Designing Early Warning System as Preventive Maintenance to Maintain Agile Resilience of Mineral Water Production Process

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Abstract— Mineral water is the most consumed drinking water in the world, it requires good quality because it affects health. PT Indra Karya produces bottled mineral water that has a variety of 330ml, 600ml, and gallon packaging. The occurrence of damage to the Tacung Cartridge Filter machine caused one batch of mineral water production to be discarded because it did not meet the pH and ozone standards which caused turbidity. Preventive maintenance of the machine is needed so that the production of mineral water is continuous and according to the specified standards. The purpose of the research is to conduct preventive maintenance with an Early Warning System approach to maintain resilience in the mineral water production process. The first research step is the calculation of Mean Time to Failure, after which the calculation of machine reliability is carried out. The second step, the application of the Early Warning System provides timely information about potential risks and preventive steps that need to be taken. The third step is to calculate the Agile Resilience Index by filling out the checklist. The results of the Mean Time to Failure calculation obtained that the Air Filter component has an optimal time of use for 118 days, the Seals and O-Ring component has 120 days and the Support Core component for 123 days. The results of the reliability calculation after the Mean Time to Failure calculation obtained a reliability of 88%. The time interval data obtained and calculated using MTTF results in the optimal time used as a measuring tool in the application of preventive maintenance with the Early Warning System. An Agile Resilience index value of 4.55 was obtained. This value shows that the company has implemented resilience and agile practices after preventive maintenance. The research is expected to improve adaptation, recovery of the company from disruptions, and help determine the maintenance and spare parts needed and decision making related to costs.

Keywords— Resilience, Agile, Resilience Maintenance, Early Warning System, Downtime Machine, Mean Time to Failure, Preventive Maintenance

I. INTRODUCTION

Mineral water is an integral part of life, mineral water is very valuable because it cannot be replaced and is the most important factor in daily life. Humans have a fundamental need for mineral water which is 1.8 - 2.0 liters / day to maintain good health [1]. Companies must maintain the production process in order to ensure product quality and safety, avoid contamination, machine damage, and non-standard products that can harm consumers and companies. Scheduling must be carried out in the production process to maximize production, optimal utilization of machinery and labor, and avoid downtime, thus ensuring the production of safe, quality, and economical drinking water. The crucial machine in the mineral water production process is the tacung cartridge filter, which is very influential because it can cause water to not meet pH and ozone standards that cause turbidity. If this happens, one production batch can no longer be used [2]. Preventive maintenance is used to direct maintenance activities with the aim of ensuring system safety and reducing unnecessary operational downtime [2]. The main focus of preventive maintenance is to prevent component failure before an unexpected upset occurs in order to cause a batch of mineral water production to be scrapped. However, if a disruption cannot be avoided, further attention is paid to the recovery of the system from unwanted changes. As a solution, increasing the recovery capacity of the system through optimization of system maintenance assets and operational costs can help the system recover from fault conditions at an optimal cost [3]. By referring to the aspects of agile and resilience, it aims to ensure that the company can recover to normal conditions in the event of a failure. This is expected to improve the company's performance and resilience in the face of potential failures in the machine [4].

II. LITERATURE OVERVIEW

A. Maintenance

Maintenance is a combination of all technical, administrative, and managerial actions during the life cycle of an item that aims to maintain or restore it to a condition where the machine can again function as it should [1].

B. Resilience

Resilience is the ability of a person or system to recover or adapt effectively in the face of existing disruptions or disruptive environmental changes while still providing added value. It includes the ability to remain stable and able to return to a normal state after experiencing disruption or difficulty[1]. Resilience is an important factor that a company must have in order to remain flexible and adjust to existing circumstances[4]. In the context of production, "resilience" refers to the ability of a system or machine to remain functional and recover from disruptions or failures that may occur during the production process in order to produce optimal output and aims to keep equipment and assets operating normally and avoid costly downtime from unexpected failures[5][6].

C. Agile

Agile maintenance is an approach that adopts agile methods in maintenance activities. Since maintenance processes require fast and flexible means, the adoption of agile methods in maintenance is very promising [3]. Agile is characterized as a fast and flexible method where its use will guarantee quality, reliability, and scalability. Agile maintenance is generally the adoption of any agile method implemented during the maintenance process. By implementing agile maintenance, maintainers can respond to customers in a short time and is a practical way to take care of customer needs [7].

D. Preventive Maintenance

Preventive Maintenance is proposed for the Just-in-Time production structure to minimize the operational cost of the system. Due to imperfect repair, the production unit is in an intermediate state between good and bad. As a result, the effective life of the system decreases over time. As the effective life decreases, the system randomly fails to operate and undergoes minimal repairs between consecutive preventive maintenance schedules [8]. To avoid shortages during minimal repairs, safety stock is built up at the beginning and after each minimal repair in the preventive maintenance cycle. Preventive maintenance on production systems is becoming increasingly important in the context of JIT manufacturing as it promotes inventory minimization and turnaround time. However, as the production system operates and the effective life of the system increases, it is generally unclear when and how preventive maintenance will be implemented while still meeting ongoing demand. This problem is even more complex if the system undergoes imperfect repair [9].

E. Predictive Maintenance

Predictive Maintenance is a type of maintenance that is based on prediction, where evaluations are made against periodic maintenance (Preventive Maintenance). This detection can be evaluated through installed indicators to collect additional data and the next repair step. Predictive maintenance uses time-based information and knowledge to report possible defects and avoid production downtime[10].

F. Company Company Context

Resilience Behavior (BR) is the company's ability to overcome the negative impact of disruption. The formula for resilience behavior is as follows [3]:

$(BR)j = \sum yi=1\ wRi\ x\ (PRi)j$

Agile behavior is the company's ability to respond quickly and efficiently to unexpected changes. The following is the formulation of agile behavior:

$(BA)j = \sum yi=1\ wAi\ x\ (PAi)j$

Description: :

-(PAi)j and (PRi)j = practice level i of the resilience paradigm for company j, respectively.

-wAi and wRi = the weight of practice i of the agile and resilience paradigms, respectively. These weights reflect the importance of each practice in the supply chain. -(BA)j and (BR)j = the behavior of company j according to the agile and resilience paradigms, respectively. If the supply chain is to be more flexible, then these practices must be implemented. The determination of the implementation value is done by normalization using a 5-point scale.

G. Index Resilience and Agile

The following is the formula for calculating the AR (Agile Resilience) index to assess the level of agile and resilience of the hotel supply chain with the following formula equation [3]:

ARj = 0.5 x $(BA\ )j$ + 0.5 x $(BR\ )$

Description:

(BA)j and (BR)j represent the behavior of company j according to the agile and resilience paradigms respectively. If you want to make the supply chain more flexible, then these practices must be implemented. To determine the value of implementation, normalization with a 5-point scale is used.

H. Index of Fit

The correlation coefficient (Index of Fit) is the value of the Pearson correlation coefficient that measures the strength of the linear relationship between two variables, such as x and y. The value of this coefficient ranges from -1 to +1. When the Index of Fit value is close to -1 or +1, it indicates that there is a very strong and highly correlated relationship between x and y. Conversely, if the value is close to zero, it indicates that there is a very strong and highly correlated relationship between x and y. Conversely, if the value is close to zero, it indicates that the linear relationship between x and y is very weak or may not exist at all[14].

I. Mean Time to Failure

Mean Time To Failure (MTTF) is the average value of the failure time of a system. MTTF can be formulated as follows:

MTTF = E(T) = $\int t\ f(t)\ dt = \int R(t)\ dt$

The MTTF values for the four types of each statistical distribution mentioned earlier are [14]:

1. Normal Distribution

MTTF=μ

2. Lognormal Distribution

$$MTTF = \mu = e^{\mu+\frac{1}{2}(\sigma)^2}$$

3. Exponential Distribution

$$MTTF = \gamma + \frac{1}{\lambda}$$

4. Weibull Distribution

$$MTTF = \eta.\tau\left(\frac{1}{\beta}+1\right)$$

J. Reliability

Reliability refers to the probability that an item will perform its specified task satisfactorily over a predetermined period of time, under specified conditions. The term "item" in the definition can include various components, subsystems, or systems considered as a whole. The reliability of a system describes the probability of the system to perform its function properly[12]. In the context of system reliability, the overall system can be calculated by multiplying the reliability of each element. This is useful in designing reliable systems, as it makes it possible to determine the reliability required for each element in order to achieve the desired overall reliability. Reliability can be formulated as follows[13]:

R(t) = Machine Reliability

Euler number (e) = 2.71828

MTTF = Mean Time to Failure
R(t) = e^(-t/MTTF)

After finding the reliability value of each component, proceed to calculate the total system reliability using the formula [13]:
R = Total Reliability
R1 = Reliability of Component 1
R2 = Reliability of Component 2
R2 = Reliability of Component 3
R = R1 x R2 x R3 ... xRn

K. Early Warning System

The application of Early Warning Systems (EWS) helps the effectiveness of maintenance work by determining which machines require maintenance and the parts needed, and assists management in making decisions regarding damage and prevention costs for each machine. This system creates a database of maintenance activities that documents maintenance reports, repairs, maintenance costs, and facilitates the implementation of maintenance and innovation in maintenance work [16]. EWS supports maintenance activities with documentation of maintenance, repair, and handling steps, parts with serial numbers, MTTF (Mean Time to Failure) calculations, repair documents and best practices, and warranty information. The system also helps in determining the maintenance and spare parts required for each machine, as well as in making decisions regarding repair costs [15].

III. RESEARCH METHODOLOGY

A. Gaining knowledge about the mineral water production system in the company whether it is resilience and agile and its correlation with the Early Warning System (EWS) aplication.

B. Obtain data on the interval time between damage, downtime and what components are replaced on the machine.

C. Calculate the Index of Fit and Mean Time to Failure values.

D. Make improvement for maintenance with an Early Warning System (EWS) aplication.

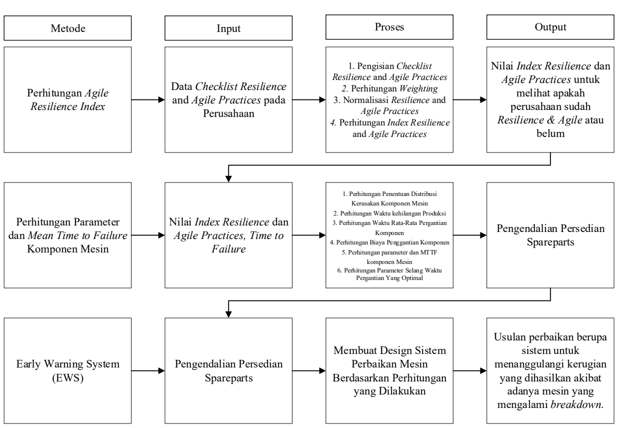

Figure 1. The Research Framework

IV. RESULT AND DISCUSSION

A. Mean Time to Failure Recapitulation

Table 1. Mean Time to Failure Recapitulation

No	Spareparts	Normal	Lognormal	Eksponensial	Weibull	Chosen	Methods
TACUNG CARTRIDGE FILTER							
1	Filter Air	-34787.26	0.54172054	3519.3487	2843.80744764	2,843.807448	Weibull
2	Seals and O-Ring	2859.8	0.000350	3644.257665	2888.041894	2888.041894	Weibull
3	Support Core	2408.71	0.000414	3388.565446	2941.650055	2,941.65005	Weibull

Table 1 shows a recapitulation of the results of the Mean Time to Failure calculation. From the calculations that have been carried out, the selected method is the weibull distribution.

B. Component Replacement

Table 2. Component Replacement

TACUNG CARTRIDGE FILTER						
No	Spareparts	Spareparts Needed	Employee Labor Cost (Rp/Hour)	Component Price	Average Time / Repair	Lost Production Cost / (Rp/Hour)
1	Filter Air	4	30.000	10.000.000	1.46975	2666.667
2	Seals and O-Ring	3	30.000	150.000	1.591	2666.667
3	Support Core	3	30.000	2.500.000	2.566	2666.667

Table 2 shows data regarding the requirements and repair costs for various spare parts of the Tacung Cartridge Filter. There are three types of spare parts namely Water Filter, Seals and O-Rings, and Support Core, each with specific spare parts requirements. Employee labor cost was set at Rp 30,000 per hour from calculation 4.8, with component prices varying from Rp 150,000 to Rp 10,000,000. The average repair time ranges from 1.46975 to 2.566 hours. In addition, the cost of lost production per hour for each spare part is Rp 2,666,667. This data provides a comprehensive overview of the cost and time aspects required for the maintenance of each spare part on the Tacung Cartridge Filter.

C. Optimal Time of Spareparts Replacement

Table 3. Optimal Time of Spareparts Replacement

No	Spareparts	Optimal Time / Hour	Optimal Time / Day	Start of Changeover Date	Changeover Schedule From Calculation
TACUNG CARTRIDGE FILTER					
1	Filter Air	2843.807448	118	1/3/2023	27/6/2023
2	Seals and O-Ring	2888.041894	120	1/3/2023	29/6/2023
3	Support Core	2,941.650055	123	1/3/2023	24/6/2023

Table 3 presents the spare parts replacement schedule for the Tacung Cartridge Filter based on the MTTF calculation. For Water Filters, the optimal replacement time is 2843.807448 hours or 118 days, so if the initial replacement date is March 1, 2023, then the next replacement schedule is June 27, 2023. Seals and O-Rings have an optimal turnover time of 2888.041894 hours or 120 days, so with the same initial turnover, the next scheduled turnover is June 29, 2023. Support Core has an optimal replacement time of 2941.650055 hours or 123 days, with the next scheduled replacement on June 24, 2023. This data helps in planning and organizing the spare parts replacement schedule effectively to maintain the optimal performance of the machine.

D. Tacung Cartridge Filter Machine Component Requirements Per Year

Table 4. Tacung Cartridge Filter Machine Component Requirements Per Year

No	Spareparts	Maintenance / Year	Unit Machine	Spareparts Changeover/ Month	Spareparts Needed / Year
TACUNG CARTRIDGE FILTER					
1	Filter Air	4	1	0.33	4
2	Seals and O-Ring	3	1	0.25	3
3	Support Core	3	1	0.25	3

Table 4 shows that there are three types of spare parts in the Tacung Cartridge Filter, namely Water Filters, Seals and O-Rings, and Support Core. Maintenance per year for the Water Filter is carried out 4 times, while for Seals and O-Rings and Support Core each is carried out 3 times. Each engine unit requires monthly spare parts replacement of 0.33 times for Water Filters and 0.25 times for Seals and O-Rings and Support Core. The need for spareparts per year for each type is 4 units for Water Filters and 3 units for Seals and O-Rings and Support Core. This data helps in planning and managing spare parts inventory more efficiently.

E. Tacung Cartridge Filter Machine Component Requirements Per Year

Table 5. Tacung Cartridge Filter Machine Component Requirements Per Year

No	Spareparts	Reliability Setelah MTTF	Reliability Mesin
TACUNG CARTRIDGE FILTER			
1	Filter Air	96%	88%
2	Seals and O-Ring	96%	
3	Support Core	96%	

Table 5 above presents reliability data for spare parts of the Tacung Cartridge Filter after reaching Mean Time To Failure (MTTF), as well as the overall reliability of the machine. Each spare part, namely the Water Filter, Seals and O-Rings, and Support Core, has a reliability of 96% after MTTF. The overall reliability of the machine is 88%. This data indicates the reliability of the spare parts and the machine as a whole, which is important for maintenance planning and component replacement to keep operations optimized.

Figure 2 illustrates the flow of the Early Warning System (EWS) application system designed for maintenance and repair of machines and spare parts. The process begins with the input of machine and spare parts data into the database, followed by recording the date of the repair request. The EWS system then provides an alert five days before the scheduled replacement, updating the repair status according to the specified schedule. Once the repair order is completed, the component schedule will be adjusted for the next repair. The final stage is the verification and update of the repair status in the system. The system ensures that maintenance is carried out on time, improving operational efficiency with early warning.

F. Early Warning System Application Process

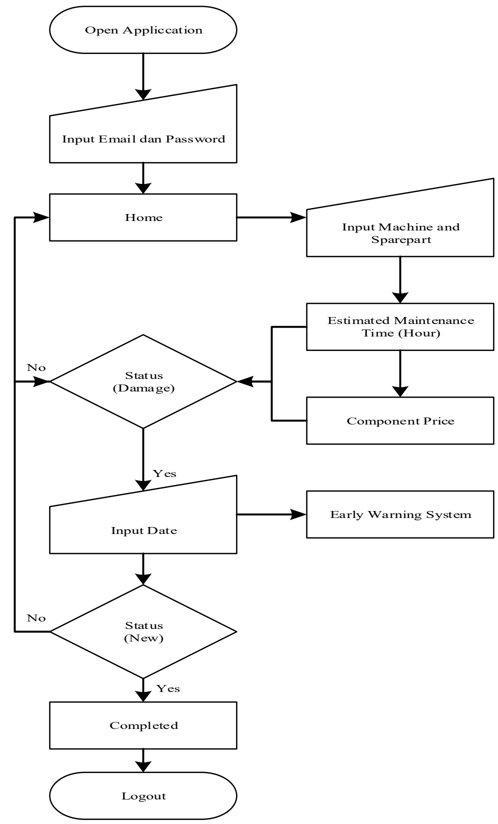

Figure 2. Early Warning System Application Process

G. Early Warning System Login Page

Figure 3. Early Warning System Login Page

Figure 3 is a view of the “Login Page”, the above view is the login page of the Early Warning System (EWS), which allows users to access the application by entering their ID and password, as well as providing password recovery options and special access for employees.

H. Early Warning System Home Page

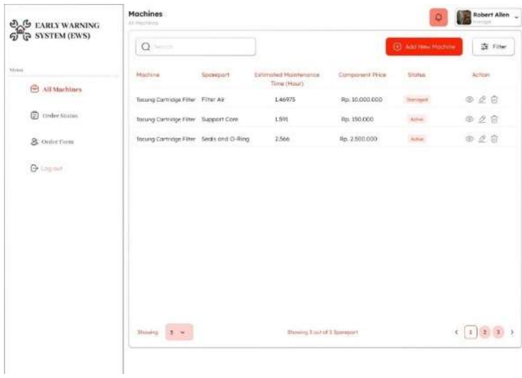

Figure 4. Early Warning System Home Page

Figure 4 is a view of the “Home Page”, which shows the page of the Early Warning System (EWS), which displays a list of machines and their component spares, estimated maintenance time, component price, status (active or damaged), and action options such as edit or delete, as well as providing features to add new machines and filter the displayed data.

I. Early Warning System Order Status

“Order Status” page of the Early Warning System (EWS), which displays a list of maintenance forms that have been submitted, including information about the requestor, machine type, submission date, EWS status (ON), request status (new, pending approval, approved), as well as action options such as viewing details, editing, or deleting the form, and provides features for adding new forms and filtering the displayed data.

J. Early Warning System Order Form

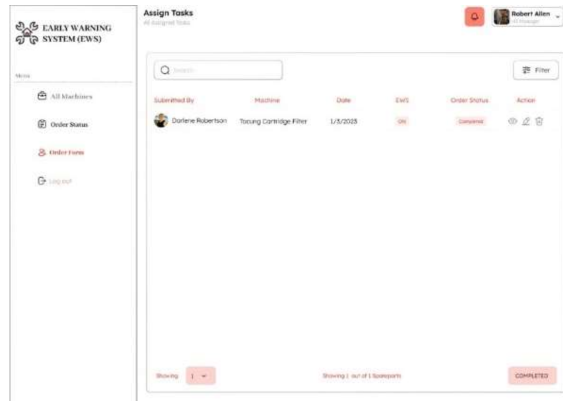

Figure 5. Early Warning System Order Form

Figure 5 is a view is the “Order Form” page of the Early Warning System (EWS) system, which displays tasks that have been assigned for maintenance, including information about the requestor, machine type, submission date, EWS status (ON), order status (completed), as well as action options such as view details, edit, or delete tasks, and provides a feature to filter the displayed data.

K. Agile Normalization Indicator

Table 6 Agile Normalization Indicator

Agile		HOD DEPARTEMEN OPERASIONAL					HOD DEPARTEMEN OFFICE					HOD DEPARTEMEN ENGINEERING					HOD DEPARTEMEN SALES & MARKETING					HOD DEPARTEMEN ACCOUNTING				
No	First-tier supplier	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	Use IT to coordinate activities in design and development					✓					✓					✓					✓					✓
2	Using IT to coordinate activities in procurement				✓				✓					✓						✓					✓	
Focal firm																										
3	Companies focus on using IT to integrate activities in manufacturing					✓					✓					✓					✓					✓
4	Integrating Supply Chain/Value Stream					✓					✓					✓					✓					✓
5	Using centralized and collaborative planning					✓				✓					✓					✓					✓	
6	Quickly reconfigure production processes				✓					✓						✓					✓				✓	
7	Produce in large or small quantities				✓						✓					✓					✓				✓	
8	Accommodate changes in the production mix				✓						✓				✓						✓			✓		
9	Minimize setup time and product changeovers					✓					✓				✓						✓				✓	
10	Organizing along functional lines					✓				✓						✓					✓					✓
11	Facilitate quick decision-making					✓					✓					✓				✓						✓
Focal firm → First-tier customer																										
12	Using IT to integrate activities in logistics and distribution				✓						✓					✓					✓					✓
13	Increase the frequency of new product introductions					✓					✓				✓					✓						✓
14	Accelerate customization in delivery capability					✓				✓						✓					✓				✓	
15	Accelerate improvements in customer service				✓						✓					✓				✓						✓
16	Accelerate response to changing market needs to capture demand information immediately				✓					✓					✓						✓					✓
17	Maintain and develop customer relationships					✓					✓					✓				✓						✓

Table 6 shows the analysis of the agile indicators across departments reveals a strong emphasis on leveraging IT to enhance operational flexibility, efficiency, and responsiveness. Each department consistently integrates IT in key areas, such as coordinating design and development, integrating manufacturing activities, and streamlining the supply chain, which are critical for building a resilient organization. IT is heavily used to reconfigure production processes, accommodate changes in production mix, and minimize setup times, indicating a focus on agility and adaptability. Additionally, departments prioritize quick decision-making and centralized planning, further supporting a responsive and cohesive operational structure. The integration of IT in logistics, distribution, and customer service ensures that the company can swiftly respond to market changes and maintain robust customer relationships, essential for resilience in a dynamic market environment. Overall, the consistent application of IT across various functions highlights a strategic approach to developing an agile organization capable of withstanding and adapting to disruptions.

L. Resilience Normalization Indicator

Table 7. Resilience Normalization Indicator

Resilience		HOD DEPARTEMEN OPERASIONAL					HOD DEPARTEMEN OFFICE					HOD DEPARTEMEN ENGINEERING					HOD DEPARTEMEN SALES & MARKETING					HOD DEPARTEMEN ACCOUNTING				
No	First-tier supplier → Focal firm	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	Use sourcing strategies to enable supplier turnover				✓						✓					✓					✓				✓	
2	Utilize flexible supply base/flexible procurement					✓				✓						✓					✓					✓
	Focal firm																									
3	Develop visibility to a clear view of upstream inventory and supply conditions					✓			✓							✓				✓					✓	
4	Design a production system that can accommodate multiple products and real-time changes					✓					✓					✓					✓				✓	
5	Using a multi-skilled workforce				✓					✓					✓						✓					✓
6	Plan the strategic disposition of additional capacity or inventory at potential "pinch points"					✓				✓						✓					✓				✓	
7	Reduced waiting time				✓						✓				✓						✓				✓	
8	Develop visibility into clear production and purchasing schedules			✓						✓					✓						✓					✓
9	Creating total supply chain visibility				✓						✓					✓				✓						✓
10	Ensuring process and knowledge backup					✓					✓					✓					✓					✓
11	Implement a culture of supply chain risk management to develop cooperation across the supply chain and help mitigate risks.			✓						✓					✓						✓					✓

Table 7 shows the resilience indicators reveal a comprehensive approach to enhancing the robustness and adaptability of the supply chain across various departments. Key strategies include the use of flexible sourcing and procurement to enable supplier turnover and a flexible supply base, ensuring that the organization can quickly adapt to changes in supplier conditions. There is a strong focus on developing visibility into upstream inventory, production, and purchasing schedules, which helps maintain a clear view of supply conditions and facilitates proactive decision-making. Designing production systems that accommodate multiple products and real-time changes, along with employing a multi-skilled workforce, enhances operational flexibility and responsiveness.

The strategic disposition of additional capacity or inventory at potential pinch points ensures that the organization can handle unexpected disruptions without significant delays. Reducing waiting times and creating total supply chain visibility further streamline operations and enhance efficiency. Ensuring process and knowledge backups, as well as fostering a culture of supply chain risk management, promotes cooperation across the supply chain and mitigates risks effectively. Overall, these indicators highlight a strategic focus on building a resilient supply chain capable of withstanding and adapting to various disruptions, maintaining operational continuity, and ensuring customer satisfaction.

M. Resilience Correlation Practices

Table 8. Resilience Correlation Practices

Resilience Practices	*Implementation Degree (PR)j*	*Weighting (wRi)*	*Resilience Reference Value wRi x (PRi)j*
PR1	*4.6*	*0.092369478*	*0.424899598*
PR2	*4.8*	*0.096385542*	*0.462650602*
PR3	*4.2*	*0.084337349*	*0.354216867*
PR4	*4.8*	*0.096385542*	*0.462650602*
PR5	*4.4*	*0.088353414*	*0.38875502*
PR6	*4.6*	*0.092369478*	*0.424899598*
PR7	*4.4*	*0.088353414*	*0.38875502*
PR8	*4.2*	*0.084337349*	*0.354216867*
PR9	*4.6*	*0.092369478*	*0.424899598*
PR10	*5*	*0.100401606*	*0.502008032*
PR11	*4.2*	*0.084337349*	*0.354216867*
Resilience Reference Value (BR)j = $\sum wRi \, x \, (PRi)j$			*4.5*

N. Agile Correlation Practices

Table 9. Agile Correlation Practices

Agile Practices	Implementation Degree (PAi)j	Weighting (wAi)	Resilience Reference Value wAi x (PAi)j
PA1	5	0.064102564	0.320512821
PA2	3.6	0.046153846	0.166153846
PA3	5	0.064102564	0.320512821
PA4	5	0.064102564	0.320512821
PA5	4.2	0.053846154	0.226153846
PA6	4.4	0.056410256	0.248205128
PA7	4.6	0.058974359	0.271282051
PA8	4.2	0.053846154	0.226153846
PA9	4.6	0.058974359	0.271282051
PA10	4.8	0.061538462	0.295384615
PA11	4.8	0.061538462	0.295384615
PA12	4.8	0.061538462	0.295384615
PA13	4.6	0.058974359	0.271282051
PA14	4.6	0.058974359	0.271282051
PA15	4.6	0.058974359	0.271282051
PA16	4.4	0.056410256	0.248205128
PA17	4.8	0.061538462	0.295384615
Agile Reference Value (BA)j = $\sum wAi \, x \, (PAi)j$			4.6

Agile Practices	Implementation Degree (PAi)j	Weighting (*wAi*)	Resilience Reference Value *wAi x* (*PAi*)*j*
AR Index Reference Value ARj = 0.5 x (BR)j + 0.5 x (BA)j			4.55

Table 9 shows the value of implementing resilience practices which is 4.4. While the value of implementing agile practices in table 4.8 is 4.6. And both values are combined in the reference AR index which is worth 4.55. This value indicates that the company has implemented resilience and agile practices. The goal of this index is 5.0, which means that the company fully implements resilience and agile practices.

V. CONCLUSSION

The calculation of Mean Time to Failure (MTTF) reveals that the optimal usage time for the Air Filter component is 2843.807448 hours, equivalent to 118 days. The Seals and O-Ring component has an optimal usage time of 2888.041894 hours, equal to 120 days, while the Support Core component has an optimal usage time of 2941.650055 hours, or 123 days. These optimal usage times are crucial to ensure that each component is replaced timely to maintain the filtration system's optimal performance. The Tacung Cartridge Filter consists of three main components: the Air Filter, Seals and O-Ring, and Support Core. After calculating the MTTF, each component has a reliability of 96%, indicating that each component has a 96% probability of functioning properly after its MTTF period. However, when considering the overall reliability of the machine, which includes all three spare parts, the machine's total reliability is 88%. This reflects the cumulative impact of each component's reliability on the machine's overall performance. The interval data obtained and calculated using MTTF produces optimal usage times that serve as benchmarks in implementing preventive maintenance with an Early Warning System (EWS). The use of an EWS helps detect problems early, enabling immediate preventive actions and reducing downtime risk. The EWS is designed to calculate optimal times and provide early warnings for subsequent maintenance actions, ensuring consistent production and supporting long-term business continuity. The Agile Resilience Index obtained is 4.55, indicating that the company has implemented resilience and agile practices. The target for this index is 5.0, meaning that the company fully adopts resilience and agile practices after improvements in maintenance using the Early Warning System.

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