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Risk Identification Activities Warehouse using Fuzzy AHP and Fuzzy FMEA Method

Garnisa Ikwanus Sofa Ullul Albab, Supriyadi*, Ahmad Nalhadi, Mohamad Jihan Shofa, Ardita Maharani

Department of Industrial Engineering, Universitas Serang Raya, Jl. Raya Cilegon Km. 5, Kota Serang, Banten 42162 Indonesia

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A B S T R A C T

Warehouse is an important part of a company's supply chain. The supply chain of a company involves various stages of activity, including the inspection stage, production stage, marketing stage, material handling stage, and finished product stage. Problems that occur related to the handling of poor product processes have an impact on the loading process and product delivery to consumers. Resolution methods from the literature can use AHP, FMEA, Fuzzy FMEA, and Fuzzy AHP-FMEA. This research tries to integrate Fuzzy AHP and Fuzzy FMEA to get a priority ranking of risk levels and provide recommendations for decisions in warehouse management. The use of fuzzy in both methods because both methods use expert opinion and fuzzy can minimize the bias value of each respondent. The result of the research is a recommendations for the priority order of improvement of various potential risks that occur in the warehouse.

*Corresponding Author
Supriyadi
E-mail: supriyadi@unsera.ac.id

1. INTRODUCTION

Uncertainty regarding a situation can often suggest the presence of risk, which refers to the chance of encountering negative outcomes such as loss, damage, or other unfavorable events (Ustundag, 2012). From a supply chain perspective, risk can be defined as the result of unreliable and uncertain resources, which can cause disruptions in the supply chain process. On the other hand, uncertainty can be understood as the corresponding risk between supply and demand (Tang & Musa, 2011). The warehouse process in supply chain operations entails risks that can negatively impact the performance of the supply chain. The warehouse is a crucial component of the company's operations because without it, production would be challenging to manage. The risks associated with the warehousing process include errors in coding, discrepancies between stock levels and records, and damages to goods (Indrawati et al., 2018).

The application of risk analysis in warehouse activities is very important to prevent all forms of unwanted losses. The results of the initial identification of a poor product handling system caused the defect rate above the company standard of 5%. The effects of these defects pose the following risks: (1) Products that do not meet quality standards will be returned or rejected by consumers, (2) Difficulties in the production process caused by defective or damaged goods, (3) Production delays that will spend a lot of time.

The risk management process typically consists of four fundamental stages: risk identification, risk assessment, risk management, and risk monitoring (Oskoue et al., 2016). One of the most commonly used methods for risk management assessment is failure mode and effect analysis (FMEA) (Chanamool & Naenna, 2016; Dağsuyu et al., 2016). This technique involves identifying failure modes within a system, evaluating their impact on system behavior, and determining strategies to eliminate or reduce their severity, occurrence, or improve detectability (Mandal & Maiti, 2014). Within FMEA, each failure mode can be assessed based on three primary factors: severity, occurrence, and detectability (Kutlu & Ekmekçioğlu, 2012). These three factors can be combined using a multiplication formula to calculate the Risk Priority Number (RPN) for each failure mode. For instance, RPN is obtained by multiplying the scores of S (severity), O (occurrence), and D (detection) (Du et al., 2016).

Conventional FMEA is considered to have several weaknesses as a planning quality control tool, including: (1) The statements in FMEA are often subjective and qualitative, (2) The three levels of S (Severity), O (Occurrence), D (Detectability) are assumed to have the same importance, but in reality the three parameters are not equally important, (3) The same RPN value obtained from multiplying the levels of S, O, D may result in different risk representations (Kutlu & Ekmekçioğlu, 2012; Vahdani et al., 2015). Therefore, to avoid the weaknesses of the FMEA method, it needs to be supported by other methods, namely the use of fuzzy logic. This logic can be integrated with other methods such as AHP. (Sukwadi et al., 2017).

Utilizing fuzzy logic in research yields more precise outcomes compared to traditional FMEA techniques (Roghanian & Mojibian, 2015). Fuzzy FMEA is a development of the FMEA method that provides flexibility to explain the uncertainty due to the vagueness of information owned or the element of subjective preference used as an assessment of the type of failure that occurs. By using the fuzzy concept in the FMEA algorithm, it can use data in the form of numerical and linguistic data, where all of these data have membership values for each attribute.

Research was then developed with the integration of Fuzzy AHP and FMEA methods (Hassan et al., 2020; Hu et al., 2009). This research uses the concept of combining AHP and FMEA by performing fuzzy AHP on the S, O, D criteria and multiplying by the FMEA value to determine the priority of risk handling. This research has shortcomings related to FMEA values which are expert opinions that still have a level of bias. This research tries to improve the integration of fuzzy AHP-FMEA by performing fuzzy AHP and Fuzzy FMEA to minimize the level of bias in each of the predetermined criteria results.

This research aims to determine the ranking of risk levels in the warehouse area based on the results of Fuzzy AHP and Fuzzy FMEA and provide recommendations for improvements in minimizing potential risks that occur. The design of the decision system obtained is expected to help accelerate management decisions in prioritizing improvements according to the level of risk that occurs.

2. LITERATURE REVIEW

2.1. Fuzzy FMEA

FMEA serves as a framework for examining the cause and effect of a possible failure during a work activity (Balaraju et al., 2019; Fazli & Kazerooni, 2022). However, during FMEA analysis, determining the probability of failure events may prove difficult or even impossible, leading to subjective and qualitative descriptions expressed in natural language, such as "performance degradation," "reliability," and "safety." Evaluating these linguistic variables objectively is challenging. Traditional FMEA approaches emphasize team diversity and capability, followed by training, which leads to high costs (Lee et al., 2017; Schuller et al., 2017).

In contrast, many decision-making and

problem-solving tasks are too complex to be understood quantitatively, requiring imprecise knowledge instead. Fuzzy set theory, introduced by Lotfi Zadeh in 1965 (Zadeh, 1965), shares similarities with human reasoning by using approximate information and uncertainty to generate decisions. Fuzzy logic, developed later from fuzzy set theory, mathematically represents uncertainty and vagueness and provides a formal tool to handle the inherent imprecision of numerous problems. Unlike traditional computing, which demands precision down to every bit, knowledge can be expressed more naturally using fuzzy sets (Ivančan & Lisjak, 2021; Zadeh, 2015). Therefore, there is potential to enhance FMEA performance by employing fuzzy set theory (Supriyadi et al., 2017; Yazdi, 2019).

2.2. Fuzzy AHP

Fuzzy AHP is a technique that combines AHP with fuzzy logic to handle uncertainty in decision-making when selecting an object (Anshori, 2012). Fuzzy AHP differs from AHP in the use of Triangular Fuzzy Numbers (TFN) to represent the pairwise comparison weights in the comparison matrix. TFN consists of three variables (a,b,c) or (l,m,u) and is defined by the triangular membership function that includes three consecutive weights. This approach enables the weight obtained to be not only one but three values. TFN is denoted by m = (l,m,u), where l#m#u, with l being the lowest value, m being the median, and u being the largest value. The purpose of the TFN approach is to reduce the uncertainty of the AHP scale, which is originally in the form of "crisp" values. The approach is implemented by fuzzifying the AHP scale to produce a new scale known as fuzzy AHP (Hassan et al., 2020).

2.3. Fuzzy AHP-Fuzzy FMEA

Fuzzy AHP – Fuzzy FMEA combines pairwise comparison and risk analysis aspects by considering uncertainty and ambiguity. Fuzzy AHP is used to assign weights to relevant criteria in Fuzzy FMEA. Fuzzy FMEA is used to identify and analyze failure risks by considering the level of uncertainty in the comparison and analysis. The application of Fuzzy AHP-Fuzzy FMEA can assist in making more comprehensive and accurate decisions in managing the risk of failure in a particular system or process, considering the uncertainty and ambiguity that may occur.

The warehouse has an important role in improving the smoothness of the logistics process. Potential risks in warehouse activities have an unfavorable impact on the supply chain of a product. Proper risk assessment is one of the managerial decisions that can provide the right solution so as not to disrupt the course of warehouse activities. Risk assessment in the warehouse can use the FMEA method (Trikal & Thakare, 2018). This model was then developed using fuzzy techniques to provide more objective results (Ustundag, 2014). To improve the decision level, the integration of fuzzy AHP and FMEA was developed (Hassan et al., 2020; Jin et al., 2022). The research uses the concept of combining AHP and FMEA by performing fuzzy AHP on the S, O, D criteria and multiplying by the FMEA value to determine the priority of risk handling. This research has shortcomings related to FMEA values which are expert opinions that still have a level of bias. This research tries to improve the integration of fuzzy AHP-FMEA by performing fuzzy AHP and Fuzzy FMEA to minimize the level of bias in each of the predetermined criteria results.

3. RESEARCH METHOD

The research was conducted by identifying potential risks that occur in the warehouse area. Risk assessment is carried out by experts according to predetermined criteria. In this study, to rank the severity of risks from the largest to the smallest, it can be evaluated by converting RPN to FRPN in Fuzzy FMEA. Strategies to minimize risks can be applied by calculating the weight of each existing supply chain process. The weighting can be done according to the AHP method.

Fuzzy FMEA itself is a tool used to assess risk using 3 parameters, namely:

1. Severity is a level of rating that indicates the seriousness of the impact caused by a potential failure mode. This impact is rated on a scale of 1 to 10, where 1 represents the least severe impact and 10 represents the most severe impact.
2. Occurrence or level of likelihood of occurrence is the level of time or likelihood of occurrence sometimes referred to, as a

numerical subjective estimate of the likelihood that causes, if they occur, will result in a failure mode and its special effects.

3. Detection is a subjective estimate of the effectiveness of controls in detecting or preventing a cause or failure mode before it affects the customer. This assumes that the cause has already occurred.

In the Fuzzy FMEA approach, linguistic terms such as Low, Moderate, and High, are used to evaluate the S, O, and D factors and their respective weights (Table 1). Rules are then established by taking these linguistic variables as input to assess the level of risk. The risk assessment results obtained from calculations using the fuzzy FMEA method will then be used to determine alternative strategies and make the right strategic decisions using the Fuzzy AHP method.

Table 1. Fuzzy membership function

Rank	Linguistic Expression	Fuzzy Number
1,2,3	Low (L)	(0.0 0.2 0.4)
4,5,6,7	Moderate (M)	(0.2 0.5 0.8)
8,9,10	High (H)	(0.6 0.8 0.10)

The steps in problem-solving with the Fuzzy AHP method are almost the same as the AHP method, except that the Fuzzy AHP method is used to convert the AHP scale into a Triangular Fuzzy Number (TFN) scale to obtain priorities (Table 2).

Table 2. Triangle fuzzy number

Scale	Level of Importance	Lower	Middle	Upper
1	Equally important	1	1	3
3	Slightly more important	1	3	5
5	Clearly more important	3	5	7
7	Very clearly more important	5	7	9
9	Absolutely more important	7	9	9

4. RESULT AND DISCUSSION

The research was conducted by collecting data through the questionnaire method. The first questionnaire collecting risk analysis data in the warehouse is addressed to experts to validate and ensuring that the risk analysis is appropriate. The second questionnaire is a pair-wise comparison aimed at weighting or determining the level of importance given to experts in the warehouse or warehouse. The research focused on the process of receiving, storing, and shipping products.

Risk measurement in this study uses the FMEA method, and then the priority level of the risk is obtained. The FMEA method describes the risk assessment process with consideration of the S (Severity), O (Occurance), and D (Detection) scales, which are rated from 1 to 10. The greater severity value indicates a greater severity value. The occurence scale is assessed by how often the failure occurs. The greater the occurence value, the higher the likelihood of failure occurring/difficult to avoid. The detection scale is assessed from failures that can be detected, the larger the scale, the less detectable.

The SOD value in the fuzzy membership function is divided into 3 parameters, namely Low, Medium, and High (Table 1). The fuzzy FMEA design shows the RPN value (Figure 1) with output variables using the rules 'very_low': 'trimf', [0 0 250]; 'medium': 'trimf', [250 500 750]; 'low':'trimf', [0 250 500]; 'high': 'trimf',[500 750 1000]; 'very_high': 'trimf', [750 1000 1000] (Karatop et al., 2021). This design resulted in 27 fuzzy rules (Fig. 2) that can be used to make decisions regarding the output recommendations (Fig. 3).

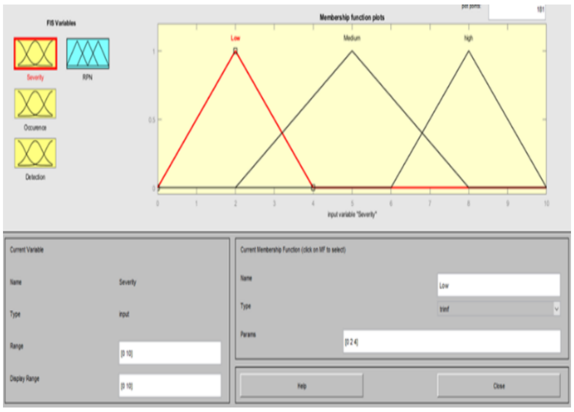

Fig. 1. Design system fuzzy

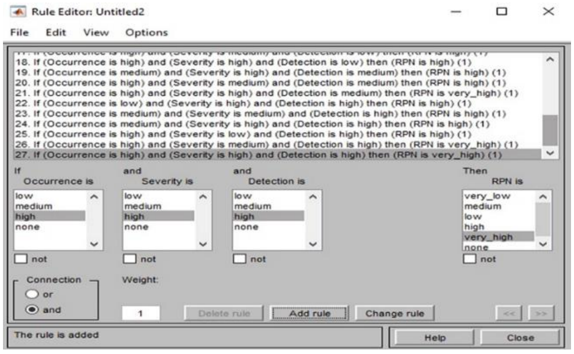

Fig. 2. Fuzzy rule base

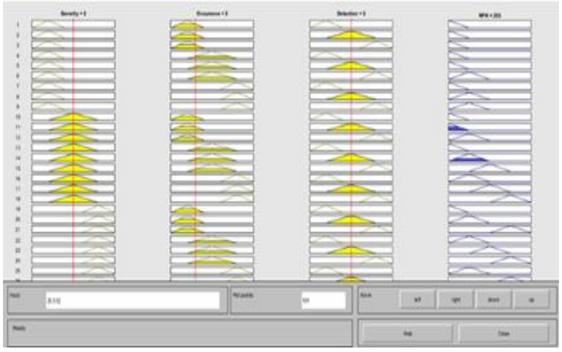
Fig. 3. Fuzzy RPN

Table 3. The fuzzy RPN results

Code	Potential Failure	S	O	D	RPN	FRPN
A	Item number on the product does not match the order	3	8	9	216	463
B	Damage to the goods received	3	3	9	81	325
C	Estimated arrival of goods to the warehouse was wrong	4	9	2	72	250
D	Limited storage area	3	6	9	162	353
E	Stock quantities do not match existing records	5	9	9	405	750
F	Incorrect placement of goods or materials	5	5	9	225	500
G	Damaged or expired goods	7	9	3	189	466
H	Inventory is too high	6	9	5	270	500
I	Deadstock or unsold products	7	9	5	315	647
J	Long delivery process	3	3	3	27	205
K	The road letter issued does not folow the order	4	4	5	80	250
L	Product damage during the journey from warehouse to customer	5	3	5	75	203

The fuzzy FMEA step based on the development of the questionnaire is done by creating a pairwise comparison matrix to describe the influence of each criterion of potential failure (Table 3). Since the assessment made is a preference comparison assessment, there is a possibility that respondents who fill in need to be more consistent in making judgments. Consistency is the effect of the coherence of evaluations made by decision-makers using a pairwise matrix. The data processing results show a Consistency Ratio value of 0.0532, smaller than 0.1 (Table 4). This value shows the degree of consistency obtained is feasible so that it can proceed to the next process.

The consistent criteria comparison is then converted into a TFN scale and calculated as the total sum of rows in the column. The TFN scale consists of lower, middle, and upper values (Table 3). The processing results with fuzzy AHP obtained a ranking of criteria based on the weights that have been determined (Table 5).

Fuzzy AHP has the advantage of being able to deal with uncertainty and ambiguity in decision-making (Javanbarg et al., 2012). In traditional AHP, pairwise judgment uses a crisp scale that cannot take into account the level of uncertainty. By using fuzzy logic in Fuzzy AHP, judgments can be made flexibly by describing membership levels on a fuzzy scale. This allows for more accurate and realistic judgments in the face of uncertainty.

Fuzzy AHP provides greater flexibility in judgment (Chan et al., 2008). In traditional AHP, pairwise comparisons are performed by assigning crisp weights to the evaluated elements. However, with Fuzzy AHP, the weights assigned can be at the level of membership in a fuzzy set. This allows for more nuanced judgments and considers the level of uncertainty in the decision-maker's preferences.

Fuzzy AHP produces more complete information. In traditional AHP, the weights assigned to elements are only integers or fractions. However, in Fuzzy AHP, the weights are expressed in fuzzy sets with membership functions that reflect levels of preference or trust. This helps in portraying the nuances and variations in the judgment of the decision-maker. In Fuzzy AHP, the membership levels in the fuzzy set can be adjusted or updated based on changing conditions or new information. This allows flexibility in changing preferences or weights when there is a change in the environment or circumstances.

Fuzzy AHP-Fuzzy FMEA integration is expected to provide better results than using traditional techniques (Table 6). Fuzzy logic in AHP is used to address uncertainty and ambiguity in pairwise comparisons by using fuzzy sets and membership functions (Sadiq & Tesfamariam, 2009). Fuzzy FMEA is used to identify and analyze failure risks by considering the level of uncertainty in the comparison and analysis. In Fuzzy FMEA, uncertainty and ambiguity in risk analysis are addressed using fuzzy logic concepts, including fuzzy variables, fuzzy sets, and fuzzy rules (Kabir & Papadopoulos, 2018). The application of Fuzzy AHP-Fuzzy FMEA can assist in making more comprehensive and accurate decisions in managing the risk of failure in a particular system or process, taking into account the uncertainty and ambiguity that may occur.

Table 4. Consistency test

	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**∑Max**	**CL**	**CR**
A	1	1	1	1	1/5	1	1/3	1	1/5	3	1/3	1/3	13.716	0.0787	0.0532
B	1	1	3	3	1/5	1	1/3	1	1/3	1	1	1/3	13.148		
C	1	1/3	1	1/3	1/3	1/3	1/3	1/3	1/3	1	1/3	1/3	13.118		
D	1	1/3	3	1	1/3	1	1/3	1/3	1/3	1	1	1/3	12.700		
E	5	5	3	3	1	3	1	1	1	3	3	3	13.180		
F	1	1	3	1	1/3	1	1/3	1/3	1/3	1	1	1/3	12.353		
G	3	3	3	3	1	3	1	1	1	3	3	1	12.199		
H	1	1	3	3	1	3	1	1	1	3	3	1/3	13.175		
I	5	3	3	3	1	3	1	1	1	3	3	1	12.334		
J	1/3	1	1	1	1/3	1	1/3	1/3	1/3	1	1	1/3	12.571		
K	3	1	3	1	1/3	1	1/3	1/3	1/3	1	1	1/3	12.968		
L	3	3	3	3	1/3	3	1	3	1	3	3	1	12.933		

Table 5. Triangle fuzzy number criteria

Code	**Importannce FN**			**Normalized FN**			**L**	**M**	**U**	**FAHP Score**
A	0.48	0.64	1.50	0.02	0.05	0.18	0.02	0.05	0.18	0.07
B	0.57	0.80	1.88	0.02	0.06	0.23	0.02	0.06	0.23	0.09
C	0.30	0.44	1.20	0.01	0.03	0.14	0.01	0.03	0.14	0.05
D	0.45	0.63	1.65	0.02	0.04	0.20	0.02	0.04	0.20	0.08
E	1.20	2.26	4.07	0.04	0.16	0.49	0.04	0.16	0.49	0.21
F	0.51	0.69	1.81	0.02	0.05	0.22	0.02	0.05	0.22	0.08
G	1.00	1.90	3.69	0.03	0.14	0.44	0.03	0.14	0.44	0.19
H	0.87	1.44	3.09	0.03	0.10	0.37	0.03	0.10	0.37	0.15
I	1.10	1.98	3.79	0.04	0.14	0.46	0.04	0.14	0.46	0.19
J	0.45	0.57	1.58	0.02	0.04	0.19	0.02	0.04	0.19	0.07
K	0.51	0.76	1.89	0.02	0.05	0.23	0.02	0.05	0.23	0.09
L	0.87	1.90	3.51	0.03	0.14	0.42	0.03	0.14	0.42	0.18

Table 6. Result

Code	Potential Failure	RPN	FRPN	FAHP-FMEA	FAHP-FFMEA	Ranking
A	The item number on the product does not match the order	216	463	10.80	32.41	7
B	Damage to the goods received	81	325	4.86	29.25	8
C	The estimated arrival of goods to the warehouse was wrong	72	250	2.16	12.50	12
D	Limited storage area	162	353	8.10	28.24	9
E	Stock quantities do not match existing records	405	750	64.80	157.50	1
F	Incorrect placement of goods or materials	225	500	11.25	40.00	5
G	Damaged or expired goods	189	466	26.46	88.54	3
H	Inventory is too high	270	500	27.00	75.00	4
I	Deadstock or unsold products	315	647	44.10	122.93	2
J	Long delivery process	27	205	1.08	14.35	11
K	The road letter issued does not follow the order	80	250	4,00	22.50	10
L	Product damage during the journey from warehouse to customer	75	203	10.50	36 54	6

The ranking results show some differences with techniques other than fuzzy AHP-Fuzzy FMEA. This shows that the implementation of this method can reduce the level of uncertainty and ambiguity that occurs. The implementation of fuzzy logic in both methods is expected to provide better decisions compared to previous research that only uses fuzzy logic in one of the methods. (Hassan et al., 2020; Hu et al., 2009; Jin et al., 2022).

The ranking results can help management determine priorities based on the risk of potential failures. In the fuzzy concept, values with high criteria are priorities that need to be resolved. The results of data processing show that stock quantities do not match existing records, and dead stock or unsold products are potential failures that fall into the high category and rank first and second.

The results of the first two priorities, namely, stock quantities do not match existing records and dead stock or unsold products, show the same results using traditional FMEA. It indicates that the level of bias in the respondent's assessment is small, so the value does not change much. The results of the third priority, namely damaged or expired goods, are different from traditional FMEA, where the third priority is inventory is too high. This difference is due to, among others, the determination of rules and decisions in fuzzy FMEA so that the value included in the bias follows the upper limit. Determination of rankings using fuzzy AHP also affects the results of Fuzzy AHP-Fuzzy FMEA formed. These results are reinforced by previous research where the results of fuzzy FMEA ranking have some differences with traditional FMEA (Chanamool & Naenna, 2016; Hassan et al., 2020; Mandal & Maiti, 2014). Stock-taking is physically calculating the amount of stock of trade goods inventory and adjusting it to the records. Usually, this is done at the end of the year. However, some companies implementing a more organized control system do it every three or four months. The way to do stock-taking in addition to requiring a warehouse stock calculation application, the company also needs a team, namely the counting team and the input team. With the development of stock-taking technology, it can use barcodes or RFID. Using barcodes or RFID allows the stock calculation process to be done more quickly and efficiently, and errors in recording and calculating goods can also be minimized.

An improvement step in potential dead stock or unsold products is to give customers discounts, which is the most straightforward strategy to eliminate unsold inventory. Providing a large discount in the hope of increasing demand for the product. On the other hand, selling these products may not generate profits, but the company can recover some production costs and increase storage space in the warehouse. Another step can be to return the product or raw material to the supplier, and the company can negotiate with the supplier to replace the stock inventory. Even if the company cannot sell the product, the supplier may know other customers willing to buy the product. Restocking usually depends on the terms and conditions of the return policy during the initial sales agreement. Usually, the compensation fee requested by the supplier is a repackaging fee.

5. CONCLUSION

Fuzzy AHP-Fuzzy FMEA applications can provide more comprehensive and accurate decision-making in managing the risk of failure in a particular system or process. Fuzzy AHP-Fuzzy FMEA can improve the results of the traditional AHP-FMEA assessment by considering the level of uncertainty and ambiguity, which results in a more accurate and realistic evaluation in the face of uncertainty. The ranking results provide convenience in assisting decisions in determining the prioritisation of improvement. The different ranking results with the traditional system show that implementing Fuzzy AHP-Fuzzy FMEA provides more comprehensive and accurate management of the failure risk level. The level of failure that is a priority for improvement based on the results of Fuzzy AHP-Fuzzy FMEA with a high category is the amount of stock not following with existing records and dead stock or unsold products. Implementing technology such as RFID or barcodes will likely improve stop-taking problems. This method is the most likely strategy to reduce unsold stock by giving customers discounts. The development of fuzzy logic is very rapidly growing. Future research can implement fuzzy logic type 2 to provide better decision results.

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