks are maintenance activities carried out by observing or measuring the performance of components. It is done when the machine is operating if there are signs of damage to the component or system. Meanwhile, scheduled restoration task is a maintenance activity by repairing the system on a certain schedule before the age limit without considering the condition of the system at that time. So, for the implementation of this activity, the system needs to be stopped temporarily.

From Table 4, by combining a conventional RCM decision worksheet with the uncertainty assessment for RRCM, it results in a proposed maintenance task. By using the assistance tools RCM decision diagram and factor of uncertainty assessment, the researchers obtain the result of two proposed maintenance tasks for the critical component hydraulic hose with one scheduled restoration task and one scheduled on-condition task.

In Table 5, the results are four proposed maintenance tasks for critical components barrel. It is with two scheduled restoration tasks and two scheduled on-condition tasks. For the barrel, the scheduled restoration task consists of repairing activities. So, the system must be stopped temporarily. Meanwhile, for the scheduled on-condition task, the maintenance activities are mostly by observing or measuring the performance of component. It can be done when the system is in operating process.

Table 4 The Result of Extended RRCM Decision Worksheet for Hydraulic Hose

Information Reference			Consequence Evaluation				H1 S1 O1	H2 S2 O2	H3 S3 O3	Uncertainty Assessment			Proposed Maintenance
F	FF	FM	H	S	E	O	N1	N2	N3	Degree of Uncertainty	Degree of Sensitivity	Degree of Importance	
1	1	1	The pressure is too high	Y	N	N	Y	N	Y		L / M	H	M / H	Scheduled Restoration Task
	2	2	Oil flow becomes seamless	Y	N	N	Y	Y			L / M	L / M	L / M	Scheduled On-condition Task

Table 5 The Result of Extended RRCM Decision Worksheet for Barrel

Information Reference				Consequence Evaluation				H1 H2 H3 / S1 S2 S3 / O1 O2 O3			Uncertainty Assessment			Proposed Maintenance
F	FF		FM	H	S	E	O	N1	N2	N3	Degree of Uncertainty	Degree of Sensitivity	Degree of Importance	
1	1	1	Warming time is getting longer	Y	N	N	Y	Y			L / M	L / M	L / M	Scheduled On-Condition Task
		2	The material used is not suitable	Y	N	N	Y	N	Y		L / M	M / H	M	Scheduled Restoration Task
2	1	1	The emphasis in the material is not maximal	Y	N	N	Y	N	Y		M / H	M / H	M / H	Scheduled Restoration Task
		2	Holding material time exceeds the standard time	Y	N	N	Y	Y			L / M	L / M	L / M	Scheduled On-Condition Task

Table 6 The Result of Extended RRCM Decision Worksheet for Motor

Information Reference				Consequence Evaluation				H1 H2 H3 / S1 S2 S3 / O1 O2 O3			Uncertainty Assessment			Proposed Maintenance
F	FF		FM	H	S	E	O	N1	N2	N3	Degree of Uncertainty	Degree of Sensitivity	Degree of Importance	
1	1	1	The motor does not move due to current short electric	Y	N	N	Y	N	Y		M / H	L / M	M / H	Scheduled Restoration Task

Table 7 The Scheduled On-Condition Task Interval in Every Critical Component

Component	Proposed Maintenance Task	Interval (Hour)
Hydraulic Hose	Periodically check for pressure on the hose in actual conditions	909,5888229
Barrel	Periodically check the barrel for pressure in actual conditions.	1142,248333

Table 8 The Scheduled Restoration for Every Critical Component

Component	Proposed Maintenance Task	Interval (Hour)
Hydraulic Hose	Repair the hydraulic hose components	1626,434843
Barrel	Perform the cleaning of raw material to be melted	1807,152191
Motor	Repair the electric current flow	1132,166378

In Table 6, for the critical component motor, the result proposes task maintenance, namely the scheduled restoration task. The calculation of time interval for maintenance tasks scheduled on-condition is half from the P-F interval of each critical component. The intervals are defined as the intervals between potential failures and failure functions (Alhilman, Atmaji, & Athari, 2017). Table 7 is the result of the proposed maintenance scheduling and proposed tasks for each critical component based on the scheduled on condition task.

Table 8 is the calculation of the scheduling of maintenance for scheduled restoration tasks. It shows the interval of the restoration task for the critical component. It shows there are repairing activities. This means that the component needs more maintenance activity compared to the schedule on-condition task previously. The qualitative measurements using the RRCM method results in the proposed maintenance task are along with its intervals for critical components of the plastic injection machine. Seven proposed maintenance tasks are obtained with three scheduled on-condition tasks and four scheduled restoration tasks for all critical components with an average preventive maintenance task time interval for two months.

Then, the cost calculation of the proposed maintenance is performed. In addition to the proposed maintenance costs, the researchers also compare the company's actual maintenance costs for critical components of plastic injection machines. Next, Table 9 shows the actual maintenance cost for each failure function of each critical component.

Based on Table 9, the total estimated cost of maintenance is obtained from the frequency of maintenance multiplied with the corrective maintenance costs incurred. The proposed maintenance cost is based on pre-determined maintenance policies. It is adjusted to the intervals of each critical component. The proposed maintenance cost is shown in Table 10.

Based on Table 10, the proposed total maintenance cost for the critical component of the plastic injection machine is IDR91.595.318. It is lower than the actual maintenance cost. With lower costs it proves that preventive maintenance activities using the RRCM method are effective in maximizing production and reducing maintenance costs.

Table 11 shows a comparison between the proposed and actual maintenance. It can be seen that the company's actual maintenance is higher than the proposed maintenance costs. The difference between the two maintenance costs is IDR10.177.258. Based on field studies, this occurs because the critical components of the plastic injection machine are included in the physical assets owned by the company that has not applied the RRCM method. Thus, the determination of the frequency of task maintenance still uses the experts' judgment or component age data from the vendor in the form of a useful lifespan. The error in estimating the frequency of maintenance or inaccurate age data of components from vendors has caused the components to experience sudden damage. Therefore , it force the maintenance engineers of the company to carry out corrective maintenance activities, which affects the maintenance costs. Overall, by applying the risk variable of uncertainty assessment in the preventive maintenance task and interval using RRCM method can be as an extension for the conventional method RCM. Moreover, it is effective to reduce maintenance costs.

Table 9 The Existing Maintenance Cost of the Company

Component	Fm	Cm	Maintenance Cost
Hydraulic Hose	6	IDR2.035.452	IDR12.212.709
	9	IDR2.035.452	IDR18.319.064
	8	IDR2.035.452	IDR16.283.612
Barrel	5	IDR2.035.452	IDR10.177.258
	5	IDR2.035.452	IDR10.177.258
	8	IDR2.035.452	IDR16.283.612
Motor	9	IDR2.035.452	IDR18.319.064
Total			IDR101.772.576

Table 10 The Proposed Cost of Maintenance Task for The Company

Component	Fm	Cm	Maintenance Cost
Hydraulic Hose	5	IDR2.035.452	IDR10.177.258
	9	IDR2.035.452	IDR18.319.064
	7	IDR2.035.452	IDR14.248.161
Barrel	5	IDR2.035.452	IDR10.177.258
	5	IDR2.035.452	IDR10.177.258
	7	IDR2.035.452	IDR14.248.161
Motor	7	IDR2.035.452	IDR14.248.161
Total			IDR91.595.318

Table 11 The Comparison of Actual
and Proposed Maintenance Cost

Maintenance	Cost Maintenance
Proposed	IDR91.595.318
Actual	IDR101.772.576

IV. CONCLUSIONS

In this research, the researchers propose the maintenance task analysis for critical components of injection plastic machine using RRCM. It is by considering the task and time interval of the maintenance, and cost for the proposed maintenance task. By using RRCM, the researchers have conducted the calculation and analysis to produce maintenance policies for components on plastic injection machines. Seven proposed maintenance tasks are obtained with three scheduled on-condition tasks and four scheduled restoration tasks for all critical components with an average preventive maintenance task time interval for two months. For the total maintenance costs, the researchers show the proposed maintenance task and the time interval of IDR91.595.318. It has a lower nominal reaching IDR10.177.258 compared to the actual maintenance costs of the company (IDR101.772.576). In the future, the researchers can explored and discuss the preventive maintenance tasks by combine several methods to get a more optimal maintenance schedule and cost. For example, the spare part inventory analysis of three critical components can be added to enhance the preventive maintenance policy task for plastic injection machines.

REFERENCES

Afzali, P., Keynia, F., & Rashidinejad, M. (2019). A new model for reliability-centered maintenance prioritisation of distribution feeders. *Energy*, *171*(March), 701-709. https://doi.org/10.1016/j.energy.2019.01.040

Atmaji, F. T. D. (2015). Optimasi jadwal perawatan pencegahan pada mesin tenun unit satu di PT KSM, Yogyakarta. *JRSI (Jurnal Rekayasa Sistem dan Industri)*, *2*(02), 7-11.

Atmaji, F. T. D., & Ngurah, A. A. (2018). Kebijakan persediaan suku cadang di PT ABC menggunakan metode RCS (Reliability Centered Spares). *Jurnal Manajemen Industri dan Logistik*, *2*(1), 90-102. https://doi.org/10.30988/jmil.v2i1.29

Alhilman, J., Atmaji, F. T. D., & Athari, N. (2017). Software application for maintenance system: A combination of maintenance methods in printing industry. In *2017 5th International Conference on Information and Communication Technology (ICoIC7)* (pp. 1-6).

Atmaji, F. T. D., & Alhilman, J. (2018). A framework of wireless maintenance system monitoring: A case study of an automatic filling machine at SB company. In *2018 6th International Conference on Information and Communication Technology (ICoICT)* (pp. 227-232).

Atmaji, F. T. D., Noviyanti, A. A., & Juliani, W. (2018). Implementation of maintenance scenario for critical subsystem in aircraft engine: Case study NTP CT7 Engine. *International Journal of Innovation in Enterprise System, 2*(01), 52-60. https://doi.org/10.25124/ijies.v1i01.85

Awad, M., & As'ad, R. A. (2016). Reliability centered maintenance actions prioritization using fuzzy inference systems. *Journal of Quality in Maintenance Engineering*, *22*(4), 433-452. https://doi.org/10.1108/JQME-07-2015-0029

Dhamayanti, D. S., Alhilman, J., & Athari, N. (2016). Usulan preventive maintenance pada mesin Komori LS440 (RCM II) dan Risk Based Maintenance (RBM) di PT ABC. *Jurnal Rekayasa Sistem & Industri*, *3*(2), 31-37.

Gupta, G., & Mishra, R. P. (2018). Identification of critical components using ANP for implementation of reliability centered maintenance. *Procedia CIRP*, *69*, 905-909. https://doi.org/10.1016/j.procir.2017.11.122

Igba, J., Alemzadeh, K., Anyanwu-Ebo, I., Gibbons, P., & Friis, J. (2013). A systems approach towards Reliability-Centred Maintenance (RCM) of wind turbines. *Procedia Computer Science*, *16*, 814-823. https://doi.org/10.1016/j.procs.2013.01.085

Jiang, X., Duan, F., Tian, H., & Wei, X. (2015). Optimization of reliability centered predictive maintenance scheme for inertial navigation system. *Reliability Engineering & System Safety*, *140*(August), 208-217. https://doi.org/10.1016/j.ress.2015.04.003

Márquez, A. C. (2007). *The maintenance management framework: Models and Methods for complex systems maintenance*. London: Springer-Verlag.

Mkandawire, B. O. B., Ijumba, N., & Saha, A. (2015). Transformer risk modelling by stochastic augmentation of reliability-centred maintenance. *Electric Power Systems Research*, *119*(February), 471-477. https://doi.org/10.1016/j.epsr.2014.11.005

Sabouhi, H., Fotuhi-Firuzabad, M., & Dehghanian, P. (2016). Identifying critical components of combined cycle power plants for implementation of reliability-centered maintenance. *CSEE Journal of Power and Energy Systems*, *2*(2), 87-97. https://doi.org/10.17775/CSEEJPES.2016.00026

Sainz, J. A., & Sebastián, M. A. (2013). Methodology for the maintenance centered on the reliability on facilities of low accessibility. *Procedia Engineering*, *63*, 852-860. https://doi.org/10.1016/j.proeng.2013.08.279

Selvik, J. T., & Aven, T. (2011). A framework for reliability and risk centered maintenance. *Reliability Engineering & System Safety*, *96*(2), 324-331. https://doi.org/10.1016/j.ress.2010.08.001

Sinha, R. S., & Mukhopadhyay, A. K. (2015). Reliability centered maintenance of cone crusher: A case study. *International Journal of System Assurance Engineering and Management*, *6*(1), 32-35.

Tang, Y., Liu, Q., Jing, J., Yang, Y., & Zou, Z. (2017). A framework for identification of maintenance significant items in reliability centered maintenance.

Energy, *118*(January), 1295-1303. https://doi.org/10.1016/j.energy.2016.11.011

Vishnu, C. R., & Regikumar, V. (2016). Reliability based maintenance strategy selection in process plants: A case study. *Procedia Technology*, *25*, 1080-1087. https://doi.org/10.1016/j.protcy.2016.08.211

Yssaad, B., Khiat, M., & Chaker, A. (2014). Reliability centered maintenance optimization for power distribution systems. *International Journal of Electrical Power & Energy Systems*, *55*(February), 108-115. https://doi.org/10.1016/j.ijepes.2013.08.025