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Design of Preventive Maintenance System for A Product Design Lab using Reliability Centered Maintenance (RCM) Methodology

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ABSTRACT

The product design and innovation laboratory, which is still relatively new, does not yet have a maintenance model to anticipate damages that may occur in the future. The purpose of this research is to build preventive maintenance to anticipate unwanted events such as sudden damage and Standard Operational Procedure (SOP) for laboratory facilities. The method used is Reliability Centered Maintenance (RCM) using EasyFit 5.5 software, obtained a repair schedule with minimum downtime. The results of the Reliability Centered Maintenance (RCM) method obtained maintenance recommendations in the form of Condition Directed (CD) on 14 components that might damage the product design and innovation laboratory facilities, Finding Failure (FF) on 8 components that might damage the design laboratory facilities. Product and innovation and time-oriented (TD) of 5 components that may cause damage to product design and innovation laboratory facilities, and results based on preventive maintenance, there is a Standard Operational Procedure (SOP) which includes the use of laboratory facilities following work instructions for the use of equipment, use of facilities the laboratory follows the work instructions for use, all validation results must be stored in the form of records in the form.

***Keywords**: downtime; product design and innovation laboratory; preventive maintenance; Reliability Centered Maintenance; Standard Operational Procedure*

ABSTRAK

Laboratorium Desain Produk dan Inovasi Institut Teknologi Del tergolong laboratorium baru, belum mempunyai sistem perawatan untuk mengantisipasi kerusakan-kerusakan yang mungkin akan terjadi dikemudian hari. Tujuan penelitian ini adalah membangun *preventive maintenance* untuk mengantisipasi kejadian-kejadian yang tidak diinginkan seperti kerusakan secara mendadak dan *Standart Operational Procedure* (SOP) untuk fasilitas laboratorium. Metode yang digunakan yaitu *Reliability Centered Maintenance* (RCM) dengan mengunakan *software EasyFit* 5.5, diperoleh jadwal perbaikan dengan *downtime* minimun. Hasil dari metode *Reliability Centered Maintenance* (RCM) diperoleh rekomendasi perawatan berupa *Condition Directed* (CD) pada 14 komponen yang mungkin terjadi kerusakan pada fasilitas laboratorium desain produk dan inovasi, *Finding Failure* (FF) pada pada 8 komponen yang mungkin terjadi kerusakan pada fasilitas laboratorium desain produk dan inovasi dan *Time Directed* (TD) pada 5 komponen yang mungkin terjadi kerusakan pada fasilitas laboratorium desain produk dan inovasi, dan juga Berdasarkan hasil *preventive maintenance* yang dibangun maka terdapat *Standart Operational Procedure* (SOP) yang mencakup penggunaan fasilitas laboratorium mengikuti instruksi kerja penggunaan peralatan, penggunaan fasilitas laboratorium mengikuti instruksi kerja perawatan penggunaan, segala sesuatu hasil pengesahan harus disimpan dam bentuk catatan dalam form.

Kata Kunci: *downtime*; laboratorium desain produk dan inovasi; *preventive maintenance*; *Reliability Centered Maintenance*; *Standart Operational Procedure*

INTRODUCTION

In order to deliver quality learning processes, the Engineering Management Study Program at the Institut Teknologi Del has just installed a laboratory that focuses on product design and innovation called the Product Design and Innovation Laboratory—abbreviated as Desprin Lab [2]. A laboratory is a place to apply scientific theory, theoretical testing, experimental evidence, research, and so on by using assistive devices as part of facilities with adequate quantity and quality [1]. As a laboratory that represents the state-of-the-art of Additive Manufacturing technology, Desprin Lab is equipped with various cutting-edge facilities such as computers with CAD software, 3D printers, and 3D scanners [3]. In addition, the Desprin Lab is supported by the smart classroom concept, where classrooms are designed with ergonomic and flexible modular work stations such as computer desks and chairs, instructor desks as well as practical tables and chairs that can be relayed out quickly as discussion rooms, classrooms, etc. exhibition and learning space. These facilities were obtained in collaboration with the Del Foundation and PT Astra International [2] [4] [5] [6].

To reliably support its function, a laboratory requires a maintenance system that ensures the reliability of machines and other facilities [7]. A collection of various components that are interconnected is a system that needs to be controlled so that the machine can function properly. If there is one component that is damaged, it will interfere with the smooth operation of the system so that the system fails to function. This results in decreased system performance and efficiency. A product or system can be said to be damaged if the product or system cannot perform its functions properly, this also applies to machines or facilities owned by a laboratory. When a machine or equipment cannot perform its function properly, then the machine or equipment can be said to be damaged or breakdown. Maintenance or maintenance activities are divided into two forms, namely planned maintenance and unplanned maintenance. Planned maintenance includes preventive maintenance and corrective maintenance [8]. Preventive maintenance is maintenance that is carried out on a scheduled basis generally periodically. Preventive maintenance aims to prevent sudden engine damage, increase reliability and can reduce downtime [9].

Since Desprin Lab is the first lab to adopt an additive manufacturing system at this university, so the benchmark for its maintenance system does not yet exist. For this reason, pioneering efforts in creating a maintenance system formulation are needed. This study seeks to fill the gap in formulating a maintenance system for an additive manufacturing-based laboratory that carries the smart classroom concept. This effort is expected to become a pilot project that can be used as a benchmark for advanced technology laboratories in the field of additive manufacturing in the future. The outcomes of this research will be the basis for building Standard Operational Procedures (SOPs) and check sheets that are appropriate to the object of treatment in the Desprin Lab in order to prevent unwanted damages that can interfere with the teaching and learning process [10].

For conditions like this, the method that suits the purpose of this research is Reliability Centered Maintenance (RCM). Reliability Centered Maintenance (RCM) is the basic foundation for physical maintenance and a technique used to develop scheduled preventive maintenance [11]. It is based on the principle that the reliability of the equipment and the structure of the performance to be achieved is a function of the design and the quality of the establishment of effective preventive maintenance will ensure the implementation of the reliable design of the equipment. The Reliability Centered Maintenance (RCM) method is expected to be able to establish a maintenance schedule and be able to know for sure the correct maintenance task that must be carried out on each machine component [12].

LITERATURE REVIEW

Reliability Centered Maintenance (RCM) focuses on preventive maintenance against frequent failures. There are four major components in RCM, namely reactive maintenance, preventive maintenance, predictive testing and inspection, and proactive maintenance (Fig. 1).

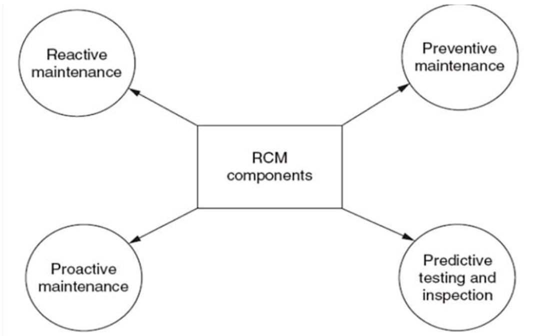

Figure 1. Four components of Reliability Centered Maintenance (RCM)

Reactive maintenance components are also known as breakdown maintenance, fix-when-fail maintenance, run-to-failure maintenance, or repair maintenance. By using a reactive maintenance approach, when a component or machine does not work according to its function, the activities that are often carried out are machine repair, maintenance, or component replacement. When carrying out reactive maintenance, what often happens is a high component replacement which causes large parts inventory, low effort in carrying out maintenance, and a high percentage of unplanned maintenance activities.

Another component, namely preventive maintenance, can be interpreted as a maintenance action to keep the system/sub-assembly operating according to its function by preparing for systematic inspections, detection, and correction of minor damage to prevent larger damage. Its activities consist of periodic inspections, replacement of parts, repair of components, adjustments, testing, lubrication, and cleaning of machines or equipment. Preventive maintenance is regularly scheduled with a number of inspections and maintenance at certain intervals intended to reduce the occurrence of failures on equipment that is prone to failure.

Predictive testing and inspecting are maintenance components that require engine performance data, testing, and visual supervision. Analysis of the condition of the machine will then be used to plan and schedule maintenance before the failure occurs. This type of maintenance helps improve maintenance in terms of design, labor, installation, scheduling, and maintenance procedures are proactive maintenance. The characteristic of this maintenance is to use a continuous improvement process by providing feedback and communication to ensure changes to the design or procedure have a positive effect.

The steps in implementing RCM are [13]:

1. System selection and information collection
2. Definition of system boundaries that depend on the complexity of the facilities from a location that aims to avoid overlapping between one system and another.
3. Description of the system to find out the components contained in the system and how the components contained in the system operate.
4. Analysis of system functions and failures using the Failure Mode and Effects Analysis (FMEA) method. Usually, a malfunction has two or more conditions that cause partial, minor, or major failure of the system [14]. Failure Mode and Effect Analysis (FMEA) is a method that aims to evaluate the system design by considering various failure modes of systems consisting of components and analyzing the effect on the reliability of the system. By tracing the effects of component failure according to the system level, critical specific items can be assessed and corrective actions are required to improve the design and eliminate or reduce the probability of a critical failure mode. The components of various failure modes and their impact on the system are written in a Failure Mode and Effect Analysis (FMEA) Worksheet. Risk Priority Number (RPN) is a measurement of relative risk. RPN is obtained by multiplying the Severity, Occurrence, and Detection ratings. The RPN is determined before implementing the recommendations from the corrective action, and it is used to find out which part is the top priority based on the highest RPN value (Eq. 1).

$$RPN = Severity\ (S) \times Occurrence\ (O) \times Detection\ (D) \qquad \text{Eq. 1}$$

Severity indicates the severity or effect that the failure mode has on the entire machine (Table 1.). Occurrence is the frequency with which damage or failure occurs. Detection is a measurement of the ability to control or control failures that can occur.

Table 1. FMEA scale for severity, occurrence, and detection [13]

Rating	***Criteria***		
	Severity	***Occurrence***	***Detection***
10	Not working at all and very hazardous	Every day	Undetectable
9	Losing major function and involve hazardous outcomes	Every 3 to 4 weeks	Very remote chance to detect
8	The system is inoperable	Every week	Remote chance to detect
7	The system may not be operable	Every month	Very low chance to detect
6	Some functions may not operate	Every 3 month	Low chance to detect
5	Losing convenience for the user	Every 6 month	Moderate chance to detect
4	Decrease in user's convenience	Every year	Moderately high chance to detect
3	Minor effect on system performance	Every 1 to 3 years	High chance to detect
2	Very minor effect on system performance	Every 3 to 5 years	Very high chance to detect
1	No effect	> 5 years	Almost certainly be detected

5. After that, it is necessary to determine the priority of each damage in order to choose a model of treatment action. The Logic Tree Analysis (LTA) method is able to give priority to each damage mode and perform reviews and functions, malfunctions so that the status of the damage mode is not the same. The priority of a fault mode can be determined by answering the questions provided in the Logic Tree Analysis (LTA).
6. The selection of treatment measures is the next step to determine the appropriate action for a particular damage mode. Treatment actions are divided into 3 types, namely:
   - Condition Directed (CD), actions taken with the aim of detecting damage by means of visual inspection, checking tools, and monitoring a number of existing data. If any signs of equipment damage are detected, it will be continued with the repair or replacement of components.
   - Time Directed (TD), an action that aims to take direct prevention of the source of damage based on the time or age of the component.
   - Finding Failure (FF), actions taken with the aim of finding hidden faults with periodic checks.

RESEARCH METHODOLOGY

This study follows 6 (six) stages of implementing RCM described in the previous section. The object of this study comprises work facilities in the Desprin Lab, such as instructor desks, student desks, instructor chairs, student chairs, computer desks, prototype shelves, 3D printer shelves, 3D printers, computers, interactive smartboards, exhaust fans, air conditioner, and room.

The period of historical data used for common equipment and facilities, such as tables, chairs, shelves, fans, air conditioners, etc. covers the range of three years data from similar facilities. Meanwhile, for facilities that have never existed such as 3D printers and 3D scanners, due to the absence of records, the failure data uses proxy data. In this study, the estimated utility of the Desprin Lab facilities used is 100% due to the absence of historical data because this lab is still just installed. Focus Group Discussions were also conducted on this research with the designers and users of this laboratory in order to help determine the priority of equipment that is considered high risk. The experts in question consist of 5 people, namely the team involved in the design and installation of Desprin Lab and currently serving as structural and functional officers of Desprin Lab.

RESULTS AND DISCUSSION

Failure Mode and Effect Analysis (FMEA)

The main output from Failure Mode and Effect Analysis (FMEA) is the Risk Priority Number (RPN). The Risk Priority Number (RPN) is the result of mathematical calculations of the seriousness of the effect (severity), the possibility of a cause causing failure related to the effect (occurrence), and the ability to detect failure before it occurs (detection) (Eq. 1). The results of the RPN show the priority level of equipment that is considered high risk as a pointer to corrective action. Table 2 shows the calculation of the RPN for laboratory facilities on several selected parts based on the highest RPN grouping.

Table 2. Risk Priority Number Calculation

FMEA *Worksheet*		**SISTEM : LABORATORIUM DESAIN PRODUK DAN INOVASI**						
Sub System	*Part*	*Function*	*Code*	*Potential Failure Mode*	*S*	*O*	*D*	*RPN*
Instructor and student desk		Table parts separated	A.1.2	Bolts under the table are loose/ the table part is not connected	5	6	10	300
Instructor and student chair		Chair parts separated	B.2.2	Bolts on the seat are loose / the seat part is not connected	9	3	10	270
Computer desk		Bumpy pad	C.1.2	Bolts under the table are loose/ the table part is not connected	8	6	10	480
Prototype shelf	LED lights	Lights off the Shelf	D.1.1	Heat generated keeps the tape from sticking	5	5	10	250
3D printer shelf		Door unable to close	E.3.2	Broken hinge	8	3	10	240
3D Printer		Bed surface stretched	F.1.3	Nozzle distance too close	7	3	10	210
Computer/ Smartboard Interactive	CPU	CPU overheated	I.2.1	Applications too heavy	7	1	10	70
		Connectors malfunction	I.2.2	*Connector* di CPU broken Frequently changing USB to connectors	7	1	10	70
Exhaust Fan		*Fan* dirty Dynamo worn out	J.2.2	A fan can't rotate	9	2	10	180
Air Conditioner			K.1.2	Frozen on the connection pipe Thermistor broken	10	2	10	200
Room	Floor/ carpet	The carpet layer is thin	L.4.3	Load accumulated	4	6	10	240

From Table 2, it can be seen that the computer desk is the facility with the most vulnerable possibility of being damaged with the highest RPN value. These conditions are then categorized in a Logic Tree Analysis to analyze component criticality and component failure modes.

Logic Tree Analysis (LTA)

LTA contains information on the number, the name of the malfunction, the component that has failed, the function of the component and the mode of the component failure, and the criticality analysis. Criticality analysis places each component’s damage into 4 categories, namely: category A (Safety problem), category B (Outage problem), category C (Economic problem), and category D (Hidden failure). These categories are expressed in the Logic Tree Analysis diagram (Figure 2).

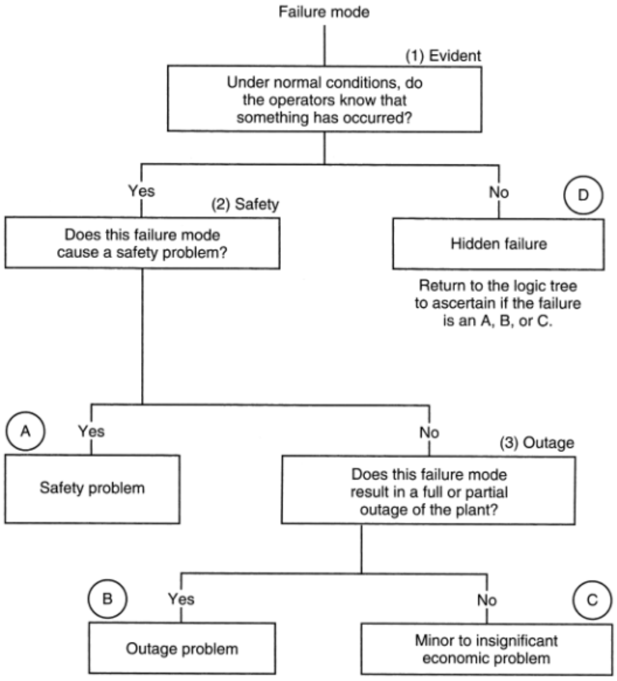

Figure 2. Logic Tree Analysis Diagram

By classifying component damage based on the failure mode, these facilities can be categorized as in Table 3.

Table 3. Logic Tree Analysis

Facility	Component	Failure Mode	Code	Evidence	Safety	Outage	Category
Desk	Desk pad	Broken/collapsed desk pad due to load or termites	A.1.2	Y	T	Y	B
		Broken/collapsed base due to load or termites	A.1.4	Y	Y	-	A
Chair	Student chair	Frame bent or broken due to corrosion	B.2.3	T	T	Y	D/B
		Chair parts separated due to loose bolts	B.2.4	Y	Y	-	A

Components included in category A include broken/collapsed bases due to accumulated loads and termites on student desks and computer desks, separation of chair parts due to loose bolts on student chairs, broken/collapsed shelf side supports on prototype shelves, broken room doors/ collapsed, the window of the room was broken, the lamp of the room was broken and the frame of the lamp of the room was broken/collapsed. Damage components included in category B such as separate desk parts due to loose bolts and also displacement of student desks, uneven computer desk bases due to loosened desk parts, and the 3D Printer side shelf door does not close. Included in category C is the frame of the computer desk is brittle by corrosion. While the damaged components belonging to category D are the frame of the student chair bent/broken by corrosion on the 3D Printer and 3D Scanner machines which were damaged by falling, filaments that were not removed from the filament pipe when using the 3D Printer machine, the sensor of the 3D Scanner machine did not work and the fan exhaust broken/ not working.

After each facility component has been successfully categorized, then the type of action is selected to categorize the most effective way to see the damage that will occur to the facility. Action selection is the final stage of the RCM process. Damage mode lists the effective actions to take next. This process will determine the appropriate action for a particular damage mode. The road map diagram of the selection of actions can be seen in Figure 3.

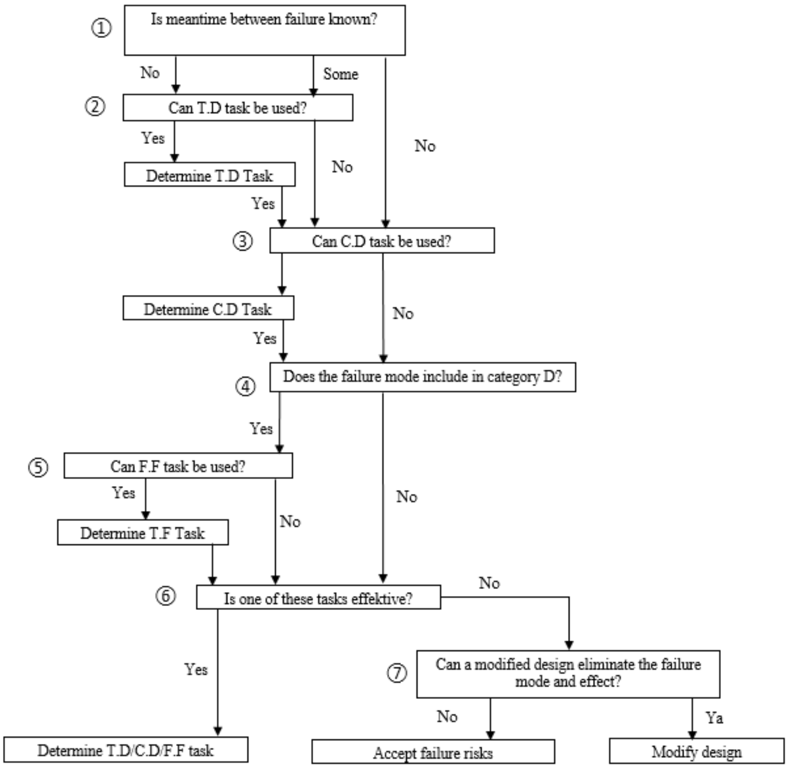

Figure 3. Selection Action Diagram

Based on the results of the selection of actions for the components that failed in the Desprin Lab, several selection measures for preventive maintenance activities can then be obtained, namely:

a. Condition Directed Maintenance Actions: There are 14 components that belong to directed maintenance actions listed in Table 4;

Tabel 4. Condition Directed Maintenance Action

No	Facility	Components
1	Student desk	Broken/collapsed base due to load or termites
2	Computer desk	Bumpy pad due to loose part of the table
3		Broken/collapsed base due to load or termites
4	Prototype shelf	The upper shelf is brittle and breaks due to the accumulation of loads or termites
5		The lower shelf is brittle and breaks due to the accumulation of loads or termites
6	Prototype display	The side support for the shelf has collapsed/broken
7	3*D* printer shelf	Cross-section of the upper shelf is brittle and broken
8		Cross-section of the lower shelf is brittle and broken
9		The side shelf door cannot be closed
10	Air Conditioner	*Frozen* on connecting pipes
11	Room	Door broken
12		Window broken
13		Bulbs broken
14		Bulbs frame broken

b. Finding Failure Maintenance Actions: There are 8 components that belong to finding failure maintenance actions listed in Table 5;

Table 5. Finding Failure Maintenance Action

No	Facility	Components
1	Student chair	The frame broke or rusted
2	Computer desk	The frame broke or rusted
3	3D Printer	Machine damaged by falling
4		Filament does not come out of the filament pipe
5		Machine damaged by falling
6	3D Scanner	Sensor malfunctions
7		Machine damaged by falling
8	Exhaust	Fan broken

c. Time Directed Maintenance Actions: There are 5 components that belong to time directed maintenance actions listed in Table 6;

Table 6. Time Directed Maintenance Action

No	Facility	Failure Components	Optimal Change Interval (Day)
1	Student desk	Table parts separated due to loose bolts and displacement	4
2	Student chair	Chair parts separated due to loose bolts	21
3	Computer desk	Frame fragile	3
4	Computer desk	The bracket monitor hub broken	54
5	Exhaust	Switch broken	2

The above maintenance actions will be manifested in the Standard Operating Procedures (SOPs). These SOPs are compiled into a book, each of which contains a purpose, scope, person in charge, procedures, and notes. The following is an example of the contents of the Standard Operating Procedure (SOP), namely Work Instructions for the Use of Instructor Tables and Chairs.

institut teknologi del	**LABORATORIUM DESAIN PRODUK DAN INOVASI INSTITUT TEKNOLOGI DEL**	Doc No. : xx Revision : 00
	Work Instruction Utilizing the Instructor's Desk and Chair	Page : 1/1 Date : dd-mm-yy

1. Only instructors (lecturers and academic assistants) are authorized to use the instructor's desk and chair in Desprin Lab
2. Students are prohibited from using the instructor's desk and chair without special authorization by instructors
3. Users are responsible for cleanliness and tidiness of the instructor's desk and chair
4. User must immediately notify lab assistant once they find damage on the instructor's desk and chair

Figure 4. SOP example

In addition, a checklist form for the maintenance of the work facilities was also made, with checking items based on failure categories. The inspection method can be done visually or using measuring instruments. Table 7 is an example of instructor and student desk maintenance.

Table 7. Checklist example

Component	Standard	Inspection Method	Date		Date		Date	
			OK	NG	OK	NG	OK	NG
Desk	Desk peel off	Visual						
	Table parts fragmented	Visual						
	Desk pad bumpy	*Waterpass*						
	Desk pad broken	Visual						
	Drawing pad stuck	Visual						
Frame	Frame bent/ broken	Visual						
Cables	Cables broken	Visual						

With the formulation of standards and work instructions for preventive maintenance at the Desprin Lab, a new milestone has been obtained for Desprin Lab as a new advanced laboratory in the field of additive manufacturing which has been equipped with a reliability assurance system. The application of these standards and work instructions through actions such as filling out check sheets, recordings, and tiered reports is believed to be a way for maintaining these facilities in the future and ensuring educational services. Consequently, the application of these standards and work instructions will reduce the Risk Priority Number (RPN) as a consequence of the improved ability to detect failures before they occur (D) and the probability of a cause causing failure (O) (Table 2).

However, this research has a shortcoming. The biggest shortcoming is that during FMEA is conducted, some facilities, such as 3D printers, interactive smartboards, and 3D scanners, are lacking real historical data. Thus, the values for the FMEA variables, especially occurrence (O) and detection (D) are obtained by estimation. This weakness can of course be anticipated by better recording future events. With a more complete historical record, further analysis can be carried out more carefully.

CONCLUSION

From the results of data analysis, several conclusions were obtained as follows:
1. Based on the results from the Failure Mode and Effects Analysis (FMEA), 27 components are found to have the highest probability of damage as indicated by the Risk Priority Number (RPN) ranking.
2. Based on the results from the Logic Tree Analysis (LTA), 29 components were determined with category A (Safety problem) as many as 10 components, category B (Outage problem) 8 components, category C (Economic problem) 1 component, and category D (Hidden failure) 8 components.
3. Based on the results from the selection of actions for the components that failed, it can be obtained several selection actions for preventive maintenance activities, namely: 14 components that are included in the CD maintenance measures, 8 components that are included in the FF maintenance measures, and 5 components included in the TD treatment measures.
4. The maintenance action plan has been outlined in the Standard Operating Procedure (SOP) and checklist forms available for use by the management of Desprin Lab.

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