The Integration of MAFMA and AHP Methods for Analysis and Risk Mitigation of Pasteurized Milk Production

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Abstract. Risk and uncertainty management is an important task in industry. Risks in raw materials such as livestock products may occur from the feed. The production process is also exposed to risks, which may be caused by controllable variables. In final products, uncontrollable actions may also pose risks. This research aimed to figure out the risks and their causes in the production process of milk and to discover applicable mitigation strategies. The methods used in this study were the Multi-Attribute Failure Mode Analysis (MAFMA) method to find the causes and Analytic Hierarchy Process (AHP) to discover mitigation strategies. The results were in the form of risks in the production process caused by: 1) raw materials, 2) the production process, 3) human resources, and 4) machinery and equipment. The highest risk in the production process is posed by undetected damage to machinery and contamination during the production process. However, both are rooted in human error: poorly trained workers, omission of checking or testing, and poor supervision of the process. Mitigation strategies, i.e. standardization and supervision of the raw materials, production process, and final product, were implemented to reduce the potential risks. In the implementation of these strategies, worker participation, either as controller or as supervisor, is very important.

Keywords: *AHP; MAFMA; production process; pasteurized milk; risk analysis; risk mitigation.*

1 Introduction

Risk management is an important task in industry. Uncertainty in agricultural product processing industries may pose risks. Many researches have studied risks related to different aspects, one of which is the production process [1,2]. Risk management is done by calculating the significance level of possible dangers and giving information to be used in risk mitigation to minimize their impact [3]. Risk management warrants thorough attention. Each process is interrelated, for instance: there is uncertainty in market demand and in the

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production process when designing and managing material handling systems [4].

Several studies related to risk analysis and risk mitigation in the production process have been conducted. Generally, risk factors in the production process can be categorized into 4 main factors, i.e. 1) raw materials, 2) the production process, 3) human resources, and 4) machinery/equipment [5,6]. The risks related to raw livestock materials are commonly related to livestock health, physical contamination, chemical contamination, microbiological contamination and antibiotics [7,8]. The risks related to the production process generally occur due to non-optimal performance as a result of inappropriate processing and cross contamination [8-10]. The risks related to human resources can come from a lack of work motivation, negligence, or health factors that decrease the performance or are even sources of contamination [7]. Machinery and equipment play an essential role in production continuity. The risks related to machinery and equipment come from poor performance of the machinery and equipment so it cannot attain the product quantity and quality targets. Damage to machinery can affect the sustainability of production. An analysis that can determine the extent of critical damage will greatly help formulate an effective and efficient maintenance management strategy [11]. The research reported in [12] revealed that the implementation of automatic maintenance that is scheduled well can significantly decrease the level of product damage. Therefore, adequate attention to the risk of machinery damage will provide high benefits for the continuity of the production process.

Risks in raw materials for livestock products may occur from the feed. According to [13], risks can be caused by dioxin contamination. Contamination occurs as a result of human activities in steel mills, cement plants, incinerators, which can lead to air pollution that is harmful to plants [14]. The risk exposure of dioxin in the air is not too influential. However, if it accumulates in feed, such as grass, it will accumulate in the fatty tissues of the animals that eat it [15] and finally will be excreted through milk [16]. This dioxin risk spreads to humans through skin absorption and airborne particles (10%) and through consumption of livestock products, such as meat, milk, milk products and fish (90%) [17]. Milk contains good and important nutrition. However, if it has been exposed to dioxin, it poses a health risk [18]. In addition, aflatoxin contamination of food may also pose a health risk [19]. Aflatoxin contamination in milk can be caused by feed that has been so contaminated by aflatoxin that preventive action needs to be taken to maintain food safety [20]. Aflatoxin produced by A. flavus and A. parasitcus fungi is categorized as a main cause of cancer [19]. Apart from antibiotics and aflatoxins contamination, other risks related to milk can come from contamination by heavy metals [21].

The production process also contains possibilities of contamination. Bacterial contamination of milk can originate from the cows, air, environment, workers, or equipment used. Risk factors causing contamination are temperature (during transportation, process, and storage), water quality, equipment, and workers. This is in line with the statement in [22] that temperatures in the pasteurization process highly affect the retention or loss of microorganisms in milk. In a research conducted by [23], another potential risk is posed by instability of the electrical energy supply during the process. This relates to the electricity used for machinery and equipment in the production process. Unstable electricity supply can cause damage to the product and also to the engine, eventually causing engine breakdown. Reference [24] revealed that another risk factor in the production process is labor, including laziness and lack of motivation.

Failure Mode and Effect Analysis (FMEA) is a deterministic technique used to determine causes of potential failure. Several studies have shown that FMEA is a fairly effective technique for assessing risk [25]. For example, it has been employed in studies on supply chain risk management [26], analysis and problems on small-scale textile business [27], waste risk measurement [28], and new product development [29]. Other studies on FMEA have been carried out related to the improvement of the quality and efficiency of manufacturing [30]. In order to improve the effectiveness and reliability of FMEA application, some researchers have developed it further by modifying or integrating it with other methods. [28] A modified FMEA method has been proposed by employing a waste priority number in waste risk assessment. Reference [31] integrated environmental dimensions in FMEA. Other studies, such as [32], implemented the integration of FMEA, Pareto diagram and HACCP in food chain risk analysis in potato chips manufacturing. Reference [33] integrated FMEA with expected cost, so that the effect of failure towards cost can be known.

These studies have shown that the development of the FMEA method can effectively help analyze various risks and potential failures in industrial systems. With regard to the requirements of the production process, it is also necessary to examine the economic aspect. Development of FMEA with the addition of an economic factor is known as Multi Attribute Failure Mode Analysis (MAFMA). MAFMA is an analysis technique developed from FMEA that is used to determine potential causes of failure. MAFMA integrates conventional aspects in FMEA with cost aspects, so that the impact of failure on cost can be found. In addition to severity, occurrence and detectability, expected cost is included in MAFMA. In other words, MAFMA is a method that integrates conventional FMEA by considering the economic aspect. Conventional FMEA only considers some failure attributes, without taking the economic aspect into account. The determination of potential failure in MAFMA is done by determining the weight of factors that can cause failure by using the Analytical Hierarchy Process (AHP) method. The factor with the largest weight is the one that can most easily cause failure. Fuzzy-AHP, which uses AHP by inserting fuzzy logic, can also be used instead [34].

Risk mitigation can be performed by setting rules in industry. The milk industry needs SOPs (standard operating procedures) that allow the division of responsibilities [34]. This study analyzed and assessed the risks that may occur in the milk production process. Furthermore, mitigation strategies were also formulated to reduce their impact.

2 Materials and Methods

This study was done in a number stages: the identification of risks in the production process, FRPN determination, determination of cause of failure criteria and sub-criteria, and formulation of mitigation strategies. The case study of the milk production process was done in XYZ. The data were obtained from interviews with management staff and workers in production and quality control areas. The present study employed two kinds of analysis, i.e. (1) Fuzzy-MAFMA to analyze risk causes in the production process and (2) AHP to determine the mitigation strategies that can be implemented to prevent risk. A flowchart of the study is shown in Figure 1.

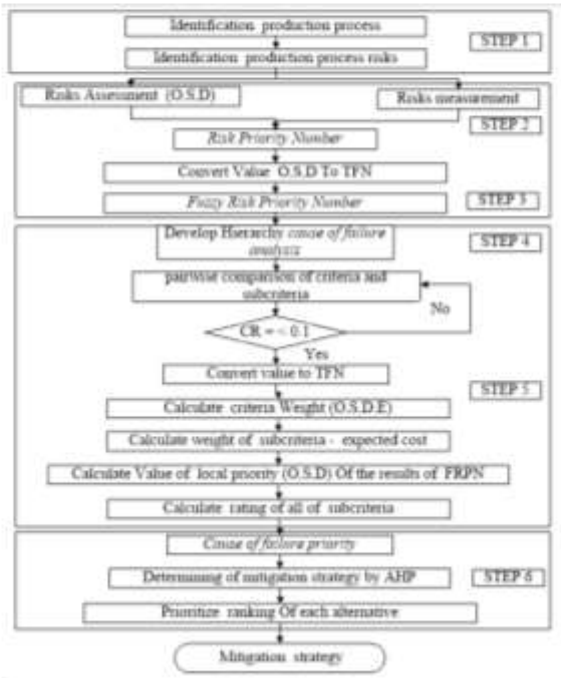

Figure 1 Flowchart of the study on risk management.

2.1 Identification of Production Process Risk

The stage of risk identification looks at the whole production process, from the input materials to the finished product. The characteristics of the raw materials for milk production, i.e. high protein, fat, and water, cause vulnerability to contamination of these raw materials, so good treatment in the raw material stage needs to be attended to. There are a number of possible risks in the production process (Table 1).

Table 1 Identification of risks in the production process.

Factors	Variable
Raw materials	Livestock health
	Bacteria contaminaton or disease
	Antibiotics
Production process	Ineffecient monitoring of CCP
	Contamination caused by unappropiate processing
	Cross contamination
Human resources	Lack of motivation
	Disease, illness
Machine and equipment	Machinary breakdown

2.2 Determination of Fuzzy Risk Priority Number (FRPN)

Determination of the fuzzy risk priority number (FRPN) starts with assessing the risk level identified based on rating three parameters, i.e. severity (S), occurrence (O), and detection (D). Determination of severity, occurrence and detection level are based on expert judgment. The judgment can be from a production manager, a quality control manager or a senior worker who have more than 5 years of relevant work experience. Judgment determination is based on the experience and history of the production process. The value of occurrence in this study was based on products processed by XYZ. The S, O, and D values were obtained from input variables in the range of 1-10 to determine the value of the risk priority number (RPN). The formula for RPN is in Eq. (1) as follows:

$$RPN = S \times O \times D \tag{1}$$

where S is severity, O is occurrence and D is detection. This RPN value is used for comparison with the FRPN result. The obtained S, O, and D scales are then converted into fuzzy numbers adapted from [32]. The concept used is the same as that of Fuzzy FMEA.

2.3 Determination of Cause of Failure Criteria and Sub-criteria

When the FRPN has been obtained, identification of risk causes is performed using Fuzzy-AHP with the following criteria: occurrence, severity, detectability, and expected cost. Expected cost is an additional criterion in MAFMA implementation and refers to the cost that is incurred or lost during the occurrence of a risk. Expected cost is obtained from a pairwise comparison matrix of causes of failure, in which the weight between criteria and sub-criteria of occurrence, severity, detectability, and expected cost related to the causes of failure are obtained.

2.4 Formulation of Mitigation Strategies

The result of cause of failure determination is the basis for the formulation of a risk mitigation strategy, which is done using AHP.

3 Results and Discussion

Based on the production process done by XYZ in milk production, the results were the risks, impacts and causes that occurred in the production process at XYZ. Below is the risk identification result obtained in XYZ's milk production process.

3.1 Raw Material Risk

Raw material risks can be categorized according to physical, chemical and biological risks. The risks occurring in the acceptance of milk supply from the farmer are: milk composition (physical chemistry) that does not meet the standards, microbiological contamination, aflatoxins and antibiotics contamination (biology), heavy metal contamination (physical), and carbonate falsification (chemistry). Risks may stop the production process because the materials do not conform to standards.

These risk causes can be categorized as follows: feed that is not quite right (cause A), unmaintained sanitary (Cause B), contamination of the tank (Cause C), and cleanliness of the environment and livestock health (Cause D).

3.2 Risks of Production Process

There are risks that can occur during the pasteurization, homogenization, precooling/cooling, and filling/sealing processes. In the pasteurization process the possible risks are temperatures that are too low or too high, a flow that is too fast, and crust formation or fouling. Too low or too high temperatures cause increased growth of microbes. A flow that is too fast will have the same impact.

If a crust forms, the product can be contaminated and its quality reduced. This can be due to damage to the heater (Cause F) or non-optimal CIP (Cause G).

The homogenization process entails the risk of thermal shock, which would cause damage to the milk by forming clumps. This is due to damage to the temperature gauges (cause H). The precooling/cooling process allows non-optimum temperatures, which would cause microbiological contamination related to the growth of pathogenic and non-pathogenic bacteria so that the quality decreases. This can happen because of incorrect ice control settings (Cause I). Filling and sealing allows the risk of damaged product caused by incorrect equipment settings (Cause J).

3.3 Risks of Human Resources

Possible risks in human resources come from worker performance. Risks that may occur in the production process that are caused by human resources can result from insufficient inspection of machinery and equipment and process control.

In the machinery and equipment inspection process, the risks that may occur are undetected damage causing bottlenecks in the production process. In risk process control activities, a possible risk is contamination that reduces the quality. This can be caused by poorly trained workers (Cause K) and workers' negligence in testing and monitoring (Cause L).

3.4 Risks of Machinery and Equipment

The possible risks from machinery and equipment breakdown concern delays in the production process. Delays decrease the production capacity. This can be caused by unscheduled maintenance (Cause M).

The risks occurring in XYZ's production process were affected by raw materials, the production process, human resources, machinery and equipment. In the raw material stage, risks identified were contamination and changing composition of the milk, either on purpose or not. In the production process stage, risks were the result of a lack of control of the process. In the human resources stage, risks occurred because the workers were insufficiently careful, resulting in damages. In the machinery and equipment stage, risks occurred because of unscheduled maintenance leading to machinery breakdown.

The existing risks in the production process were then measured based on the occurrence, severity, and detectability levels to determine the RPN value. The values of O, S, and D were then converted to fuzzy numbers to determine the FRPN value. The values of O, S, and D, RPN and FRPN are listed in Table 2.

Table 2 Measurement and assessment of risk in RPN.

Activity	Potential effect of failure	Potential Cause of failure	RPN	Rank	FRPN	Rank
Raw materials	Milk composition (physical chemistry) does not meet standards	Giving feed that is not quite right (Cause A)	60	6	2.028	4
	Risk of microbiological contamination (TPC exceeds the prescribed standards)	Unmaintained sanitary (Cause B)	45	7	1.267	10
	Heavy metal contamination	Contamination of the tank (Cause C)	30	10	1.352	8
	Aflatoxin and antibiotics contamination	Environment cleanliness and livestock health (cause D)	90	3	2.535	3
	Carbonate falsification	Cheating breeder (Cause E)	28	11	1.262	9
Process	Too low or too high temperatures	Damages on heater (cause F)	36	9	1.014	11
	Crust on fouling	Non-optimum *CIP* (cause G)	60	5	1.690	6
	Thermal shock	Damaged temperature gauges (cause H)	12	13	0.541	13
	Unreached optimum temperature	Incorrect ice control setting (cause I)	72	4	2.028	5
	Damaged product	Pressure mismatch (cause J)	42	8	1.521	7
Human resources	Undetected damages in machinery	Poorly trained workers (cause K)	320	1	10.815	1
	Contamination during process	Workers did not inspect and test (cause L)	216	2	6.083	2
Machinery	Bottlenecks in the production process	Unscheduled maintenance (cause M)	24	12	0.901	12

It can be seen in Table 2 that there are ranking differences in the assessment using RPN and FRPN. These differences occur because RPN assessment was done by multiplying the O, S, and D levels, while FRPN calculation is based on expert judgment, increasing the weight of the O, S, and D values. The table above shows that the highest risks in the production process were undetected damage to machinery and contamination during the production process, which are both rooted in human error.

Based on the risks that were observed, further analysis was done by implementing the Fuzzy MAFMA concept, i.e. adding expected cost as a criterion. Adding expected cost was done by creating a pairwise comparison matrix using the following criteria: occurrence, severity, detectability, and expected cost. The value of the consistency ratio (CR) for pairwise comparison between criteria was 0.058 < 0.1. Weighting was done to get the weight of each criterion: severity = 0.346, occurrence = 0.085, detectability = 0.174, and expected cost = 0.395.

In the assessment that used FRPN, the priority value for expected cost was not generated so that determining the priority of cause of failure related to expected cost and conversion to fuzzy numbers to determine the priority value needed to be performed.

The weighting values of each sub-criterion for the criteria severity, occurrence, detectability, and expected cost can be seen in Table 3. The local priority value of severity, occurrence, and detectability was obtained from the weighting values of severity, occurrence, and detectability in FRPN and the expected cost value was obtained from the priority in the pairwise comparison matrix that had been converted o fuzzy numbers.

Table 3 Weight values for sub-criteria of S, O, D and expected cost.

Criteria	Criteria Weight	Cause of failure												
		A	B	C	D	E	F	G	H	I	J	K	L	M
Occurrence	0.250	0.032	0.016	0.009	0.016	0.009	0.016	0.016	0.009	0.016	0.048	0.032	0.016	0.016
Severity	0.308	0.026	0.022	0.026	0.022	0.017	0.017	0.017	0.017	0.026	0.013	0.035	0.035	0.035
Detectability	0.410	0.014	0.021	0.035	0.042	0.049	0.021	0.035	0.021	0.028	0.014	0.056	0.063	0.009
Expected cost	0.032	0.003	0.000	0.016	0.012	0.027	0.014	0.007	0.016	0.017	0.010	0.021	0.028	0.009
Global Value		0.076	0.059	0.086	0.092	0.102	0.068	0.076	0.063	0.087	0.085	0.144	0.142	0.069
Priority		8	13	6	4	3	11	9	12	5	7	1	2	10

Global assessment of each cause of failure sub-criterion was done to determine priority of risk causes. The priority of the risk causes can be seen in Table 3. It is known that the most crucial risk cause in the production processes is human resources: poorly trained workers and omission of testing and monitoring during the production process.

3.5 Mitigation Strategies

Based on the results of determining cause of failure in the production process, strategies were determined to reduce risk. A number of mitigation strategies can be formulated by using the following 4 criteria: risks related to raw materials, risks related to the production process, risks related to human resources, and risks related to machinery and equipment. To determine the strategy, the AHP method was used. A number of alternative strategies can be used, such as:

standardization and supervision (A1), handling and storage of materials (A2), calibration of machinery and process control (A3), sanitation and CIP (A4), implementation of SOP, SSOP and QC (A5), and maintenance scheduling (A6).

Based on the results of AHP calculation on the main criteria, it was found that the 4 aspects (risks related to raw materials, risks related to the production process, risks related to human resources, and risks related to machinery and equipment) were consistent with CR < 10% (0.07). The next step was calculating the sub-criteria for the risks related to raw materials, of which he result was a CR value of 0.089. In the calculation of sub-criteria for the risks related to the production process, the result was a CR value of 0.058. For the sub-criteria for the risks related to human resources, the obtained CR value was 0.41 and for those of the risks related to machinery and equipment the CR value was 0.07. The weights of the alternative strategies can be seen in Figure 2.

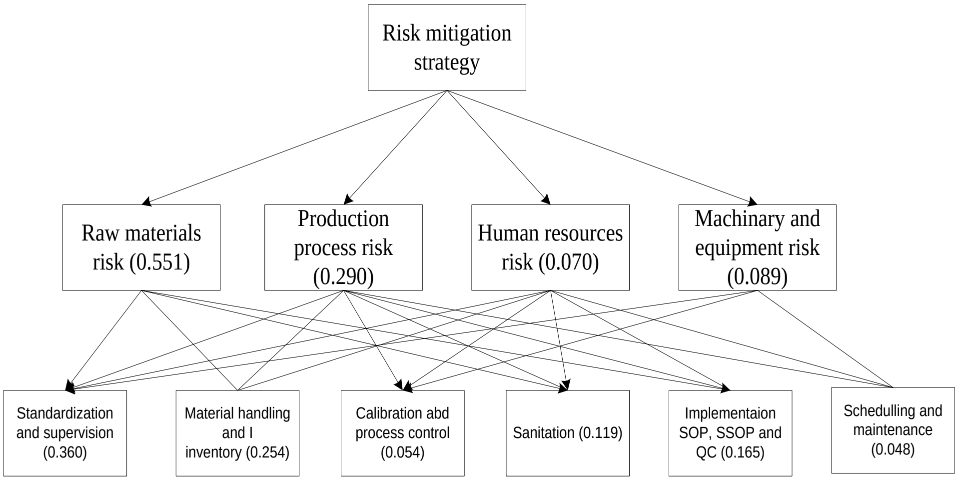

Figure 2 Hierarchical structure of risk management.

Figure 2 shows that the first priority is standardization and supervision. This is in line with the cost of failure obtained from the Fuzzy-MAFMA calculation, which is poorly trained workers and omission of checking/monitoring and lack of supervision. The standardization and supervision strategy was also implemented in the other stages: raw materials, the production process and end product. What needed to be ensured in this implementation was worker participation, either as controller or supervisor. Another applicable strategy was handling and storage of raw materials. Raw materials that are vulnerable to microbes need special treatment. The condition of the raw materials highly affects the end product.

4 Conclusion

The risks observed in the milk production process at XYZ were undetected damage to machinery and contamination during the production process caused by human resources. Based on the existing risks, a further analysis was done by using the MAFMA concept, i.e. by adding the expected cost criterion. The analysis revealed that the most crucial risk cause in the production process was human resources in the form of poorly trained workers and omission of checking/monitoring and lack of supervision during the production process. To reduce risks, mitigation strategies were determined. The outcome was standardization and supervision of raw materials, production process and end product. What needs to be attended to in the implementation was worker participation, either as controller or as supervisor. Another applicable mitigation strategy is handling and storage of raw materials. Raw materials that are vulnerable to microbes need special treatment. The condition of raw materials highly affects the end product.

References

[1] Wang, H., Khan, F., Ahmed, S. & Imtiaz, S., *Dynamic Quantitative Operational Risk Assessment of Chemical Processes*, Chemical Engineering Science, **142**, pp. 62-78, 2016.

[2] Serra, P., Colauzzi, M. & Amaducci, S., *Biomass Sorghum Production Risk Assessment Analysis: A Case Study on Electricity Production in the Po Valley*, Biomass and Bioenergy, **96**, pp. 75-86. 2017.

[3] Berg, H., *Risk Management: Procedures, Methods and Experiences*, RT&A, **2**(17), 1, pp. 79-95, 2010.

[4] Mital, P., Goetschalckx, M. & Huang, E., *Robust Material Handling System Design with Standard Deviation, Variance and Downside Risk as Risk Measures*, Int. J. Production Economics, **170**, pp. 815-824, 2015.

[5] Sausa, C.P. de, *The Impact of Food Manufacturing Practices on Food Borne Diseases*, Brazilian Archives of Biology and Technology, **51**(4), pp. 815-823, 2008.

[6] Melhem, I.B., *Impact of the Human Resources on the Risk Management and the Company Performance*, International Journal of Economics & Management Sciences, **5**(2), pp. 1-5. 2016.

[7] Schaper, C. Lassen, B. & Theuvsen, L., *Risk Management in Milk Production: A Study in Five European Countries*, 113th EAAE Seminar “A Resilient European Food Industry and Food Chain in a Challenging World”, Chania, Crete, Greece, date as in: September 3-6, 2009.

[8] Oliveira, L.P. de, Soares e Barros L.S., Silva, V.C. & Cirqueira, M.G., *Microbiological Quality and Detection of Antibiotic Residue in Raw and*

Pasteurized Milk Consumed in the Recôncavo Area of the State of Bahia, Brazil, J Food Process Technol, **3**(137), pp. 1-5, 2012.

[9] Panfiloiu, M., Cara, M.C., Perju, D.M. & Dumitrel, G.A., *Quality Control of Pastry Products Using the HACCP Method,* Chemical Bulletin of Politehnica, **56**(70), pp. 47-52, 2011.

[10] Kurt, L. & Ozilgen, S., *Failure Mode and Effect Analysis for Dairy Product Manufacturing: Practical Safety Improvement Action Plan with Cases from Turkey,* Safety Science, **55**, pp. 195-206, 2013.

[11] Ozkok, M., *The Effects of Machine Breakdown on Hull Structure Production Process,* Scientia Iranica, **20**(3), pp. 900-908.

[12] Azizi, A., *Evaluation Improvement of Production Productivity Performance using Statistical Process Control, Overall Equipment Efficiency, and Autonomous Maintenance*, Procedia Manufacturing, **2**, pp. 186-190.

[13] National Academy of Sciences/National Research Council (NAS/NRC). *Dioxins and Dioxinlike Compounds in The Food Supply: Strategies to Decrease Exposure*, Washington, DC, United States: National Academy Press, 2003.

[14] Welsch-Pausch, K. & McLachlan, M.S., *Fate of Airborne Polychlorinated Dibenzo-P-Dioxins and Dibenzofurans in an Agricultural Ecosystem*, Environ Pollut, **02**(1), 129-37, 1998.

[15] Schulz, A.J, Wiesmuller, T., Appuhn, H., Stehr, D., Severin, K. & Landmann, D., *Dioxin Concentration in Milk and Tissues of Cows and Sheep Related to Feed and Soil Contamination*, J. Anim. Physiol. Anim. Nutr., **89**, pp. 72-8, 2005.

[16] Mamontova, E.A., Tarasova, E.N., Mamontov, A.A., Kuzmin, M.I., McLachlan, M.S. & Khomutova, M.I., *The Influence of Soil Contamination on The Concentrations of Pcbs in Milk in Siberia*, Chemosphere, **67**, pp. 71-78, 2007.

[17] Fürst, P., Beck, H. & Theelen, R.M.C., *Assessment of Human Intake of Pcdds and Pcdfs from Different Environmental Sources*, Toxicol Subst J. **12**, pp. 133-150, 1992.

[18] Williams, J.H., Phillips, T.D., Jolly, P.E., Stiles, J.K., Jolly, C.M. & Aggarwal, D., *Human Aflatoxicosis in Developing Countries: A Review of Toxicology, Exposure, Potential Health Consequences and Interventions*, The American J. Clinical Nutrition, **80**, pp. 1106-1122, 2004.

[19] Nguyen-The, C., *Biological Hazards in Processed Fruits and Vegetables Risk Factors and Impact of Processing Techniques,* LWT – Food Science and Technology, **49**, pp. 172-177, 2012.

[20] Claeys, W. L., Cardoen, S., Daube, G., Block, J. D., Dewettinck, K., Dierick, K., Zutter, L. D., Huyghebaert, A., Imberechts, H., Thiange, P.,

Vandenplas, Y. & Herman, L., *Raw or Heated Cow Milk Consumption: Review of Risks and Benefits*, Food Control, **31**, pp. 251-262, 2013.

[21] Zhang, Q., Cremer, J.L., Grossmnn, I.E. & Sundaramoorthy, A., *Risk-Based Integrated Production Scheduling and Electricity Procurement for Continuous Power-Intensive Processes*, Computers and Chemical Engineering. **86**, pp. 90-105, 2016.

[22] Schaper, C., Lassen, B. & Theuvsen, L., *Risk Management in Milk Production: A Study in Five European Countries*, 113th EAAE Seminar "A Resilient European Food Industry and Food Chain in a Challenging World", Chania, Crete, Greece, date as in: September 3-6, 2009.

[23] Tixier, J., Dusserre, G., Salvi, O. & Gaston, D., *Review of 62 Risk Analysis Methodologies of Industrial Plants*, Journal of Loss Prevention in the Process Industries **15**, pp. 291-303. 2002.

[24] Curkovic, S., Scannell, T. & Wagner B., *Using FMEA for Supply Chain Risk Management*, Modern Management Science & Engineering, **1**(2), pp.251-265, 2013.

[25] Silva de Santis, S.H. da, Marcicano, J.P.P, Dedini, F.G., Sanches, R.A. & de Held, M.S.B., *Use of Quality Tools for Problem Analysis (FMEA and Ishikawa Diagram) in a Small Textile Business*, J. Textile Sci. Eng., **6**(258), pp. 1-6, 2016.

[26] Sutrisno, A., Gunawan, I. & Tangkuman, S., *Modified Failure Mode and Effect Analysis (FMEA) Model for Accessing the Risk of Maintenance Waste*, Procedia Manufacturing, **4**, pp. 23 -29, 2015.

[27] Segismundo, A. & Miguel, P.A.C., *Failure Mode and Effects Analysis (FMEA) in the Context of Risk Management in New Product Development: A Case Study in an Automotive Company*, International Journal of Quality & Reliability Management, **25**(9), pp. 899-912, 2008.

[28] Parsana, T.S. & Patel, M.T., *A Case Study: A Process FMEA Tool to Enhance Quality and Efficiency of Manufacturing Industry*, Bonfring International Journal of Industrial Engineering and Management Science, **4**(3), pp. 145-152, 2014.

[29] Arvanitoyannis, I.S. & Varzakas, T.H., *Application of Failure Mode and Effect Analysis (FMEA), Cause and Effect Analysis and Pareto Diagram in Conjunction with HACCP to A Potato Chips Manufacturing Plant*, International Journal of Food Science & Technology, **42**(12), pp. 1424-1442, 2007.

[30] Braglia, M., *MAFMA: Multi-Attribute Failure Mode Analysis*, International Journal of Quality and Reliability Management, **17**(9), pp. 1017-1033, 2000.

[31] Baloch, A.U. & Mohammadian, H., *Fuzzy Failure Modes and Effects Analysis by Using Fuzzy Vikor and Data Envelopment Analysis-Based Fuzzy AHP*, International Journal of Advanced and Applied Sciences, **3**(8), pp. 23-30, 2016.

[32] Santoso, I., Sa'adah, M. & Wijana, S., *QFD and Fuzzy AHP for Formulating Product Concept of Probiotic Beverages for Diabetic,* Telkomnika, **15**(1), pp. 391-398, 2017.

[33] Wang, Y.M., Chin, K.S., Poon, G.K.K. & Yang, J.B., *Risk Evaluation in Failure Mode and Effects Analysis Using Fuzzy Weighted Geometric Mean*, Expert Systems with Applications, **36**, pp. 1195-1207, 2009.

[34] Ghosh, A., Sindhu, S., Panghal, A. & Bhayana, S., *Modelling the Enablers for Risk Management in Milk Processing Industry*, International Journal of Management and International Business Studies, **4**(1), pp. 9-16, 2014.