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Fuzzy-FMECA: Right Solution for Jet Dyeing Machine Damage Prevention

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ABSTRACT

Jet dyeing machines, essential for producing high-quality and environmentally friendly textiles, face persistent issues with defects that lead to production stoppages, compromised cloth quality, and significant financial losses for companies. These challenges hinder operational efficiency and undermine the competitive edge of textile manufacturers in a rapidly evolving market. Jet Dyeing machines continue to innovate to produce high quality and environmentally friendly textiles, with the discovery of defects causing cloth production to stop, cloth quality to decline, and company losses. The Fuzzy-FMECA approach enhances accuracy and adaptability in identifying failure risks, improving maintenance for complex jet dyeing systems. This study aims to identify the root causes of jet dyeing machine damage for preventive maintenance design. Studies using robust fuzzy-FMECA can identify critical components of jet dyeing machines with a high degree of accuracy. This can improve machine reliability and reduce fabric quality failures. The dominant machine failures identified in jet dyeing components are leakage, short circuits, and installation errors. The Pareto analysis shows that leaks, tears, and short circuits are responsible for over 70% of total failures. The most critical components include the main pump and electric socket, both with an RPN score of 7.42, representing a significant 30% of overall risk. Other high-risk components such as the steam pipe packing and heat exchanger steam pipe also have an RPN of 7.25. These findings indicate that over 60% of the failures arise from just a few key components. These findings have succeeded in identifying the critical components of the jet dyeing machine (main pump and socket) which have the highest potential risk of failure. The proposed preventive maintenance design can reduce these risks, but needs to be refined with consistent, competent and monitored inspections. The preventive maintenance design significantly mitigates risks, requiring ongoing refinement through regular, skilled, and supervised inspections to ensure optimal effectiveness.

1. Introduction

The Jet Dyeing machine, the giant in the textile dyeing line, was not born overnight (Alsharief et al., 2022; Shrwardi et al., 2023). The journey is like a neatly woven thread (Hannan et al., 2023;

Muthu, 2016). The level of innovation from the development of high quality textile quality (Banna et al., 2023; Shamsuzzaman et al., 2023). Not only that, the quality development model influenced by super critical color texture on carbon dioxide is developing rapidly in the manufacturing area of Jiangsu Province(Bourdeau-Laferrière et al., 2021; Zhao et al., 2023). This is different in the Korean manufacturing area which tends towards an environmental safety level framework(Jeong et al., 2023; Sharma et al., 2022). With the existing development of various areas of the country, the role of nanoparticles is increasing with anti-fade coating with UV protection and bacteria resistance (Alsharief et al., 2022).

Jet Dyeing machines have an important opportunity for the textile industry to dye fabrics with large capacities. This machine has advantages in terms of efficiency and produces even color (Ćatić et al., 2020; He et al., 2021). However, over time, this machine will experience damage due to continuous use for more than 5 years(van der Ven et al., 2023). This damage can be characterized by defects in fabric products and machines that often stop suddenly, and have the potential to experience thickening(Akter et al., 2023; Bhattacharyya & Doloi, 2019; Wirth et al., 2023). The high chance of machine failure is evidence of the need for efforts to design a sustainable maintenance schedule (Crespo del Castillo et al., 2023; Suryono & Rosyidi, 2018)

There have been 3 defective conditions in fabric products in the last 2 weeks. There are dye spots on the fabric area which results in it not being colored evenly (Fig.1(a)), dye streaks on the `fabric area (Fig. 1(b)), and outprints with fabric areas that have a different color from the base color. The damage that occurs to jet dyeing machines has reached a crucial peak in terms of service life reaching 10 years, resulting in 3 types of product defects that will have an impact on company losses (Fig. 1) (Cie, 2015; Lichtarowicz, 2012).

(a) Dye spots (b) Dye Line Defects (c) Outprints

Fig. 1. Production Defects Due to Damage to Jet Dyeing Machines (Source: Manufacture X, 2023)

Jet dyeing machine with overflow type, capacity of up to 1.000 kg, fabric circulation speed of up to 100 meters/minute with dye flow of 1.5 liters/minute, has dye strength of up to 20% with dye tank dimensions of 5 cubic meters using touch screen PLC control (Fig. 2). In general, these specifications experienced a decrease in performance in that the fabric circulation speed decreased by 50%, dye flow decreased by 30%, color strength decreased by 8% due to 10 years of use focusing only on corrective maintenance, so that the loss reached 34 hours 37 minutes and the dimensional loss was 139,159 yards. with a dominant average damage of the main pump 6 times, the socket 6 times the damage and the steam pipe packing 7 times the damage which is the cause of loss of fabric production on the jet dyeing machine. In particular, the consequences arising from corrective maintenance are experiencing a water indicator error of 30% which causes product failure due to the water consistency not complying with the SOP, an error indicator light of 20% causing failure of the fabric production process, the main pump leaking 20% causing water to overflow onto the floor production, packing heating, steam pipes, cylinder valves, condensate, tanks, steam heat exchangers, cooling water pipe connections, glass door seals, tube rail seals, air hoses, contact stops, suction valves, and air leak valves each amounting to 10 % causes the production process to be imperfect based on 10 times monitoring that has been carried out. From general and specific conditions, this results in fabric products not passing quality, because SNI 08-0046-2007 has not been fulfilled in terms of quality, fabric color, fabric evenness, fabric color, fabric luster and resistance to dissolution. Based on the failure conditions that occurred, corrective maintenance has still been implemented for the last 10 years. For this reason, it is necessary to construct an appropriate maintenance model approach based on identifying component failures (Fig. 2).

Damage to the jet dyeing machine at Manufacturing This damage caused cloth production to stop, cloth quality decreased, and company losses with an average cloth damage of 8.185.882 yards with an estimated time loss of 34 hours 37 minutes. To reduce damage to jet dyeing machines, preventive measures need to be taken, such as replacing worn components regularly, routine maintenance, and using higher quality components (Fig. 3).

Fig. 2. Jet Dyeing Machine (Source: Manufacturing X, 2023)

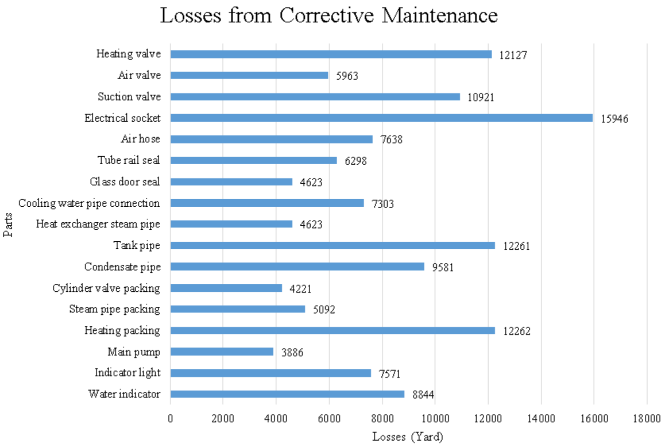


Fig. 3. Losses from Corrective Maintenance (Source: Manufacturing X, 2023)

The conditions that have been conveyed need to be done as soon as possible to prevent further damage and result in fabric production stopping completely. Repairs as quickly as possible will have the opportunity to reach the SNI 08-0046-2007 standard. With the SNI 08-0046-2007 target, it will have an impact on minimizing losses for manufacturing X, because it will be able to operate as before.

Industrial machines are closely related to the reliability of industrial electrical currents, this study states that there are 39% disruptions in connection damage & 36% third parties with the innovation of the TPM, RCM & 4DX combined maintenance model, applied to 40 feeders, able to reduce SAIFI 33%, SAIDI 29% , ENS 32%, disruption 50%, and OEE up 0.027% (Musthopa et al., 2023). For this reason, in the process industry it is necessary to increase the superior ICT component in PBK (82.4% agree) and its impact on reducing costs (78.9% agree) (Fumagalli et al., 2008). Not only that, preventive and predictive models become parameters with the collaboration of machine learning and deep learning with the implementation of Ddriven data, which has the opportunity for cost and time efficiency of up to 80% (Rihi et al., 2022). Existing innovations continue to develop to the contribution of IT-based innovation & increase in data maturity and maintenance strategies for MSMEs (82.4%) (Grooss, 2022). These various innovations require in-depth risk studies, quantitatively with fuzzy logic 1-5 interval, as a reference for complex care (Ni et al., 2022; Pradana et al., 2023; Pradana, Dewanti, et al., 2022; Pradana, Fahmi, et al., 2022). Contribution made to the power grid due to more accurate prioritization of failure modes 7.049 times successful (Zúñiga et al., 2023). This success also succeeded in identifying 16 potential failure risks, the electrical subsystem with the highest RPN value (168) and the highest FRPN (117) with better risk mitigation than conventional FMEA (Balaraju et al., 2019).

From the existing findings, there is no jet dyeing machine object yet, therefore the implementation will be carried out on this machine. Not only that, his contribution will have an impact on the preventive maintenance design that will be built to produce a sustainable maintenance schedule.

Fuzzy-FMECA emerges as an ideal solution for complex systems like jet dyeing machines, effectively addressing uncertainty in risk assessment while enhancing reliability and maintenance strategies for improved operational efficiency. Although some studies have employed the FMEA and Fuzzy approaches (Pradana et al., 2023), as well as FMEA with RPN (Zúñiga et al., 2023; Balaraju et al., 2019), there is a gap in research that combines Fuzzy and FMECA in-depth. A combined Fuzzy-FMECA study is necessary to provide a more accurate approach to identifying and mitigating risks of industrial machine component failures (Table 1). This approach will not only enhance the accuracy of failure mode prioritization but also improve risk mitigation more effectively than conventional methods. Such a combination has the potential to offer advantages in dealing with complex systems with high levels of uncertainty, thereby improving overall maintenance efficiency.

Table 1. Literature Review

Study	FMEA	Fuzzy	RCM	TPM	Big Data	FMECA
Musthopa et al. (2023)			✓	✓		
Rihi et al. (2022)					✓	
Grooss (2022)					✓	
Pradana et al. (2023)		✓				
Zúñiga et al. (2023)	✓					
Balaraju et al. (2019)	✓					

Source: data processing, 2023

With the latest construction with the fuzzy-FMECA methodology which will be applied to jet dyeing machines, it will increase accuracy in assessing the possibility and impact of failure which is more robust than FMEA with a systematic, more adaptive level of logic applied to complex systems, producing more specific recommendations in designing preventive maintenance. The level of interview review provided to the professional team will minimize uncertainty in assessing the likelihood of failure. This methodology is very adaptive, because the condition of the machine system is complex with 17 components that need to be identified quickly, accurately and logically.

This study aims to identify the root causes of jet dyeing machine damage accurately and comprehensively in designing preventive maintenance. This study is important to carry out to minimize future damage with the fuzzy-FMECA methodology. This methodology excels in the accuracy of assessing the probability of failure impact, is adaptive in complex systems and produces specific recommendation strategies to achieve the SNI 08-0046-2007 standard, so as to minimize fabric manufacturing losses.

Illustration of this study with interview activities with a professional team of jet dyeing machines to produce information on components and probability of failure. Identify the probability of failure using a fuzzy logic scale built in the matrix laboratory. Root cause analysis by assessing the likelihood and impact of failure.

The study's contribution produces comprehensive prevention techniques, improves the quality of fabric products, increases the life of jet dyeing machines and minimizes machine maintenance costs. This study also contributes to the accuracy of fuzzy-FMECA which is feasible to apply to these machines.

2. Method

2.1. Research Design

The research design uses a mix-method with a very robust fuzzy-FMECA approach (Karande, 2019; Management Association, 2012; Prabir Jana, 2020). This design has a high chance of identifying and evaluating the failure rate of jet dyeing machines in textile manufacturing (Siswantoro et al., 2020; Stanton et al., 2023; Vellesalu et al., 2023). The study of the integration of fuzzy logic and FMECA has not been studied from the perspective of jet dyeing machines (Iadanza et al., 2021). This is proof of the importance applied to the machine as a development of the FMEA methodology (Balaraju et al., 2019), because it is able to determine 3 risk exploitation factors in detail with the type-II fuzzy inference system (Di Nardo et al., 2022; Manurung1 et al., 2021; Sezer et al., 2022; Zúñiga et al., 2023). The fuzzy-FMECA decision was due to qualitative data collection techniques originating from 6 teams of textile production experts. The entire expert team explained the potential failure of the jet dyeing machine which will be modeled numerically for the fuzzy-FMECA process (Kiran, 2023; Octavia & Noya, 2019). A robust methodology will contribute to presenting uncertainty so that the level of accuracy increases with the integration of the fuzzy mamdani inference system used (Balaraju et al., 2019; Pradana, Dewanti, et al., 2022; Salah et al., 2023). The implementation of this methodology will be applied to jet dyeing machines because they have been the cause of 3 types of fabric quality failures to achieve sustainable preventive maintenance design targets (Grooss, 2022; Musthopa et al., 2023; Rihi et al., 2022).

2.2. Population, Sampling Technique and Sampling Size

The population that will be explored is jet dyeing machines which are likely to fail. The correct sampling technique uses purposive sampling which experiences damage most often, thus causing fabric damage such as defects in color spots, color lines and outprints. (Chakraborty & Chakraborty, 2015; Horrocks & Anand, 2015). The sampling size used 1 overflow type jet dyeing machine with 17 component failures. This decision was due to secondary data on failures from each component and scheduled observation times.

2.3. Research Instrument

The first instrument conducted interview activities with 1 person as general maintenance manager, 2 people as engineering and 2 people as analysts on the jet dyeing machine. Conduct an interview session to identify 17 components when a failure occurs by classifying failure mode, failure effect, failure causes, initial risk severity worth 1 – 10, risk occurrence worth 1-10, risk detection worth 1-10, then the three initial risks are multiplied to produce Risk Priority Number values to be sorted from largest RPN value to lowest (Royer et al., 2020; Sezer et al., 2022; Wardana, 2019). Corrective action analysis is carried out for each RPN to produce a preventive maintenance plan by brainstorming (Di Nardo et al., 2022; Kiran, 2023) (Table 2).

Table 2. Part Machine

Part	Frequency
Steam pipe packing	7
Main pump	6
Terminate contact	6
Packing heating	5
Condensate pipe	5
Air indicator	4
Indicator light	4
Steam pipe heat exchanger	4
Suction valve	4
Valve heating	4
Packing cylinder valve	3
Tank pipe	3
Cooling water pipe connection	3
Glass Door Seal	2
Rail tube seal	2
Air hose	2
Air valve	2

Source: Data Part, 2023

The second instrument carried out observations to ensure the accuracy of the results of interviews which were conducted for 12 month at 08.00 – 16.00 WIB when the jet dyeing machine was operating to obtain a qualitative visual analysis regarding component knowledge, type of damage, signs of damage, frequency of damage, severity level and prevention efforts. (Elbadawi et al., 2018). The third instrument uses the RMATLAB2017b system to construct a fuzzy model from the results of interviews and observations into the FMECA model (Behera et al., 2018). This model was developed into fuzzy-FMECA to assess the accuracy of severity, occurrence and detection variables in producing RPN in detail, so that the identification of the most critical failure modes can be found precisely.

2.4. Research Procedure

The research procedure is shown in Fig. 4. The Fuzzy-FMECA method is carried out using fuzzy logic to assess the severity and frequency of failure (Buja et al., 2023; Sezer et al., 2022). This stage changes the discrete input values into fuzzy values [0 10] in trimf form. This technique uses a fuzzy scale consisting of 3 values, Low (0 0 5), Medium (0 5 10) and High (5 10 10) for Fuzzy-severity, Fuzzy-Occurrence and Fuzzy-Detection, and Fuzzy-RPN uses very low (0 0 2.5), low (0 2.5 5), medium (2.5 5 7.5), high (5 7.5 10) and very high (7.5 10 10) (Karatop et al., 2021; Kiran, 2023). These values are then converted into numerical values to calculate the Defuzzified RPN (Risk Priority Number) score (Siswantoro et al., 2020). The ruler editor uses the constructed value parameters. The RPN score is a score used to measure the risk of failure. A high RPN score indicates that this failure mode has a high risk (Iadanza et al., 2021). The failure mode with the highest Fuzzy RPN score is the most critical failure mode and requires immediate countermeasures (Balaraju et al., 2019; Zúñiga et al., 2023).

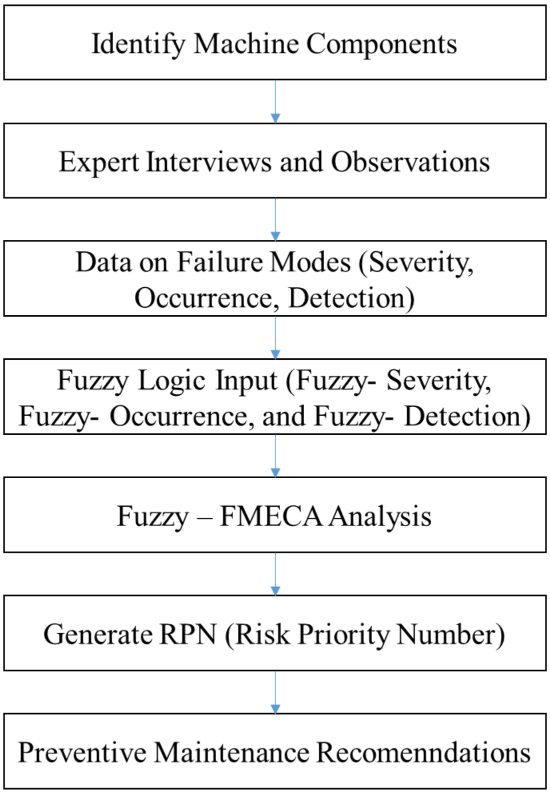


Fig. 4. Research Flow Chart

3. Results And Discussion

3.1. Result

The most common component damage is leakage (Fig. 5). This damage is caused by wear, corrosion, and installation errors. Observation results of the frequency of failure of jet dyeing machine components show that the dominant identification is leaks, tears, short circuits and errors. From these four identifications, a general cause and effect analysis was carried out using the cause and effect diagram (Fig. 6) of jet dyeing machine failure using the following 6 indicators of personnel, materials, measurements, machines, methods and environments.

Damage to production machine components is caused by various factors, namely personnel, machines, materials, methods, measurements and the environment. To reduce the risk of damage to machine components, it is necessary to carry out integrated prevention efforts involving all these factors. Based on the identification of the Pareto diagram, the cause-effect diagram is identified from the severity, occurrence and detection values using fuzzy-FMECA which is designed in the fuzzy-Mamdani MATLAB design.

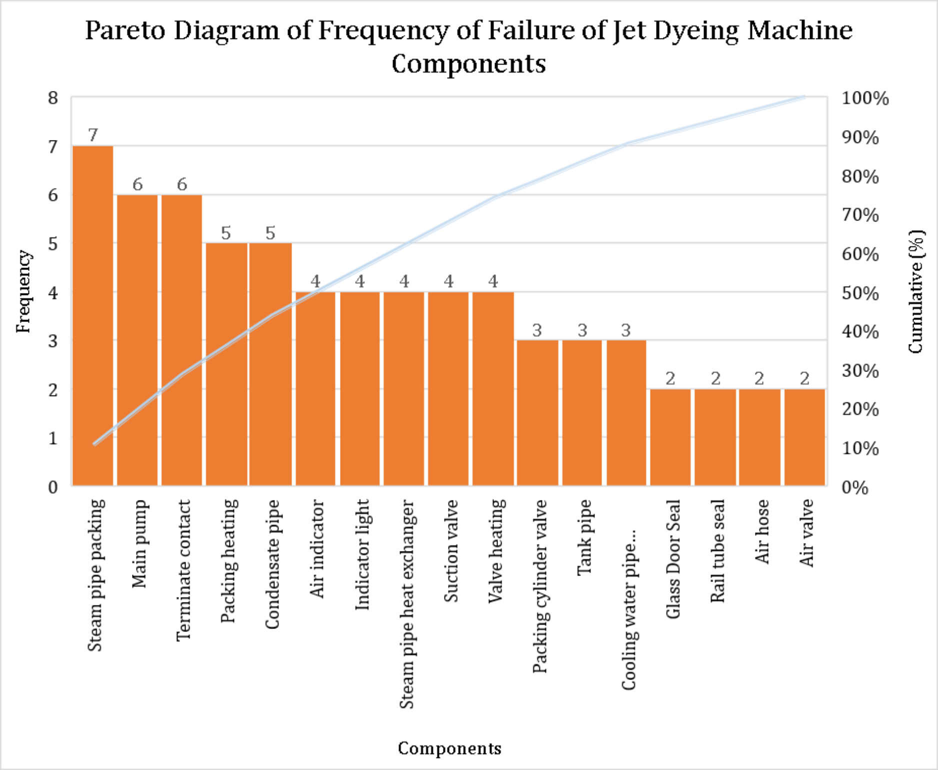


Fig. 5. Pareto Diagram of Frequency of Failure of Jet Dyeing Machine Components. Source: observational data processing, 2023

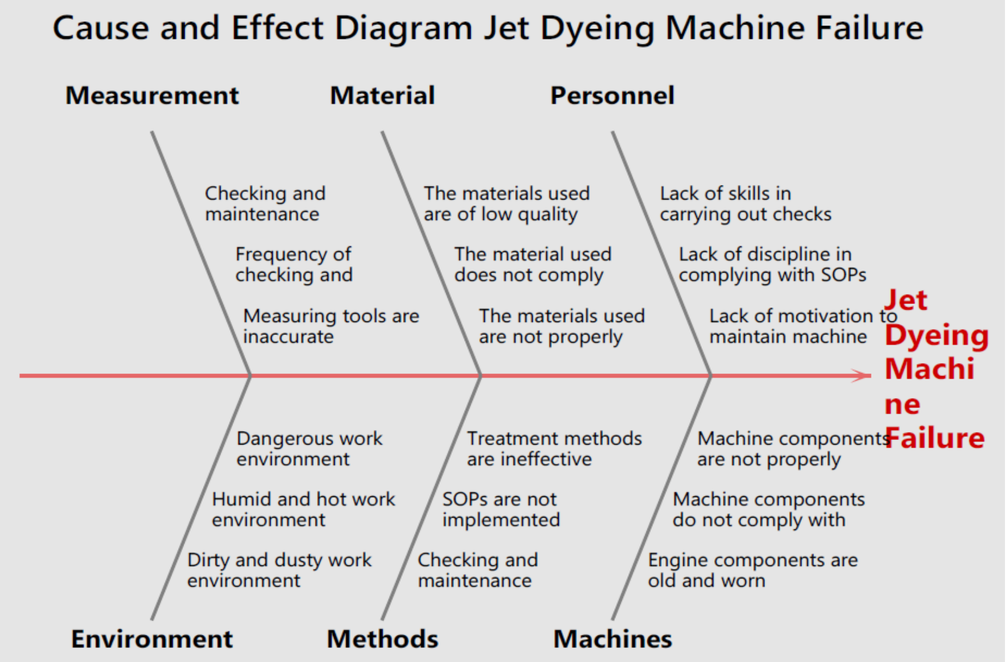
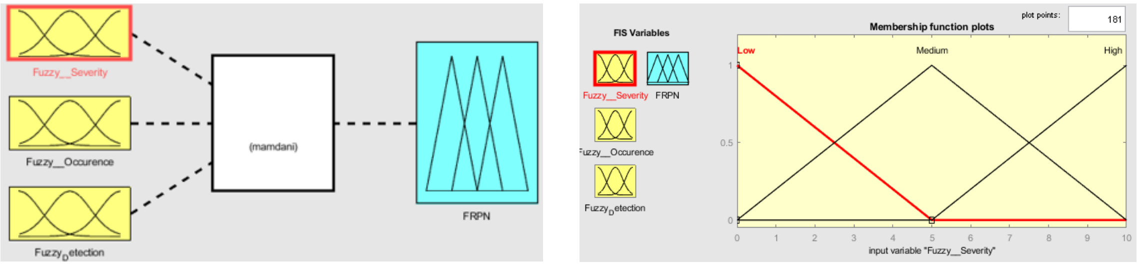


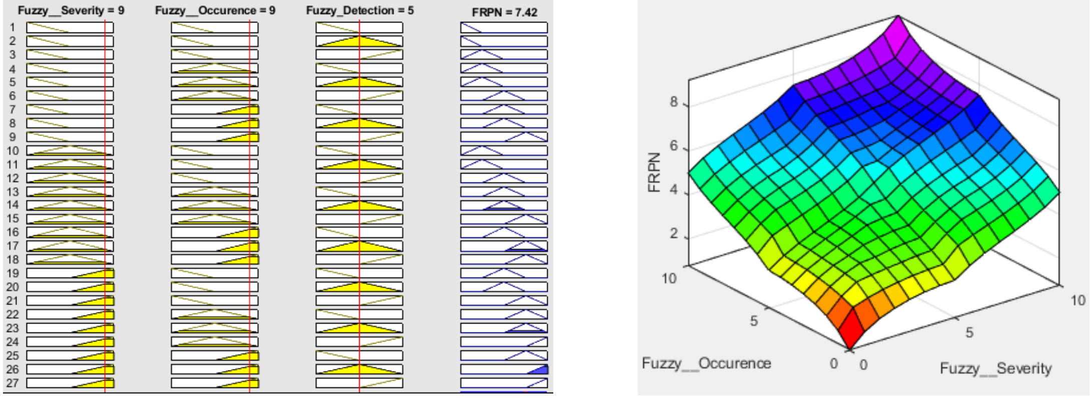
Fig. 6. Cause and Effect Diagram Jet Dyeing Machine Failure. Source: observational data processing, 2023

3.2. Fuzzy-FMECA Design

Based on the results of observations, the fuzzy logic design process uses the Mamdani model (Fig. 7(a)). In designing the membership function according to the methodology (Karatop et al., 2021) (Fig. 7(b)).



(a) Fuzzy Logic Mamdani (b) Membership Function Plots



(c) 27 Ruler Viewers Main Pump Sampling (d) Surface Viewer Main Pump Sampling

Fig. 7. Fuzzy Logic Mamdani Model

Testing uses the main pump component with a severity value of 9, fuzzy occurrence 9 and fuzzy detection 5, so that the RPN defuzzification is 7.42, recapitulating the results of the RPN defuzzification of 16 other components in the defuzzified RPN and ranking (Fig. 7(c)). Fuzzy logic is used to model the severity of damage to production machine components. The severity level of damage is represented as a real value between 0 and 1. This value indicates the degree of membership of a damage to a certain severity category (Fig. 7(d)).

3.3. Defuzzied RPN and Ranking

Defuzzied RPN and Rank is shown in Table 3. Damage to production machine components using the Fuzzy FMEA method, it can be concluded that the most critical components are the main pump and contact stop. These two components have the highest RPN value, namely 7.42. This shows that these two components have a high potential risk of failure. Damage to the main pump can cause water leaks onto the production floor. This damage can disrupt the production process and even cause work accidents. Damage to the socket can cause components to become unusable, which can disrupt the production process.

3.4. Histogram of Fuzzy

Histogram of fuzzy is shown in Fig. 8. It is consisting of (a) Fuzzy severity histogram, (b) Fuzzy occurrence histogram (c) Histogram fuzzy detection and (d) RPN defuzzied histogram.

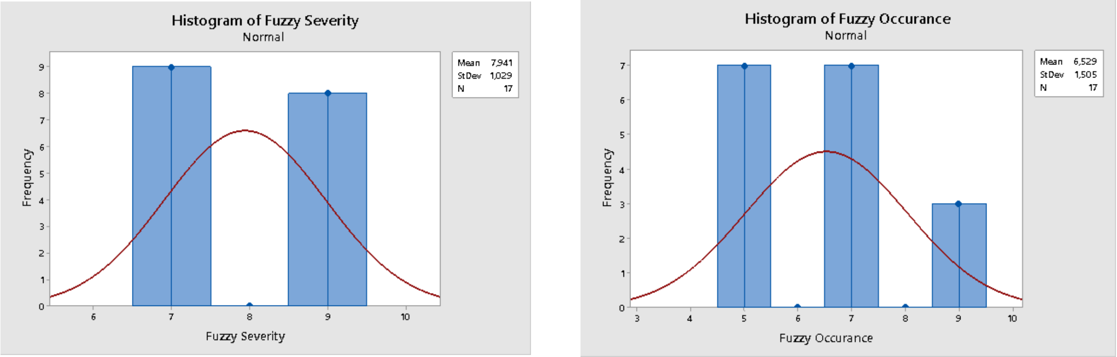
3.5. Modular Parts Jet Dyeing

Modular Parts Jet Dyeing (Table 4) presents a list of modular components used in the jet dyeing process. These components are classified based on modular rank, namely the ranking of components in a module. Component ratings range from 1 to 6, with a rating of 1 indicating the most important component. The most important component in the jet dyeing process is the main pump. The main pump functions to pump water and dye into the dyeing machine. Other important components are steam pipe packing, water level indicator and heating packing. Other components in the table have more specific roles in the jet dyeing process. For example, cylinder valve packing functions to prevent leaks in the cylinder valve, while the air valve functions to regulate air flow.

Table 3. Defuzzied RPN and Rank

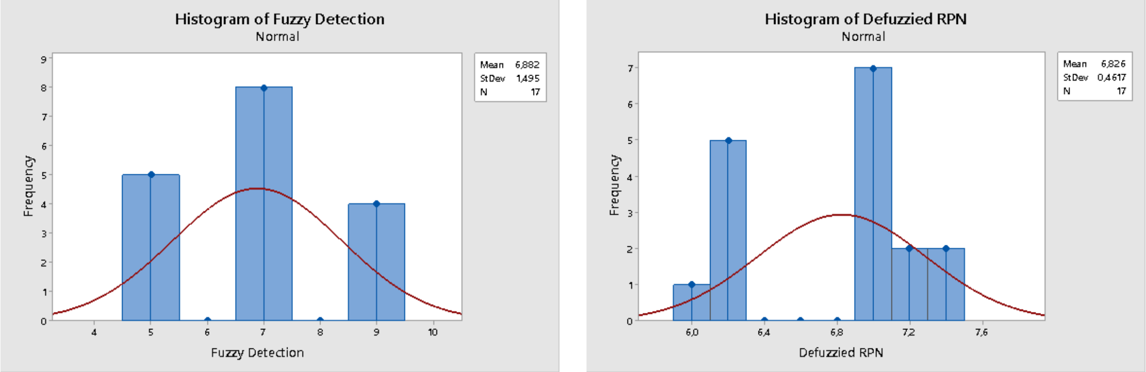
Component Name	Fuzzy Severity	Information	Fuzzy Occurrence	Note	Fuzzy Detection	Information	Fuzzy RPN	Rank
Play pump	9	Water overflows onto the production floor	9	Very often	5	May be detected quickly	7.42	1
Electric socket	9	Component cannot be used	9	Very often	5	May be detected quickly	7.42	1
Packingsteam pipe	9	The production process is not perfect	9	Very often	7	Difficult to detect quickly	7.25	3
Heat exchanger steam pipe	9	The production process is not perfect, the temperature of the production area increases	7	Often	9	Very difficult to detect quickly	7.25	3
Water indicator	7	Product failure due to water consistency not following SOP	7	Often	9	Very difficult to detect quickly	7.05	5
Packing heating	9	The production process is not perfect	7	Often	7	Difficult to detect quickly	7.05	5
Packingcylinder valve	9	The production process is not perfect	5	Seldom	7	Difficult to detect quickly	7.05	5
Condensate pipe	7	The production process experienced defects	7	Often	9	Very difficult to detect quickly	7.05	5
Tank pipe	7	Water overflows onto the production floor	5	Seldom	9	Very difficult to detect quickly	7.05	5
Valve heating	9	Failed products do not meet standards	7	Often	7	Difficult to detect quickly	7.05	5
Air hose	9	The machine does not work perfectly	5	Seldom	5	May be detected quickly	6.9	11
Indicator light	7	Production process failure	7	Often	5	May be detected quickly	6.29	12
SealGlass door	7	The production process is not going well	5	Seldom	7	Difficult to detect quickly	6.29	12
Sealtube rail	7	The production process experienced a bottleneck	5	Seldom	7	Difficult to detect quickly	6.29	12
Suction valve	7	Production process failure	7	Often	7	Difficult to detect quickly	6.29	12
Valvewind	7	The production process does not run perfectly	5	Seldom	7	Difficult to detect quickly	6.29	12
Cooling water pipe connection	7	The production process is not perfect, water comes out of the connection	5	Seldom	5	May be detected quickly	6.05	17

Source: MATLAB data processing, 2023



(a) Fuzzy severity histogram

(b) Fuzzy occurrence histogram



(c) Histogram fuzzy detection (d) RPN defuzzied histogram

Fig. 8. Histogram of Fuzzy

Table 4. Modular Parts Jet Dyeing

Rank	Modular Rank	Modular Parts
1	1	Play pump
1		Electric socket
3	2	Steam pipe packing
3		Heat exchanger steam pipe
5	3	Water indicator
5		Packing heating
5		Valve cylinder packing
5		Condensate pipe
5		Tank pipe
5		Valve heating
11	4	Air hose
12	5	Indicator light
12		Glass Door Seal
12		Tube rail seal
12		Suction valve
12		Air valve
17	6	Cooling water pipe connection

Source: data processing, 2023

3.6. Preventive Maintenance Brainstorming Design

The Brainstorming Preventive Maintenance is shown in Table 5. There is some information in the table such as Component Name, Timetable, Activity Description and Maximum Duration.

Table 5. Brainstorming Preventive Maintenance

Component Name	Timetable							Activity Description	Maximum Duration
	M	T	W	Th	F	S	Su		
Packingsteam pipe	🟩	🟩	🟩	🟩	🟩	🟩	🟩	Every day carry out inspections for contaminants and other disturbing substances that might cause leaks	5 minutes per inspection
Heat exchanger steam pipe	🟩	🟩	🟩	🟩	🟩	🟩	🟩	Every day carry out inspections for contaminants and other disturbing substances that might cause leaks	5 minutes per inspection
Water indicator	🟩	🟩			🟩	🟩		Every four times a week, calibrate to maintain the accuracy of the indicators	8 minutes per inspection
Packing heating	🟩	🟩			🟩	🟩		Every four times a week, carry out inspections for contaminants and other disturbing substances that might cause leaks	5 minutes per inspection
Condensate pipe	🟩	🟩			🟩	🟩		Every four times a week, carry out inspections for contaminants and other disturbing substances that might cause leaks	5 minutes per inspection

Component Name	Timetable							Activity Description	Maximum Duration
	M	T	W	Th	F	S	Su		
Valve heating	🟩	🟩			🟩	🟩		Carry out inspections every four times a week to ensure the valve is functioning properly (this can be in the form of lubrication, inspection of clogged impurities, etc.)	5 minutes per inspection
Play pump	🟩	🟩			🟩	🟩		Carry out inspections every four times a week to ensure the main pump is functioning properly (this can be in the form of lubrication, inspection of clogging impurities, etc.)	5 minutes per inspection
Electric socket	🟩	🟩			🟩	🟩		Carry out inspections every four times a week to ensure the socket is functioning properly (this could be checking the electric current, etc.)	5 minutes per inspection
Suction valve		🟩		🟩		🟩		Carry out inspections three times a week to ensure the valve is functioning properly (this can be in the form of lubrication, checking for clogged impurities, etc.)	5 minutes per inspection
Valve cylinder packing		🟩		🟩		🟩		Every three times a week, carry out inspections for contaminants and other disturbing substances that might cause leaks	5 minutes per inspection
Tank pipe		🟩		🟩		🟩		Every three times a week, carry out inspections for contaminants and other disturbing substances that might cause leaks	5 minutes per inspection
Indicator light			🟩			🟩		Every two times a week, check the indicator lights	5 minutes per inspection
SealGlass door			🟩			🟩		Twice a week, check the seal to ensure there is no liquid seeping	5 minutes per inspection
Sealtube rail			🟩			🟩		Twice a week, check the seal to ensure there is no liquid seeping	5 minutes per inspection
Valvewind			🟩			🟩		Carry out inspections twice a week to ensure the valve is functioning properly (this can be in the form of lubrication, checking for clogged impurities, checking for leaks, etc.)	5 minutes per inspection
Air hose			🟩			🟩		Carry out inspections twice a week to ensure the air hose is functioning properly and does not experience leaks (this can be in the form of cleaning dirt, etc.)	5 minutes per inspection
Cooling water pipe connection		🟩			🟩			Carry out inspections twice a week to ensure that the cooling water pipe connections are functioning properly, are not clogged and are not leaking	5 minutes per inspection

3.7. Discussion

Based on the results of the fuzzy FMEA analysis, it can be concluded that the most critical components in a jet dyeing machine are the main pump and contact stop. These two components have the highest RPN value, namely 7.42. This shows that these two components have a high potential risk of failure.

By identifying the root cause of jet dyeing machine damage, more targeted preventive measures can be taken. Proper precautions can significantly reduce the risk of jet dyeing machine component failure.

The fuzzy-FMECA methodology used in this study was proven to be effective in identifying the root cause of jet dyeing machine failure. This methodology is able to accurately assess the probability of the impact of failure, so that it can produce appropriate recommendation strategies to reduce the risk of failure that supports SNI 08-0046-2007.

By applying the results of this study, it is hoped that damage to jet dyeing machines can be minimized in the future. This will increase productivity and efficiency of the production process, as well as minimize fabric manufacturing losses. Recommendations to increase the effectiveness of this study:

a. Conduct further studies to identify other factors that can cause jet dyeing machine damage. These factors can be environmental factors, operational factors, and maintenance factors.
b. Conduct research to develop more effective recommended strategies to reduce the risk of jet dyeing machine failure. The recommended strategy can be a repair strategy, replacement strategy, or preventive maintenance strategy.
c. These recommendations can be made to increase the effectiveness of this study and provide greater benefits to the fabric manufacturing industry.

This study has succeeded in identifying the root cause of jet dyeing machine damage accurately and comprehensively. The results of the fuzzy-FMECA analysis show that the main pump and socket components are the most critical components and have a high potential risk of failure. The preventive maintenance brainstorming design that has been carried out is also good enough to reduce the risk of failure of jet dyeing machine components. However, there are several things that need to be considered to increase its effectiveness.

The preventive maintenance design emphasizes regular inspections of critical components to enhance the reliability of the jet dyeing machine. Daily checks on packing steam and heat exchanger pipes will identify contaminants and potential leaks. Weekly inspections of the water indicator, packing heating, and valves will ensure proper functioning, while checks on the main pump and electric socket will maintain operational integrity. Additional inspections on suction valves, tank pipes, indicator lights, seals, and cooling water connections will further minimize risks. Each inspection is time-efficient, taking only 5 to 8 minutes, contributing to overall efficiency in machine operation.

This study supports the findings of (Errouha et al., 2019), revealing that both works focus on optimization and control to enhance system efficiency and reliability. The first seeks to improve a PV water pumping system using Fuzzy Logic Control for better performance, while the second emphasizes identifying root causes of jet dyeing machine damage to implement preventive measures, reducing component failure and enhancing machine longevity. This study supports the findings of (Baradaran & Tavazoei, 2022), both the fuzzy system for water consumption in agriculture and identifying root causes of jet dyeing machine damage emphasize the importance of targeted measures. By understanding specific factors—whether soil moisture, air pollution, or machine component stress—precise interventions can significantly enhance efficiency and reduce resource waste in their respective fields. Not only that, the failure of components both statements emphasize the importance of identifying key factors to enhance safety and performance. In the construction industry, identifying and prioritizing safety parameters through methods like fuzzy AHP helps improve worker safety. Similarly, pinpointing the root causes of jet dyeing machine damage allows for targeted preventive measures, reducing the risk of component failure (Younesi Heravi et al., 2022).

Overall, this study has made a significant contribution in efforts to minimize damage to jet dyeing machines. Damage to jet dyeing machine components is dominated by leaks (9), tears (9), and short circuits (9). In the Fuzzy-FMECA analysis, the highest RPN values for the main pump and power socket each reached 7.42, indicating a high risk of damage. In addition, a total of 16 components were analyzed with the lowest RPN of 6.05, and all components required preventive maintenance with varying frequencies, ranging from twice to every day. Initial productivity is set at 100 units per production batch, with a 2% increase for each batch. After five production cycles, the results reach 520.4 units per batch (100, 102, 104.04, 106.12, and 108.24). If the initial efficiency is 90%, the initial production loss is 10 units per batch, resulting in a total loss of 52.04 units after five batches, indicating an increase in productivity and a reduction in losses over time. By applying the results of this study, it is hoped that the risk of failure of jet dyeing machine components can be reduced to a minimum. This will increase productivity and efficiency of the production process, as well as minimize fabric manufacturing losses.

4. Conclusions

This study applies the fuzzy-FMECA methodology to identify root causes and critical components of jet dyeing machine damage, revealing that the Main Pump and Socket components pose the highest risk, primarily due to leaks, tears, and short circuits. With an RPN value of 7.42, these components require prioritized preventive maintenance to mitigate damage. Productivity improved to 520.4 units per batch after five cycles, demonstrating enhanced efficiency and reduced losses. The study highlights the importance of focused preventive maintenance, real-time monitoring, and risk reduction strategies to optimize costs, ensure safety, and boost textile production reliability. While the findings are specific to jet dyeing machines, they underscore the potential of fuzzy-FMECA for complex manufacturing systems and propose adapting this approach to other machinery. Recommendations include implementing and refining preventive maintenance designs, exploring material improvements for critical components, and developing real-time monitoring systems to enhance safety, efficiency, and global competitiveness in the textile industry.

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