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Six Sigma Approach with Integration of FMEA-Fuzzy SWARA-Fuzzy WASPAS to Minimize Bottled Water Defects

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Abstract. *Along with the increasingly tight competition, companies are required to always be consistent in improving the quality of its products. Improvement of product quality can be achieved through minimization or even reduction of product defects. This study aims to minimize defects by providing improvement suggestions based on critical failure modes The Six Sigma approach is adopted to reduce the occurrence of product defects. The FMEA-FSWARA-FWASPAS FMEA method is integrated in the six sigma approach, especially to determine the priority of failure modes and the recommended efforts to minimize failure modes that trigger product defects. FSWARA is used to determine severity, occurrence, and detection weights as failure mode assessment criteria. Meanwhile, determination of the critical failure mode is based on the results of the evaluation using FWASPAS. This research is based on a case study in which 5 types of defects were found, namely, skewness, underfilling, leaks, broken lids, and broken boxes. The main causes lie in the human factor and the machine factor. The results showed that there were 3 critical failure modes, namely, the wrong setting of the cutter timer by the operator, the frequent change in the heater temperature, and material getting damaged.*

Keywords: *bottled water, defect, six sigma, fuzzy, FMEA, SWARA, WASPAS .*

I. Introduction

Pressure from globalization is forcing manufacturing organizations to move towards three competitive areas: quality, cost, and responsiveness. In order to survive and be able to provide customers with good products, manufacturing organizations need to ensure that their processes are continuously controlled and their product quality improved (Judi et al., 2011). Manufacturing organizations have applied various quality control techniques to improve the quality of processes by reducing their variability. Various methods are available to control the quality of product or process. One of the most widely used methods is six sigma.

Six sigma is the latest innovation in quality management, and is a strategy or system that regulates and improves quality significantly (Gaspersz, 2005). According to Pande et al., (2000) and Pete & Larry, (2002), DMAIC, which stands for Define, Measure, Analyze, Improve, and Control, is used in every stage throughout the implementation of quality improvement in six sigma.

Pangestu & Fahma (2019) implemented six sigma to reduce defect rates and simulated the improvement using Monte Carlo simulation. The results showed that every success in quality improvement has a positive impact on the company through an increase in the process capability index. Failure prevention measures require failure analysis to identify the potential failures as well as their causes and effects. In carrying out this prevention, failure analysis can be carried out using a concept called Failure Mode and Effect Analysis (FMEA).

FMEA was introduced as an analytical risk assessment technique that tries to identify and assess possible risks and determine the associated causes and effects of various risk events (Fattahi & Khalilzadeh, 2018). The factors Severity (S), Occurence (O), and Detection (D) can be used to determine the validity of the assessment and risk identification. However, the drawback of conventional FMEA is the assumption that these three factors are equally

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important (Liu et al., 2015). Therefore, it is necessary to develop an approach to overcome one or more limitations of conventional FMEA and to increase its effectiveness. Mohammadi et al., (2018) took an integrated approach based on FMEA and fuzzy sets to assess risks associated with construction projects and to overcome the limitations of conventional FMEA in the construction industry. Their research results revealed that the most critical risks include schedule changes, failure to finance on time, failure to provide equipment, delays in issuance of permits, poor planning by contractors, inflation rates, changes in government policies, and poor quality of equipment.

The literature review above shows that considerable effort has been made to overcome the weaknesses of conventional FMEA in risk assessment. Although this method is widely used, the identification and assessment of risks in the FMEA technique still needs more research because previous researches have not paid enough attention to two important and necessary principles: 1) Attention to accuracy and effectiveness of ranking, 2) Importance of a strong approach to determine the weights of assessment criteria based on the decision maker's judgement (Alvand et al., 2021).

Alvand et al., (2021) proposed an integrated approach to conventional FMEA. This integrated approach is proposed based on the use of Stepwise Weight Assessment Ratio Analysis (SWARA) and Weighted Aggregated Sum Product Assessment (WASPAS) methods under a fuzzy environment that gains advantage from all aforementioned methods. The Fuzzy SWARA (FSWARA) is applied because of its ability to solve problems such as the inability to assign different weights to the S, O, and D factors and the failure to take into account uncertainties resulting from conflicting expert opinions during the comparison process in conventional FMEA techniques (Alvand et al., 2021). Fuzzy WASPAS (FWASPAS) is used to address the uncertainty in expressing the values of S, O, and D factors for the identified risks. FWASPAS improves the chance of obtaining more consistent and best values (Alvand et al., 2021).

FMEA-FSWARA-FWASPAS integration has the advantage of being more prepared to accommodate assessments or evaluations because it has an additional language factor that facilitates decision makers. To the best of the author's knowledge, no studies related to six sigma have used the Fuzzy-FMEA-SWARA-WASPAS integration as one of the methods in the DMAIC cycle. Therefore, this study proposes the integration of FMEA-FSWARA-FWASPAS as one of the methods used at the analyze stage to minimize defects that occur in the company. The proposed integration is as follows: FMEA is used to identify the failure modes of critical defects, then FSWARA is used to determine the weight of the S, O, and D criteria, and FWASPAS is used to determine the priority of critical failure modes based on the failure mode rating. The six sigma approach with integrated FMEA-FSWARA-FWASPAS will be used to solve a real problem faced by a company.

II. Research Method

Define phase

The define phase focuses on quality improvement activities (Gaspersz, 2005). At this phase, the Critical to Quality (CTQ) is determined. CTQ is a criterion that becomes a limit for a company in determining the quality of the products it produces (Zhan & Ding, 2015). CTQ selection is done by using a pareto diagram.

Measure phase

The purpose of the measure phase is to measure how well the work process can produce output from input (Tannady, 2015). The actions taken at this stage include calculating the DPMO value, calculating the sigma value, and measuring process capability.

Analyze phase

The analyze phase aims to find the causes of failure down to the root causes and to provide feedback accordingly (Tannady, 2015). To analyze the causes of the problem, a fishbone diagram is used (Tague, 2005). After the causes of defects have been analyzed, FMEA is used to identify potential failures (failure modes), their causes, their effects, and current detection.

FMEA is often used as an identifier of sources or factors that cause quality problems (Chrysler & Motors, 2008). FMEA is an analytical risk assessment method that attempts to identify and assess possible risks and determine the associated causes and effects of various risk events (Fattahi & Khalilzadeh, 2018). Furthermore, FSWARA and FWASPAS are used to determine the critical failure modes.

Integrated FMEA - Fuzzy SWARA - Fuzzy WASPAS

The Stepwise Weight Assessment Ratio Analysis (SWARA) method can be used to solve various problems, including disagreements, architectural selection problems, machine selection problems, staff selection problems, corporate social responsibility (CSR) issues, and sustainability options (Keršuliene et al., 2010). Rosiana et al., (2021) succeeded in integrating Rough SWARA and COPRAS in evaluation of Third Party Logistics provider performance.

In general, FSWARA is considered as a suitable method for evaluating weights and criteria (Mardani et al., 2017). Therefore, in this study, FSWARA is used to determine the weight of the S, O, D criteria with the aim of reducing subjectivity and uncertainty in assessing criteria.

According to Mavi et al., (2017), there are 5 steps in implementing FSWARA to assign weight to the S, O, D criteria.

1. Sort the criteria in descending order in terms of expected importance, that is, the most important criteria are ranked first, and the least important are ranked last.
2. Determine the relative importance ratio $\tilde{S}_j$ for criterion j to the previous criterion j-1 using linguistic variables, as shown in Table 1, starting from the second criterion to the last. After calculating the values of $\tilde{S}_j$ for all DMs, the aggregate relative importance ratio $\tilde{S}_j$ is obtained using Equation (1).

$$\tilde{s}_j = (\tilde{s}_j^l, \tilde{s}_j^m, \tilde{s}_j^r) = \sum_{t=1}^{r} \frac{(\tilde{s}_j^l, \tilde{s}_j^m, \tilde{s}_j^r)}{r} \quad (1)$$

Table 1. FSWARA linguistic expressions and numbers

Linguistic Variable	Response Scale
Equally Important	(1,1,1)
Moderately Less Important	(0.67, 1, 1.5)
Less Important	(0.4, 0.5, 0.67)
Very Less Important	(0.286, 0.33, 0.4)
Much Less Important	(0.22, 0.25, 0.286)

Source : (Mavi et al., 2017)

3. Calculate the comparative importance coefficient using Equation (2) for each criterion.

$$\tilde{k}_j = \begin{cases} \tilde{1} & j = 1 \\ \tilde{s}_j + 1 & j > 1 \end{cases}, \quad \tilde{k}_j = (\tilde{k}_j^l, \tilde{k}_j^m, \tilde{k}_j^r) \quad (2)$$

4. Calculate *recalculated weighting factors* using Equation (3).

$$\tilde{q}_j = \begin{cases} \tilde{1} & j = 1 \\ \dfrac{\tilde{q}_{j-1}}{\tilde{k}_j} & j > 1, \end{cases} \quad \tilde{q}_j = (\tilde{q}_j^l, \tilde{q}_j^m, \tilde{q}_j^r) \quad (3)$$

5. Calculate *relative importance weight* using Equation (4).

$$\widetilde{w}_j = \frac{\tilde{q}_j}{\sum_{k=1}^{n} \tilde{q}_k}, \widetilde{w}_j = (\widetilde{w}_{jl}, \widetilde{w}_{jm}, \widetilde{w}_{ju}) \quad (4)$$

The Weighted Aggregated Sum Product Assessment (WASPAS) is one of the most accurate and effective MCDM methods (Zavadskas et al., 2014). This method is a unique combination of the MCDM approach, namely, the Weighted Sum Model (WSM) and Weighted Product Model (WPM). WASPAS method can optimize assessment for the selection of the highest and lowest value (Handayani & Marpaung, 2018).

After the criteria weights have been calculated, FWASPAS is applied to prioritize critical failure modes. There are seven steps in the FWASPAS method. The steps are listed below (Turskis et al., 2015).

1. Forming of Fuzzy Decision-Making Matrix (FDMM). The first step in FWASPAS is to form the initial decision as follows:

$$\tilde{X}_r = \begin{bmatrix} \tilde{x}_{11}^r & \cdots & \tilde{x}_{1j}^r \cdots \tilde{x}_{1n}^r \\ \vdots & \ddots & \vdots \ \ddots \ \vdots \\ \tilde{x}_{il}^r & \cdots & \tilde{x}_{ij}^r \cdots \tilde{x}_{in}^r \\ \vdots & \ddots & \vdots \ \ddots \ \vdots \\ \tilde{x}_{m1}^r & \cdots & \tilde{x}_{mj}^r \cdots \tilde{x}_{mn}^r \end{bmatrix}$$

$$i = 1, m, \qquad j = 1, n, \qquad r = 1, k$$

$\tilde{x}_r = [\tilde{x}_{ij}^r]_{m\times n}$ is the initial fuzzy decision matrix where $\tilde{x}_{ij}^r$ is the fuzzy evaluation of the i-th option against the j-th decision criteria by the Decision Maker (DM). The DM score for each failure mode is based on Table 2. The results of FSWARA will be used in FWASPAS when calculating the weighted sum model (WSM) and weighted product model (WPM). In this process, the integrated FMEA - Fuzzy SWARA - Fuzzy WASPAS is carried out.

Table 2. Fuzzy verbal expressions and corresponding fuzzy numbers

Priorities	Priorities fuzzy equivalent
Very Low	(1,1,1)
Low	(1, 3, 5)
Medium	(3, 5, 7)
High	(5, 7, 9)
Very High	(7, 9, 11)

Source : (Patil & Kant, 2014)

2. The matrix must be integrated using Equation (5) for each member of the matrix, to form the initial fuzzy group decision.
$$\tilde{\tilde{x}}_{ij} = \tilde{\tilde{x}}_{ij\alpha}, \tilde{\tilde{x}}_{ij\beta}, \tilde{\tilde{x}}_{ij\delta} = \sum_{r=1}^{k} \frac{(\tilde{x}_{ij\alpha}^r, \tilde{x}_{ij\beta}^r, \tilde{x}_{ij\delta}^r)}{k} \quad (5)$$
3. Normalization of the fuzzy decision matrix is based on Equations (6) and (7):
   - For negative criteria
$$\tilde{\tilde{x}}_{ij} = \frac{\tilde{x}_{ij}}{max_i\, \tilde{x}_{ij}} \quad (6)$$
   - For positive criteria
$$\tilde{\tilde{x}}_{ij} = \frac{min_i\, \tilde{x}_{ij}}{\tilde{x}_{ij}} \quad (7)$$

   where $\tilde{\tilde{x}}_{ij}$ is the normalized decision- making matrix.
4. Calculate values of the optimality function for each option according to WSM. The weighted sum model matrix is obtained by multiplying the standard weight by the normal matrix, according to Equation (8).
$$\tilde{Q}_i = \sum_{j=1}^{n} \tilde{\tilde{x}}_{ij}\tilde{w}_{j,}\ \ i = \overline{1,m} \quad (8)$$
   where $\widetilde{w}_j$ is the weight of the S, O, D criteria calculated from the FSWARA method using Equations (1) to (4).
5. Calculate values of the optimality function according to WPM for each option. The weighted multiplication matrix is derived from the elements of the normal fuzzy matrix to the fuzzy weight power, according to Equation (9):
$$\tilde{P}_i = \prod_{j=1}^{n} (\tilde{x}_{\overline{ij}})\, \widetilde{w}_j, i = 1, m \quad (9)$$
6. The result of fuzzy performance measurement for each option are fuzzy numbers Q_i and P_i in Equations (10) and (11).
$$Q_i = \frac{1}{3}\tilde{Q}_i = \frac{1}{3}(\tilde{Q}_{i\alpha} + \tilde{Q}_{i\beta} + \tilde{Q}_{i\delta}), i = 1,..,n \quad (10)$$
$$P_i = \frac{1}{3}\tilde{P}_i = \frac{1}{3}(\tilde{P}_{i\alpha} + \tilde{P}_{i\beta} + \tilde{P}_{i\delta}), i = 1,..,n \quad (11)$$
7. The integrated utility function value of the FWASPAS for each could be define as folllows:
$$k_i = 0.5Q_i + 0.5P_i, 0 \le k_i \le 1 \quad (12)$$

Based on k_i^λ values of the options are ranked according to increase in value. However, an important issue in the FWASPAS method is to improve the accuracy and effectiveness of the ranking in the decision-making process. To achieve this objective, Equation (13) is used to evaluate the total relative importance in determining the ranking of the options.

$$k_i^\lambda = \lambda \sum_{j=1}^{n} Q_1 + (1-\lambda)\sum_{j=1}^{n} P_i, \lambda = 0,\dots,1, 0 \le k_i^\lambda \le 1 \quad (13)$$

Where λ is the FWASPAS parameter. Calculation of the optimal value of λ is obtained using Equation (14).

$$\lambda = \frac{\sum_{j=1}^{n} P_i}{\sum_{j=1}^{n} P_i + \sum_{j=1}^{n} Q_i} \quad (14)$$

The sorting of the critical failure modes is done based on k_i^λ, where the highest rank has the largest k_i^λ value.

Improve phase

At this stage, various efforts are made to eliminate the sources of product defects or process failures. The proposed improvements will use the 5W1H method (what, who, where, when, how and Why to overcome the failure mode by dissecting it into 6 questions: what, why, when, where, who, and how. These six questions can comprehensively explain the solutions needed and can do so with objective information.

III. Result and Discussion

Define Phase

CV. Kinarya Berkah Abadi produces Bottled Drinking Water (AMDK) under the brand Q-Mas M. The average defect rate in the company's production process is 7.8%. The production process starts from the raw material that is pumped from the water reservoir. Then the water is filled into the sand filter up to the carbon filter. Next, it goes through a sterilization process commonly called ozonation. The ozonized water then flows into the filling unit and rishing unit, which has previously been sterilized with UV light. Afterwards, the water is flowed into the finished product storage tank, from which samples are taken by the QC manager for testing. If the test results meet the requirements, the process is concluded with the packaging of the finished product into cups, bottles, and gallons.

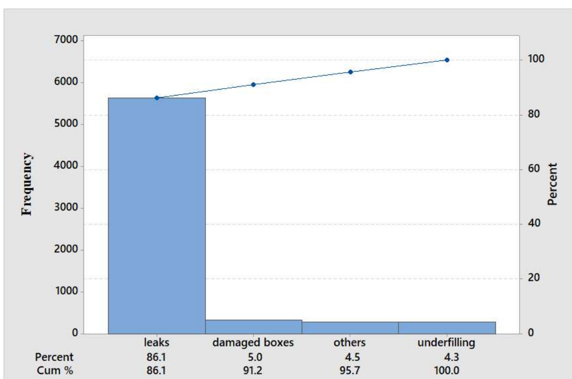

Figure 1. Pareto diagram

The water filling process is the process where the most defects occur. There are 5 types of defects, which are skewness, underfilling, leaks, damaged lids, and damaged boxes. After knowing the type of defects, the number of defects that occur is investigated. After these procedures, the type of defect that will be classified as CTQ (Critical to Quality) is determined using a Pareto diagram.The result of the Pareto diagram calculation is shown in Figure 1. It demonstrates that the critical defect is the "leaks" defect since its percentage exceeds 80%, specifically at 86.1%.

Measure Phase

Based on company data from January 2021 to April 2022, the DP U, DPO, and DPMO values as well as the sigma level are as follows.

$$\text{DPU} = \frac{Number\ of\ defective\ units}{Number\ of\ units\ produced}$$

$$\text{DPU} = \frac{6539}{83094} = 0.078694$$

$$\text{DPMO} = \frac{DPU}{Number\ of\ defects} x\ 1.000.000$$

$$DPMO = \frac{0,.78694}{5} x\ 1.000.000 = 15738,8$$

$$sigma\ level = normsinv\left(\frac{1.000.000 - DPMO}{1000000}\right) + 1,5$$

$$sigma\ level = 2,484261$$

From the results of these calculations it can be concluded that the company is at the average level of the Indonesian industry with CPOQ (cost of poor quality) which cannot be calculated (Gazpers, 2005).

Analyze Phase

Figure 2 shows the result of the analyze phase using fishbone diagram, which is based on 5 categories: man, machine, material, method, and environment. The diagram discovers 19 causes. In the human factor, there are 7 causes such as the operator wrongly setting the heater temperature, disobedience of the SOP, and insufficient number of operators. Within the method factor, there are 4 causes including lack of warning signs and notice as well as unorganized production schedule. In the machine factor, there are 4 causes such as the frequent change in the heater temperature and the decreasing machine performance. There are 2 causes related to the material, namely, the cup lids being thin and the cup thickness not complying with the standards. Finally, the environmental factor contributes one cause, which is the storage space being too small.

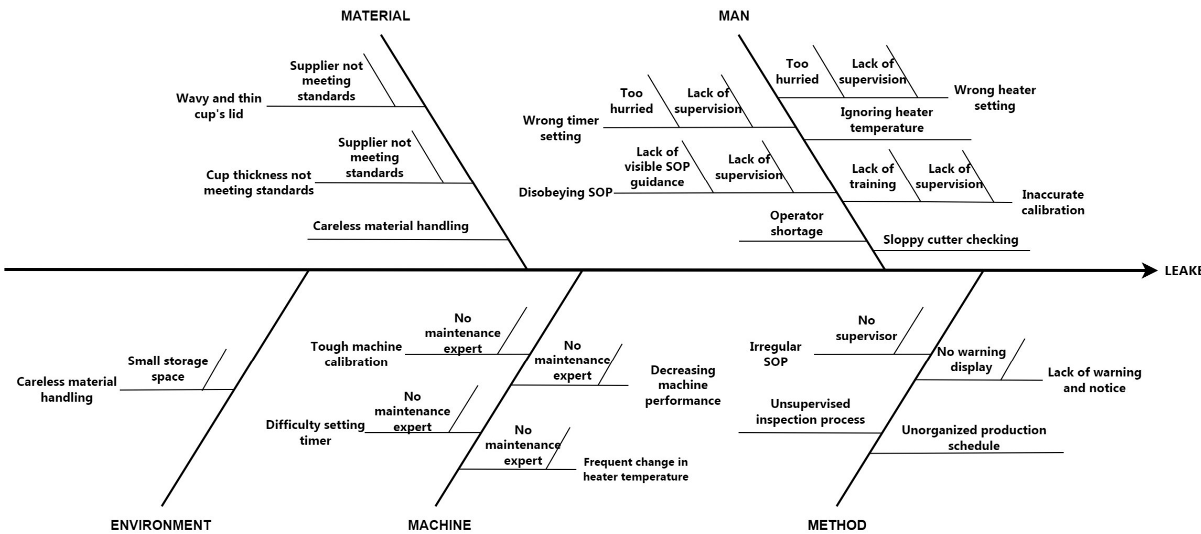

Figure 2. Fishbone diagram

Identification of Failure Modes, Causes, Effects, and Current Detection

After analyzing the causes of leaky cup defects using fishbone diagrams, the next process is to identify potential failures, causes, effects, and current detection. This process is carried out through brainstorming and analysis with the field supervisors as DM (Decision Maker). The referred supervisors are the QC manager, QC staff, and 2 production operators based on the causes that have been analyzed in the fishbone diagram. It can be seen in Table 3 that there are 8 process activities involved in the water filling process. From the 8 process activities, 11 failure modes were obtained along with their associated causes, effects, and current detection.

Calculation of Severity, Occurence, and Detection Criteria Weight using Fuzzy SWARA

After the previously discussed process, the respective weight of the S, O, and D criteria is calculated. To perform the calculation, data must first be collected through a questionnaire with the person in charge of the field as the DM (Decision Maker). Table 4. shows the assessment from DM on each criterion. The Severity criterion is left blank because it is considered a comparative importance of the criteria. Furthermore, the conversion of linguistic variables into fuzzy numbers uses Table 1.

The steps for weighting the criteria S, O, D with FSWARA are according to the explanation in the research method. Calculation of relative importance ratio $\tilde{S}_j$, comparative importance coefficient $\tilde{k}j$, recalculated weighting factors q̃j, dan relative importance weight $\widetilde{w}j$ using equations 1-4. Calculation results for occurrence criterion (O) are as follows :

$$\tilde{\mathrm{s}}_{\mathrm{j}} = \sum_{1}^{4} \frac{\begin{pmatrix} 0.286 + 0.67 + 1 + 0.4, \\ 0.33 + 1 + 1 + 0.5, \\ 0.4 + 1.5 + 1 + 0.67 \end{pmatrix}}{4}$$

$$= (0.588, 0.708, 0.893)$$

$$\tilde{k}j = (0.5875 + 1,0.7075 + 1,0.8925 + 1)$$

$$= (1.588, 1.708, 1.893)$$

$$\tilde{q}j = \left(\frac{1}{1.893}, \frac{1}{1.708}, \frac{1}{1.585}\right)$$

$$= (0.528, 0.586, 0.630)$$

$$\boldsymbol{\widetilde{w}j} = \left(\frac{\mathbf{0.528}}{\mathbf{2.004}}, \frac{\mathbf{0.586}}{\mathbf{1.898}}, \frac{\mathbf{0.630}}{\mathbf{1.772}}\right)$$

$$= (0.264, 0.309, 0.355)$$

Convert the fuzzy relative importance weights $\boldsymbol{\widetilde{w}j}$ to non-fuzzy (crisp value) based on Center of Area method.

$$wj = \frac{1}{3}\left(\overset{\sim l}{0.264} + \overset{\sim m}{0.309} + \overset{\sim r}{0.355}\right)$$

$$= 0.309$$

Table 5 shows the fuzzy and non-fuzzy importance weights of the criteria S, O,and D. In Table 5, the severity criterion has the highest

Table 3. Failure modes, causes, effects, and current detection

No	Process Activities	Failure Mode	Cause	Effect	Current Detection
1	Material loading (moving cups and lids from the warehouse to the production room)	Material (cup and lid) become damaged (FM1)	Careless material (cup and lid) handling The material (cup and lid) from the supplier does not meet the standards (cup thickness varies and the lids are thin and wavy)	Many cups have defect in the form of leaks during the production process	Sampling of material (cup and lid) from suppliers
2	Setting heater temperature	Wrong setting of heater temperature by operator (FM2)	Operator is negligent due to workload overload Lack of supervision	Lid is not completely closed, resulting in leaks	Operator resets the heater temperature
3	Setting heater timer	Wrong setting of heater timer by operator (FM3)	Operator is negligent due to workload overload Lack of supervision	the heater goes down exactly at the mouth of the cup	Operator resets the heater timer
4	Setting cutter timer	Wrong setting of cutter timer by operator (FM4)	Operator is negligent due to workload overload Lack of supervision	the cutter does not go down exactly at the mouth of the cup	Operator resets the cutter timer
5	Perform checking on cutter	Blunt blade (FM5)	Operator is sloppy when checking the cutter	Cutter is unable to cut the lid	The production operator sharpens the cutter blades
6	Running test (checking of machine when it is running)	Wrong machine calibration (FM6)	Lack of supervision Lack of training for operator	Production process experiences delay	Operator checks and recalibrates the machine
7	Production process	Rapid change in the heater temperature (FM7) Timer changing when machine is running (FM8)	There are no machine repair experts	The cup's lid is not perfectly closed	Operator periodically checks the indicator of machine temperature Operator periodically checks the machine timer
		Frequent change in machine settings (FM9)	Performance of machine is decreasing There are no machine maintenance experts	Many cups have leaks during the production process	Operator periodically checks the machine settings
		Operator's neglect in supervising the production process (FM10)	Insufficient number of operators There are no supervisors		None
8	Packaging of finished product	Cup leaks inside the box (FM11)	Operator sloppiness during inspecting	Cardboard packaging becomes wet and product requires repackaging	Repackaging for damaged cardboard

value, which is 0.530. Next, the occurrence criterion gets a value of 0.309 while the detection criterion has a value of 0.166. These values will later be used in the WASPAS fuzzy calculations as the importance weights for each criterion.

Tabel 4. The results of the assessment of the DM

Criteria	DM1	DM2	DM3	DM4
S	-	-	-	-
O	VLI	MoLI	EI	LI
D	EI	LI	MoLI	MoLI

Prioritize and Identify Critical Failure Mode Using Fuzzy WASPAS

In Table 3, failure modes, causes, effects and current detection have been identified in each water filling process. Furthermore, the Decision Maker, namely the QC manager, QC staff, and 2 production operators assess S, O, and D in each failure mode based on Table 2. The severity assessment is based on how severe the effect is when the failure mode occurs. Occurrence ratings are based on how often the cause of the failure mode occurs. While the detection assessment is

Table 5. Recapitulation of calculations on S, O, D Criteria

	$\tilde{s}_j$			$\tilde{k}j$			$\tilde{q}j$			$\tilde{w}j$			wj
S	0	0	0	1	1	1	1	1	1	0.499	0.527	0.564	0.530
O	0.588	0.708	0.893	1.588	1.708	1.893	0.528	0.586	0.630	0.264	0.309	0.355	0.309
D	0.685	0.875	1.168	1.685	1.875	2.168	0.244	0.312	0.374	0.122	0.165	0.211	0.166

based on how successful current detection is in detecting failures.

Based on the results of this assessment, the next step is to determine the value of k_i^{λ} for each failure mode using equation 5-14.

Table 6. The rank of each failure mode

Failure Mode	λ	k_i^{λ}	Rank
FM 4		0.705	1
FM 7		0.618	2
FM 1		0.606	3
FM 9		0.541	4
FM 8		0.534	5
FM 5	0.481	0.527	6
FM 6		0.501	7
FM 10		0.482	8
FM 2		0.461	9
FM 3		0.443	10
FM 11		0.4278	11

Table 6 shows the ranking of each failure mode. In this reserach, the critical failure mode was taken from the top three rankings. So that the critical failure modes that are further analyzed in the improve phase are:

1. Failure mode 4 : wrong setting of cutter timer by operator, which has a k_i^{λ} value of 0.705
2. Failure mode 7 : frequent change in heater temperature, which has a k_i^{λ} value of 0.618.
3. Failure Mode 1 : material getting damaged, , which has a k_i^{λ} value of 0.606.

Improve Phase

The proposed improvement solutions will apply the 5W1H method on the three critical failure modes by dissecting them into 6 questions: what, why, when, where, who, and how. These six questions can comprehensively explain the solutions needed and can do so with objective information. Table 7 demonstrates the 5W1H analysis which is used to provide improvement solutions on critical failure modes.

In failure mode "wrong setting of cutter timer by operator" there are two causes of failure, namely operator negligence due to workload overload and lack of supervision. Furthermore, there are 3 proposed improvement solutions to eliminate these two causes, as follows :

1. Production scheduling based on demand by considering the setup time, machine availability, and the number of available operators.
2. Applying *reward* dan *punishment* system.
3. Recruiting production supervisors with experience in the field of drinking water production.

There is one cause that has the potential to cause a failure mode "frequent change in heater temperature". Improvement solutions provided to eliminate the causes of "nonexistence of engine repair experts" is recruiting experts with experience in the field of maintenance.

In failure mode "material getting damaged" there are two causes of failure, namely operator carelesness during material loading and lack of standardized material from supplier). Furthermore, there are 3 proposed improvement solutions to eliminate these two causes, as follows:

1. Applying the 5S work principle, which include seiri = concise, seiton = neat, seiso = clean, seiketsu = treat, and shitsuke = diligent in the material handling process, so that operators will be more careful. According to Knechtges et al., 2013, the 5S Method aims to create and maintain a cleaner, more organized and safer workplace. because a problem cannot be seen properly in an unorganized place. So the 5S method is considered suitable to be a solution

Table 7. Proposed 5W1H Improvement

Rank	Failure Mode	Cause	*what*	*why*	*where*	*who*	*when*	*how*	k_i^λ
1	Wrong setting of cutter timer by operator	Operator negligence due to workload overload	Unorganized production schedule	Impromptu scheduling causes workload overload	Production room	Production manager	Prioritized in August 2022 after conducting research	Production scheduling based on demand by considering the setup time, machine availability, and the number of available operators	0.705
								Applying *reward* dan *punishment* system	
		Lack of supervision	Production supervisors are needed to supervise operators	To supervise production operators from being negligent, which was previously only done by production managers	Production area	Production manager	Prioritized in August 2022 after conducting research	Recruiting production supervisors with experience in the field of drinking water production	
2	Frequent change in heater tempera -ture	Nonexis-tence of engine repair experts	Maintenance staff are needed to handle machine maintenance	To regularly check the machine components, so that the machine remains in optimal condition and does not break down quickly	Production departmen t of factory / Filling machine	Production manager proposes hiring	Second priority in August 2022 after conducting research	Recruiting experts with experience in the field of maintenance	0.618
3	aterial etting amaged	Operator carelesness during material loading	Applying the 5S principle in the material handling process	Due to operator carelessness, there is a big possibility of dents and leak due to being slammed and piled up	Material storage warehouse	Product-ion operators, material handling staff, QC staff	Third priority in August 2022 after conducting research	Applying the 5S work principle, which include seiri = concise, seiton = neat, seiso = clean, seiketsu = treat, and shitsuke = diligent in the material handling process, so that operators will be more careful	0.609
		Lack of standardize d material from supplier (varied cup thickness, thin and wavy lid)	Create contract for goods returning and increase QC sampling rate	Because there are still variations of the material that does not meet the standard	Material receiving area	QC staff	Third priority in August 2022 after conducting research	Create contract with material supplier/vendor with stricter material return policy	
								Increase sampling at the time of material receiving the goods to lower the	

to the problem of "the material getting damaged.

2. Create contract with material supplier/vendor with stricter material return policy.
3. Increase sampling at the time of material receiving the goods to lower the possibility of damage.

IV. CONCLUSION

This research focuses on controlling defect rate products through identification of failure modes that need to be prioritized and their root causes. Efforts to reduce the risk of these modes are then formulated. The six sigma approach is considered by integrating the FMEA - Fuzzy SWARA - Fuzzy WASPAS.

The evaluation of failure modes is based on severity, occurrence, and detection criteria. The determination of each criteria's weight utilizes Fuzzy SWARA method, where the highest weight with a value of 0.530 is assigned to the severity criteria. Priority for assessing the second and third criteria is based on occurrence and detection, whose weights are 0.309 and 0.166 respectively. Based on the priority of failure modes determined using the Fuzzy WASPAS method (value of k_i^{λ}), there are 3 critical failure modes that must be prioritized.

By using the six sigma approach with the proposed integration of FMEA - Fuzzy SWARA-Fuzzy WASPAS, this study provides .an alternative approach for quality managers in analyzing failure modes, detecting the causes and impacts of failure, and determining priority for failure modes as well as solution to improve production quality, especially minimizing the level of product defects.

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