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Markov Chain Method in Decision Implementation of Preventive Maintenance Scheduling to Reduce Equipment Downtime in PT. ADF Indonesia: Case Study

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ABSTRACT

PT. ADF is a company operating in the shoe manufacturing industry located in Indonesia. PT. ADF has the problem of machine downtime which is currently still relatively high and requires quite a long repair time. The aim of this research is to reduce the high downtime of equipment or machines with the Markov chain method approach used in selecting the next strategy to produce a better probability of implementing scheduled preventive maintenance (PM) compared to Corrective Maintenance (CM), so that implementing a maintenance schedule is chosen to reduce downtime. equipment/machines. This strategy can reduce obstacles or disruption to production schedules. Based on the Pareto diagram, it is known that the largest downtime is caused by damage to the Rotary injection molding machine and molding machine at 80%. After implementing the preventive maintenance scheduling system as intended, the effectiveness of implementing preventive maintenance can be determined by knowing the results of calculating downtime data on Rotary printing machines and printing machines which were previously 2180 minutes/3 months to 729 minutes/3 months or the equivalent of a cost reduction of IDR. 54,735,613.00 to IDR. 18,303,790.00 or the company obtains savings of 66.56%.

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1. INTRODUCTION

Production scheduling and equipment maintenance planning are two important aspects of the manufacturing system, both are interdependent in getting good productivity, and equipment maintenance activities have a significant impact on system costs and performance (Sharifi & Taghipour, 2021). In recent decades production planning has been investigated with incentives from various angles and various important elements in the manufacturing process, such as: Machine or equipment setup, maintenance scheduling, waiting time elimination, energy consumption, and production synchronization, many decision support tools and algorithms have also been developed. to assist production planning (Liu, et al. 2021). Good system performance is the hope of every company, including performance in equipment maintenance. To achieve this, more and more companies are replacing reactive equipment maintenance strategies with proactive equipment strategies, such as Preventive maintenance, predictive maintenance, and aggressive maintenance strategies in the form of Total Productivity Maintenance (TPM) (Atikno et al, 2022). From research that has been done before, there is a strong positive relationship between strategy and performance of proactive and aggressive maintenance (Swanson, 2001). This strong positive relationship means that proactive (preventive and predictive) and aggressive (TPM) maintenance strategies will have an impact on improving company performance (Wardhani & Widjajati, 2023). Effective maintenance of equipment is essential for every operation, in general, equipment maintenance aims to extend equipment life, increase equipment availability and maintain equipment condition in good condition. On the other hand, equipment that is not properly maintained can cause more frequent equipment failures, shorter equipment life, and worse equipment function resulting in delayed production schedules. Furthermore, due to equipment that does not function properly, can result in scrap products or products with dubious Quality (Swanson, 2001).

PT. ADF is a company engaged in the shoe industry in Indonesia which has an operating system 24 hours a day with a 3-shift system. The company has several production machines that are interdependent from one machine to another so that when one machine experiences a problem, the production process will be hampered and result in decreased productivity, and losses must be borne by the company. Based on the company's internal data, the downtime that occurred due to equipment damage in the last 3 months was 2180 minutes or the equivalent of IDR. 54,735,613.00, the biggest breakdown occurred in the Rotary molding machine and molding machine which reached 80% of the total overall breakdown. This research aims to reduce equipment downtime caused by sudden and unpredictable machine breakdowns with the pilot project of the two machines, scheduling equipment maintenance (preventive maintenance) is the solution offered and is expected to reduce equipment downtime and companies get cost savings.

2. LITERATURE REVIEW

Markov Chain Analysis is a method that studies the properties of a variable in the present based on past properties to predict the properties of these variables in the future (Alloa, Hatidjaa, & Endong, 2013). Markov chain with the ability to predict future events based on past and present events can be used to find out the probability of an event that will come based on previous events, Markov chain analysis can also be used in choosing a decision from several choices (Mas'ud, Safitri, & Abassyahil, 2016). Previous studies have shown that Markov chain analysis can help companies choose preventive maintenance as a replacement strategy for corrective maintenance and can generate a difference in the cost of preventive maintenance and corrective maintenance for the maintenance of the proposed blow molding machine in light damage conditions, IDR. 7,458,916.08 with a difference of 77% in moderate conditions, IDR. 871,821.32 with a difference of 9.1% and heavy conditions obtained IDR. 6,587,094.72 with a difference of 68% (Ramadhan et al. 2020). Costs incurred by the company IDR. 50,922,766 and from the cheapest proposed maintenance (P3) using the Markov Chain method the maintenance fee is IDR. 45,360,870 consisting of Welding Machine maintenance costs IDR. 8,868,923 Lathe Machine IDR. 17,989,371 and Over Head Crane IDR. 18,502,576 (Sanusi, Saputra, & Hidayat, 2020). The studies mentioned above with Markov chain analysis can be used as a tool to choose the right strategy in planning machine maintenance in preparing production needs to get optimum profits. Equipment maintenance is a series of activities aimed at extending equipment lifetime, increasing equipment availability, and maintaining equipment in good condition. To reduce: equipment failure, shorter equipment life, and worse equipment function resulting in delayed production schedules and keep products in good quality condition as planned (Swanson, 2001). Daryus (2007) in the book states the role of equipment maintenance as a means of supporting the industry or production process which is very important to get products that are of good quality, reasonable prices, and faster delivery to consumers (p.1). as in Figure 1.

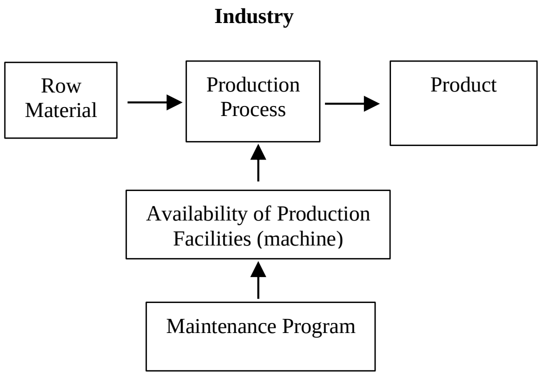

Figure 1. The role of the maintenance program as a support for production activities
Source: Daryus (2007)

Figure 1 explaining the role of the equipment maintenance program is important to ensure the availability or readiness of production facilities, in this case, production machines, in carrying out the production process in the form of transformation of raw materials as an input to get output in the form of products. Of course, the condition of production facilities (machines) that are good will produce quality products at reasonable prices and delivery times to consumers can be accelerated, all three of which will result in increased industrial competitiveness. Equipment maintenance in its implementation recognizes 2 main criteria, namely Breakdown or Corrective maintenance, namely machine repairs carried out due to machine damage and of course this activity is carried out without any prior planning, and Preventive maintenance which is a machine/equipment repair activity before the machine/equipment is damaged with a scheduling system that planned so that disruption of production and unpreparedness of machines/equipment can be reduced. Breakdown or corrective maintenance is equipment maintenance and maintenance activities carried out after damage or abnormalities occur in the equipment which results in the deterioration or decrease in the function of the equipment (Mulya, Yusnita, & Lestari, 2022). Breakdown or corrective maintenance activities are often referred to as repairs or repairs.

Factors for damage to the machine also vary, such as lack of maintenance, human error, and the machine's use time being too long. The focus of the breakdown maintenance itself is to find a solution so that the machine can be repaired immediately and can be started again and the same damage does not happen again. In general, breakdown maintenance is done by replacing the problematic components so that the machine can return to operation.

Research by Muhtadi (2009), confirmed that marked maintenance workers will only work after damage to the machine or equipment. If we use this system, machine or equipment damage will occur many times and the frequency of damage will be almost the same every year. This means that some of the machines or equipment at the factory are often repaired. In factories that operate continuously, it is recommended to provide machine backup (stand-by machine) for vital machines. In addition, this system for the annual disassembly of factory machinery is not used because, during engine overhaul and repair, spare engine units are used (p.39). At first glance, breakdown or corrective maintenance activities require low costs because these activities are only carried out if damage occurs, but the potential for repeated damage and disruption of production schedules is high and if production activities do not want to be disrupted, you must provide replacement equipment or machines, then breakdown or corrective maintenance activities this as a whole will have a fairly expensive cost. Preventive maintenance is routine and scheduled equipment maintenance activities aimed at eliminating the potential for equipment failure (downtime) as well as restoring equipment reliability as indicated by longer equipment lifetime (Swanson, 2001). This type of preventive inspection and repair is made taking into account the availability of labor, spare parts, materials for repairs, and other factors. Repair costs and the length of time the machine/equipment is not operating can be minimized compared to repairing the same machine but carried out after the machine is completely damaged (Muhtadi, 2009). Preventive maintenance has very important uses, especially for equipment that is classified as a critical unit which has the following characteristics: if the damage endangers the health or safety of pre-workers if the damage will affect the quality of the product produced, if the equipment damage will disrupt the smooth running of the entire production process and if the equipment investment is large enough (Daryus, 2007). Preventive maintenance in practice carried out by a company or factory can be divided into routine maintenance and periodic maintenance. Routine maintenance, Routine maintenance is a maintenance activity that is carried out regularly, for example, every day. Periodic maintenance, Periodic maintenance is a maintenance activity that is carried out within a certain period, for example once every once a week, then increases once every month, and finally once every year (Pandi, Santosa, & Mulyono, 2014).

Downtime is a condition in which a system or equipment or service does not function at all. This can be caused by systems, equipment, and services experiencing unplanned interruptions or damage or due to maintenance or maintenance schedules being carried out. Mean time to failure (MTTF) is the average interval or interval of damage that occurs when the equipment or machine is repaired until the equipment or machine is damaged again. Mean time to failure is an indicator that is closely related to usability (lifetime) and equipment replacement (Bhattacharyya, Ali Khan, & Mitra, 2021). Knowing the mean time to failure (MTTF) value indicates the level of equipment reliability and knowing the mean time to failure value will indicate when the equipment must be replaced. Kurniawan (2013) states Mean Time to Repair (MTTR) is the average time to make repairs needed by a component or equipment (p.61). This mean time to repair is an indicator of the skill of the maintenance or repair executor in fixing a problem. The two variables Mean time to failure (MTTF) and Mean time to repair (MTTR) are the basis for calculating the value of equipment or machine downtime caused by breakdown or preventive maintenance.

3. RESEARCH METHOD

PT. ADF Indonesia, which is the object of this research, is a company engaged in the shoe industry with various types of shoes produced. PT. ADF Indonesia in its production process uses several machines, namely: Automatic cutting machine, Molding Machine, Rotary Injection Molding Machine, Insole Making Machine, Healasting Machine, Toelasting Machine, and Press machine. This study aims to reduce equipment or machine downtime, which is one of the variables that interfere with the smooth production process in various equipment or machines used due to the cessation of the production process and corrective maintenance. This research is quantitative discrete using Markov chain analysis which aims to make a picture or descriptive and choose a strategy about a situation objectively using numbers, starting from data collection, interpretation of the data, and the results. Data collection is in the form of secondary data using the method of gathering facts and data in the form of company documents, which describe the condition of equipment/machinery and the consequences of machine failure and disruption of the production process in the company. The data collected in this study are data on damage to equipment/machinery and its components, data on loss time caused by machines or components that cause breakdowns, and data on loss of production costs due to machine breakdown during the production process.

Data processing in this study follows the following steps: using Pareto diagrams to determine critical machines from machine breakdown data, then determining critical components of critical machines based on the damage that has occurred, performing calculations, and analyzing component damage data by calculating the time to failure (TTF).) and time to repair (TTR) critical components from critical machines based on the date of damage until the repair is completed. Then calculate the mean time to failure (MTTF) and mean to repair (MTTR) values, for component replacement intervals and component availability levels, the final step is calculating reliability, and downtime costing before and after preventive maintenance. The steps of this research are described in the research flow diagram as shown in Figure 2.

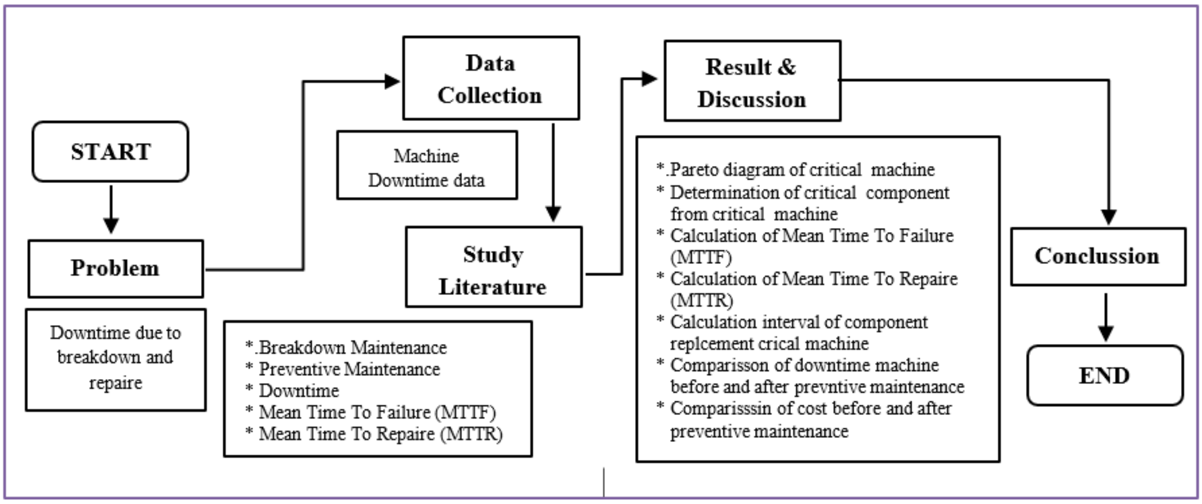

Figure 2. Research flow chartstated

4. RESULT AND DISCUSSION

The data that has been successfully collected through recording total time losses from the maintenance implementing or maintenance department is data on machine readiness opportunities to carry out the production process for the previous 1 year period and breakdown data for April, May, and June 2022 is data describing the latest equipment/machine readiness. The first step in this research is to classify data on all the machines used in the production process, namely: Automatic cutting machine, Molding Machine, Rotary Injection Molding Machine, Insole Making Machine, Healasting Machine, Toelasting Machine, Press machine. This classification is based on the total breakdown time that occurred on these machines for January, February, and March 2022 by using a Pareto chart to find out which machines can be classified as critical machines to be used as a pilot project to solve the problem, namely the high downtime due to machine breakdowns. machine breakdown data as referred to above can be seen in Table 1.

Table 1. Machine breakdown data

Machine name	Breakdown Time (Minutes)
Rotary Injection Molding Machine	1204
Molding Machine	976
Automatic Cutting Machine	185
Insole Making Machine	178
Healing Machine	123
Toelasting Machine	67
Press Machine	40
Total	**2773**

Source: Internal maintenance data 2022

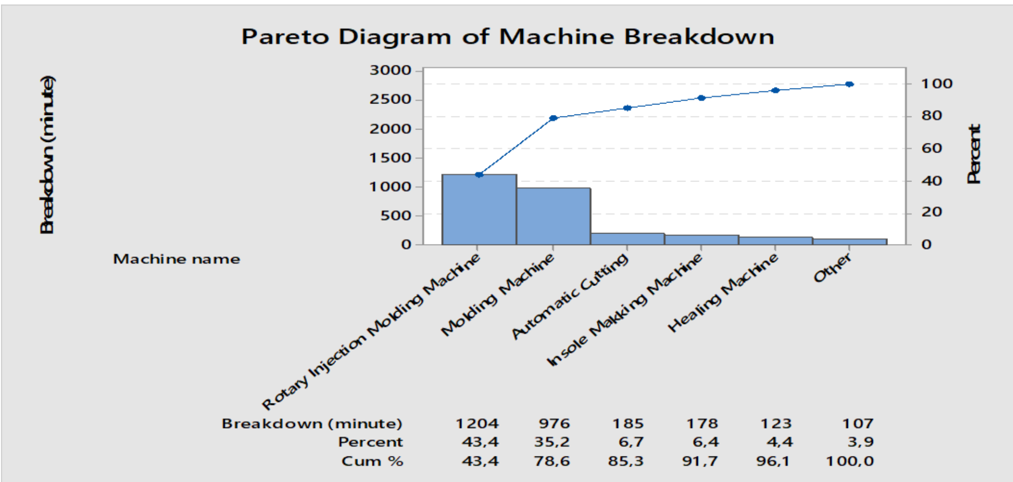

Figure 3. Pareto Diagram of Machine Breakdown
Source: data processing 2022

Based on Table 1 and the Pareto diagram above, it is known that two critical machines are the biggest contributors to breakdowns, namely: Rotary injection molding machines and Molding machines which account for 80% of the total breakdown that occurs in three months. Next determine the type of critical components, breakdown frequency, and total breakdown time for each critical machine, critical component data from each critical machine is presented in Table 2 and 3.

Table 2. Critical component data of Rotary Injection Molding Machines

Component Name	Breakdown Frequency	Breakdown Time (Minutes)	Breakdown time percentage
Pulleys	7	639	53%
gearbox	4	400	33%
Bearings	3	119	10%
Nozzle	3	21	2%
Rollers	1	10	1%
Flat Rotation	2	15	1%
Total	**15**	**1204**	**100%**

Source: Internal maintenance data 2022

Table 3. Breakdown data for Molding Machine Components

Component Name	Breakdown Frequency	Breakdown Time (Minutes)	Breakdown time percentage
Pulleys	6	460	47%
gearbox	3	395	40%
Bearings	3	90	9%
Nozzle	1	21	2%
Rollers	2	10	1%
Total	**49**	**651**	**100%**

Source: Internal maintenance data 2022

Of the two selected critical machines, the critical components of each machine will be sought. Based on the breakdown data, there are two critical components of the machine in the Rotary Injection Molding Machine, namely damage to the Pulley and Gearbox. As for the Molding Machine, the critical component is damage to the Pulley and Gearbox as well. By using the MTTF calculation, a summary of MTTR calculations for Rotary Injection Molding Machines can be seen in Table 5 and for Injection Molding Machines can be seen in Table 6.

Table 4. The results of the calculation of the critical component MTTF on critical machine

Component Name	**MTTF / Life Time (Hours)**
Pulleys	166
Gearbox	308
Bearings	360
Nozzle	720
Rollers	720
Fit Rotation	1080

Source: Internal maintenance data 2022

Table 5. The results of the calculation of the critical component MTTR on Critical engine Rotary Injection Molding

Component Name	**MTTR (minutes)**
Pulleys	26.6
Gearbox	26.7
Bearings	17
Nozzle	7
Rollers	5
Flat Rotation	15

Source: Internal maintenance data 2022

Table 6. The results of the calculation of the critical component MTTR on Injection Molding machine

Component Name	**MTTR (minutes)**
Pulleys	21,9
gearbox	28.2
Bearings	11.3
Nozzle	7
Rollers	5

Source: Internal maintenance data 2022

The facts mentioned above require companies to take effective steps so that production downtime caused by machine breakdown can be kept to a minimum to obtain savings (cost savings) to increase company profitability. The company's internal data from the previous and current 1 year shows that the probability of machines not being damaged by non-corrective maintenance (NCM) in the sense that they are ready for production does not occur breakdown or corrective maintenance (CM) if preventive maintenance (PM) is carried out compared to without preventive maintenance (PM). NPM) is as presented in Table 7. below:

Table 7. Opportunity matrix is not broken with Preventive maintenance and non-preventive maintenance

Previous and current year	Next year	
	NCM	CM
PM	0.78	0.22
NPM	0.18	0.82

Source: Internal company data

Based on Table 7 it can be seen the probability of the machine not being damaged/non corective mantenance (NCM) if preventive maintenance (PM) is 0.78 and the probability that the machine ot being damaged/non corective mantenance (NCM) if preveus carried out preventive maintenance is 0.22 and the probability that the machine is damaged (CM) if preventive maintenance is not carried out (NPM) is 0.82 and the probability that the machine is not damaged (NCM) if preventive maintenance is not carried out is 0.18. The probability matrix data of the machine is not damaged in terms of machine readiness for the production process as in Table 7 above. Markov chain analysis can be carried out to find out opportunities for the next 3 Years period with Markov chain analysis, namely by multiplying the automatic transitions in each period, as follows:

The probability that the machine transition matrix is not damaged during the previous and current period (p^1) is:

$$p^1=\begin{pmatrix} NCM/PM & CM/PM \\ NCM/NPM & CM/NPM \end{pmatrix} \text{ so } p^1 = \begin{pmatrix} 0.78 & 0.22 \\ 0.18 & 0.82 \end{pmatrix}$$

The probability that the machine transition matrix is not damaged in the next 3 years (p^2) is by multiplying the transition matrix:

$$p^{n+1}=(p^{n-1})^2$$

$$p^2= xp^1p^1$$

$$p^2=\begin{pmatrix} 0.78 & 0.22 \\ 0.18 & 0.82 \end{pmatrix} x \begin{pmatrix} 0.78 & 0.22 \\ 0.18 & 0.82 \end{pmatrix}$$

$$p^2=\begin{pmatrix} 0.65 & 0.35 \\ 0.29 & 0.71 \end{pmatrix}$$

The probability that the engine will not be damaged in the next 3 years based on Markov chain analysis are: (i) The probability that the machine is not damaged (NCM) if preventive maintenance (PM) is carried out is 0.65. (ii) The probability of the machine being damaged (CM), if preventive maintenance (PM) is carried out, is 0.35. (iii) The probability that the machine will not be damaged (NCM), if preventive maintenance (NPM) is not carried out, is 0.18. (iv) The probability of the machine being damaged (CM), if preventive maintenance (NPM) is not carried out, is 0.71. The results of the Markov chain analysis above show that the preventive maintenance (PM) strategy is for the next 3 years in preparing the production process with a 65% chance of the machine not being damaged in the sense that it is ready for production and a 35% chance of the machine being damaged, but vice versa if preventive measures are not carried out maintenance (NPM) the chance of the machine not being damaged in the sense that it is ready for production is only 18% and the chance of the machine being damaged is 71% so that PT. ADF Indonesia chooses a Preventive maintenance (PM) strategy for its production machines, especially on the two machines that experience the biggest breakdown in the previous year namely: Rotary Injection Molding Machine and Molding Machines. Based on the Markov chain analysis above, the company decided to implement an equipment maintenance system or preventive maintenance aimed at reducing downtime due to machine breakdown as referred to above. After implementing the maintenance system, it is possible to evaluate the effectiveness of the equipment/machinery maintenance system carried out in the company by looking at the machine breakdown data in the first 3 months (January, February, and March 2023) after implementing preventive maintenance, it can be seen that the effectiveness of implementing this system. Based on the calculation of machine downtime before and after preventive maintenance which can be seen in Table 8 and 9.

Table 8. Calculation of downtime before and after preventive Maintenance of Rotary Injection Molding machines

Component Name	Total Loss Time Before Preventive (minutes)	Total Loss Time After Preventive (minutes)
Pulleys	639	214
Gearbox	400	125
Bearings	119	85
Nozzle	21	0
Rollers	10	0
Flat Rotation	15	0
Total	1204	424

Source: Internal data processing 2022

Table 8 above can be seen that there is a decrease in total loss time after the implementation of the equipment/machine maintenance system (preventive maintenance) on Rotary injection molding machines, namely from 1204 minutes/3 months to 424 minutes/3 months, this fact can be interpreted as implementing this preventive maintenance system effective in reducing total lost time on rotary molding machines.

Table 9. Calculation of downtime before and after preventive Maintenance of Injection Molding

Component Name	Total Loss Time Before Preventive (minutes)	Total Loss Time After Preventive (minutes)
Pulleys	460	180
Gearbox	395	95
Bearings	90	30
nozzle	21	0
Rollers	10	0
Total	976	305

Source: Internal data processing 2022

Table 9 above shows that there is a decrease in total loss time after implementing a preventive maintenance system for molding machines, from 976 minutes/3 months to 305 minutes/3 months. also, reduce the total lost time on the molding machine. Next, the calculation of machine maintenance costs before and after preventive maintenance for Rotary Injection Molding machines is carried out with a loss that must be borne every minute of IDR. 25,108.00 can be seen in Table 9 and Injection Molding Machines can be seen in Table 10.

Table 10. Cost Calculation before and after preventive maintenance of Rotary Injection Molding Machines

Component Name	Cost Before PM	Cost After PM
Pulleys	IDR. 16,044,063.00	IDR. 5,373,129.00
Gearbox	IDR. 10,043,232.00	IDR. 3,138,510.00
Bearings	IDR. 2,987,861.00	IDR. 2,134,187.00
Nozzle	IDR. 527,268.00	IDR. 0.00
Rollers	IDR. 251,081.00	IDR. 0.00
Flat Rotation	IDR. 376,621.00	IDR. 0.00
Total	IDR. 30,230,128.00	IDR. 10,645,826.00

Source: Internal data processing 2022

Table 11. Cost calculation before and after preventive maintenance of Injection Molding Machines

Component Name	**Cost Before PM**	**Cost After PM**
Pulleys	IDR. 11,549,717.00	IDR. 4,519,454.00
Gearbox	IDR. 9,917,691.00	IDR. 2,385,268.00
Bearings	IDR. 2,259,727.00	IDR. 753.242.00
nozzle	IDR. 527,270.00	IDR. 0.00
Rollers	IDR. 251,081.00	IDR. 0.00
Total	IDR. 24,505,485.00	IDR. 7,657,964.00

Source: Internal data processing 2022

Based on Table 10 and Table 11, it can be seen that there is a decrease in costs that must be borne by the company due to machine downtime before preventive maintenance on rotary injection molding machines and molding machines of IDR.54,735,613.00 to IDR. 18,303,790.00

5. CONCLUSION

The results of implementing a preventive maintenance system can reduce the Rotary injection molding and molding machine downtime from 2180 minutes/3 months to 729 minutes/3 months. While the reduction in costs resulting from the implementation of this IDR.54,735,613.00 to IDR.18,303,790.00 there is a saving of 66.56%. The level of machine reliability has also increased significantly which is marked by a decrease in downtime of 66.56% as well. Based on the results obtained in this research, it is recommended to future researchers that the Markov chain approach can be used as a decision-making method in choosing one of the two alternative solutions offered, as in this research, where the preventive maintenance (PM) approach is the main choice in solving problems in this research. This research also obtained good results using the Markov chain approach and preventive maintenance in solving equipment downtime problems at PT ADF. It is recommended that future researchers try to use a combination of other decision-making approaches in solving similar and other problems, to enrich the research to increasingly varied solving problems in the manufacturing or service industries.

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