Application of multi attribute failure mode analysis of milk production using analytical hierarchy process method

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Abstract. Pusat Koperasi Induk Susu (PKIS) Sekar Tanjung, East Java is one of the modern dairy industries producing Ultra High Temperature (UHT) milk. A problem that often occurs in the production process in PKIS Sekar Tanjung is a mismatch between the production process and the predetermined standard. The purpose of applying Analytical Hierarchy Process (AHP) was to identify the most potential cause of failure in the milk production process. Multi Attribute Failure Mode Analysis (MAFMA) method was used to eliminate or reduce the possibility of failure when viewed from the failure causes. This method integrates the severity, occurrence, detection, and expected cost criteria obtained from depth interview with the head of the production department as an expert. The AHP approach was used to formulate the priority ranking of the cause of failure in the milk production process. At level 1, the severity has the highest weight of 0.41 or 41% compared to other criteria. While at level 2, identifying failure in the UHT milk production process, the most potential cause was the average mixing temperature of more than 70 °C which was higher than the standard temperature (≤70 °C). This failure cause has a contributes weight of 0.47 or 47% of all criteria. Therefore, this study suggested the company to control the mixing temperature to minimise or eliminate the failure in this process.

1. Introduction
In the 21st century, the needs for quality products is critical. Therefore, it is necessary to maintain and control the product quality as a guarantee to the consumer that the marketed product has good quality [1]. This is crucial for companies to increase customer’s interest and satisfaction level.

Currently, the development of dairy products is rapidly increasing, as indicated by a lot of milk brands in the market. Consumer preference and loyalty are the keys to the company’s success to win the competition.

Pusat Koperasi Induk Susu (PKIS) Sekar Tanjung East Java is one of the modern dairy industries that established by the cooperation of six cooperatives. Ultra High Temperature (UHT) milk is produced by PKIS Sekar Tanjung. The main problem faced by PKIS Sekar Tanjung is the failure of the production process that is not accordance with the standard. Milk is a very sensitive product and easily damaged, therefore a research to identify the most potential failure in the production process is required. This is important to find an action or strategy to be carried out for minimising the failure immediately. Thus, PKIS can produce high quality and competitive products. Therefore, this study aimed to apply Multi
Attribute Failure Mode Analysis (MAFMA) on the milk production process by using Analytical Hierarchy Process (AHP)” method for measuring the weight of criteria.

2. Research Methods
This research was conducted at PKIS Sekar Tanjung, located at Jalan Raya Puntir Martopuro Village Purwosari Subdistrict. Data processing and analyses were carried out in Computational Laboratory and System Analysis, Department of Agroindustrial Technology, Faculty of Agricultural Technology, Universitas Brawijaya, Malang.

2.1. Research procedure
The first step, in this study, was to conduct the preliminary survey to find out the real condition of PKIS Sekar Tanjung. This was then followed by a survey using structured questionnaires and interview to obtain baseline data for a problem formulation. The next step was an in-depth interview with an expert respondent, the head of the production department, who know better about the problem in the company. The identification of the problems was aimed to enable researchers to determine the steps needed in this study. MAFMA is one of the methods used to eliminate or reduce the possibility of failure when viewed from the root of the failure cause [2]. Therefore, this method can be used to minimise or prevent the failure. The formulation of the priority ranking of causes of failure is carried out by AHP approach [3].

2.2. MAFMA method.
MAFMA is a method that integrates Failure Mode and Effect Analysis (FMEA) with the economic aspect [2]. This method aims to identify the causes of overall failure to determine the most potential causes of failure. This method can be applied by identifying process functions, identifying potentially failed products and processes, analyzing the effects, identifying the causes of failure and the variables in the process, and ranking each failure in determining priorities for corrective action, and documenting the results. Determination of the highest weight for each criterion was carried out using the AHP approach based on severity, occurrence, detection, and expected cost.

2.2.1. Severity
Severity is a rank that shows a serious effect that comes from the failure mode (Table 1).

| rank | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10 |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|----|
| criteria | negligible severity | mild severity | moderate severity | high severity | potential safety problems |

2.2.2. Occurrence
Occurrence shows the frequency of a problem that cause of failure, as shown in Table 2.

| Degree | Frequency of occurrence | Rating |
|--------|-------------------------|--------|
| Remote | 0.01 per 1000 item      | 1      |
| Low    | 0.1 per 1000 item       | 2      |
|        | 0.5 per 1000 item       | 3      |
| Moderate | 1 per 1000 item      | 4      |
|         | 2 per 1000 item         | 5      |
|         | 5 per 1000 item         | 6      |
| High   | 10 per 1000 item        | 7      |
|        | 20 per 1000 item        | 8      |
| Very High | 50 per 1000 item    | 9      |
|         | 100 per 1000 item       | 10     |
2.2.3. Detection
Detection is a control tool applied to detect the cause of failure, as can be seen in Table 3.

**Table 3. Detection rating criteria.**

| Rating | Criteria                                         | Frequency of detection |
|--------|--------------------------------------------------|------------------------|
| 1      | Preventive methods are very effective            | 0.01 per 1000 item     |
| 2      | Possible causes are very low                     | 0.1 per 1000 item      |
| 3      | Possible causes are moderate                     | 0.5 per 1000 item      |
| 4      |                                                  | 1 per 1000 item        |
| 5      | Possible causes are moderate                     | 2 per 1000 item        |
| 6      |                                                  | 5 per 1000 item        |
| 7      | The probable cause is still high.                | 10 per 1000 item       |
| 8      |                                                  | 20 per 1000 item       |
| 9      | The probable cause is very high                  | 50 per 1000 item       |
| 10     |                                                  | 100 per 1000 item      |

2.2.4. Expected cost
Expected cost is an assessment of cost aspects. To identify the cause of failure, it is necessary to integrate conventional aspects of popular FMEA procedures with economic considerations [3].

2.3. AHP
The AHP method provides a framework for addressing situations involving multiple intuitive, qualitative, and quantitative criteria on the MAFMA. Therefore, after obtaining the highest rating of the criteria, both corrective and evaluation actions can be taken.

2.4. Data analysis
2.4.1. Weighting of scoring criteria (Level 1)
Score of criteria used were based on the questionnaires filled by the head of the production department. The collected data were analysed using AHP with the following steps:

- Create a hierarchy. Hierarchy is used to explain the problem in a smaller section. Hierarchy consists of several levels, the top level is the main goal, the second level is the criteria, and the last level is the risk to be assessed based on the impact occurred. Factors and alternatives to the cause of failure are arranged in a hierarchical structure.
- Develop an opinion matrix from respondents. The score of criteria, sub-criteria, and alternatives as a critical function is essential for the corresponding element of the higher level. Both qualitative and quantitative criteria can be compared using informal ratings to gain score and priority. For qualitative criteria, AHP pairwise comparisons are used to determine simple weight and rank. So the analysis can concentrate on two factors at a time. The verbal assessment is translated into scores through the discrete use of a nine-point scale.
- Calculate the priority vector or vector eigen (VP). The normalization matrix is obtained by dividing the value of each matrix cell in pairs of criteria by the total of each column. The score of VP) is obtained by dividing the total value of normalization of each criterion by the total value of normalization of all criteria.

\[ VP_i = \frac{\sqrt[n]{\prod_{k=1}^{m} a_{ij}(k)}}{\sum_{i=1}^{n} \sqrt[m]{\prod_{k=1}^{n} a_{ij}(k)}} \]

Where:
- \( a_{ij} \) : the value of the comparison scale between criterion i and j
- \( VP_i \) : score ratio of each variable with total weight of variable
Determining the value of $\lambda_{\text{max}}$ used the formula below:

$$\lambda_{\text{max}} = \sum (\text{number of columns to } j \times V_P i \text{ for } i = j)$$

Where: $\lambda$ is the number of times the weighted matrix per criterion with $V_P$ per criterion

Determining the consistency index (CI) is carried out by the formula below:

$$\text{CI} = \frac{\lambda_{\text{max}} - n}{n-1}$$

Where: $n$ is the number of criteria

- Calculate the value of consistency ratio (CR). The consistency ratio is the benchmark consistency of the paired comparisons. The consistency ratio is the results of the consistency index (CI) and random index (RI), by the following formula:

$$\text{CR} = \frac{\text{CI}}{\text{RI}}$$

Testing is done by finding the value of consistency ratio for the respondent. If the consistency ratio is less than or equal to 0.1 means the assessment is valid.

- Determine the alternative weights of each pairwise comparison

2.4.2. Assessment the alternative (Level 2)
Assessment the alternative at level 2 are used to determine the most potential impact on the production process from the hierarchy level alternatives based on the questionnaire filled by the head of the production department to determine the level of the industry’s capability in addressing the cause of failure with a pairwise comparison method.

3. Results and Discussion
PKIS Sekar Tanjung is a primary cooperative that holds milk products from six cooperatives in East Java. This company produces various types of milk products such as UHT milk, pasteurized milk and fresh milk.

3.1. Potential failure identification strategy in production process
The proposed identification process fits the failure identification criteria. The criteria are used based on MAFMA to determine the most potential failure in the production process. MAFMA is based on the AHP technique, which considered the four different factors of severity, occurrence, detection, and expected cost as decision attributes, possible causes of failure as decision alternatives, and the selection of failure cause as the goal decision. The goal, attributes and alternatives formed a three-level hierarchy, in which the pairwise comparison matrix was used to estimate the attribute weights and the local priorities of the failure cause with respect to the expected cost attribute [4].

Hierarchical structure consists of 3 levels, the main goal is the most potential failure occurs in the production process. Then the criterion level (Level 1) is based on the criteria on MAFMA (i.e. severity, occurrence, detection, and expected cost). Alternative level (Level 2) as an initial preventive measure of the various types of failures that occur.

The hierarchy of failure of the milk production process in PKIS Sekar Tanjung can be seen in Figure 1. The figure shows that at level 1, the severity indicated as the serious effects of failure mode has the highest impact with a weight of 0.41. This was followed by the detection indicated as a control tool used to detect the cause of failure with a value of 0.29. Occurrence indicated as the value of the frequency a problem occurs, was in the third rank with a value of 0.22. While, the expected cost indicated as the
evaluation of the cost aspect ranks fourth with a value of 0.07. This result confirmed that the severity contributed as the most potential failure cause in the milk production process in PKIS Sekar Tanjung, with the value of 41%. Several measures can be done PKIS Sekar Tanjung to overcome their problem of the non-standardised milk production process. The alternative strategy is therefore needed for the company to achieve and follow the standard process for producing UHT milk. Also, based on the consideration and the assessment of potential causes of failure from the head of the production department, the cost factor was selected as the main problem faced by the company compared to the severity. This is in accordance with Hetharia [5] who stated that severity factor is not a big problem in the company.

Figure 1. The hierarchy structure of potential failure causes in the production process

The results and criteria from level 1 were used to determine the strategy to minimise or remove the failure. The study found that there were four potential causes of failure in the UHT milk production process, include the mixing temperature is not standard (i.e. less than 70 °C), the fresh milk temperature is not standard, the steam barrier on the aseptic tank is not standard, and the sterilisation temperature is less than the standard of 140 °C.

As shown in Figure 1, the highest weighting criterion (Level 2) was the mixing process temperature of less than 70 °C with a value of 0.47. In the second rank was the potential failure cause of the aseptic tank temperature less than 110 °C, with a weight value of 0.28. The temperature of fresh milk of less than 10 °C contributed as the third failure cause, with the weight value of 0.18. In the last place was the sterilization temperature of less than 140 °C with a weight of 0.07. These results indicated that the most potential failure cause in the milk production process in PKIS Sekar Tanjung was the inconsistency of the mixing process temperature. In this company, the mixing temperature was higher than 70 °C, which is not meeting the standard for UHT milk processing of ≤ 70 °C. Mixing is a stage where the formulated additive ingredients were mixed together with the fresh milk to form a milk emulsion with the appropriate and standardised composition. The mixing process is a critical in the production process [6].

The process of mixing in PKIS Sekar Tanjung begins by heating water at a temperature of 75 °C. This temperature determines the solubility rate of the dairy product. Before the water reaches the optimum temperature the required additive ingredients such as sugar, salt, dyes and stabilizers cannot be mixed. If the additive ingredients were added below the optimal temperature, this will affect the milk solubility level and will eventually affect the next process. In this company, the solubility level was tested regularly in the QC physics-chemical laboratory. Then, after the desired (i.e. standard) temperature is reached, a pre-determined volume of pasteurised milk is added.

3.2. CR results
The CR is the value used to determine the level of consistency of respondents in assessing each potential identification criteria of failure in the milk production process at PKIS Sekar Tanjung. The hierarchy CR value should be ≤ 10%, otherwise the quality of information should be improved by improving pairwise comparison questions [6]. The results showed that the CR at each level was 0.01 (Level 1) and 0.07 (Level 2). It can be seen that the CR values at each level were smaller than 0.1, indicating that the calculation was consistent and did not require repetition.

4. Conclusion
This study demonstrated that MAFMA combined with AHP approach can be used to determine the potential cause of failure in the UHT milk production process. Despite the severity criteria has the highest weight value of 0.41, based on the expert evaluation, the expected cost criteria is considered as potential failure cause in this company. Further investigation revealed that the high temperature (i.e. 75 °C) in the mixing process was selected as the most potential cause in the milk production process failure. Therefore, the company need to apply several measures on keeping the mixing temperature within the standard value of ≤ 70 °C, to minimise and remove the mixing process failure.

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