A Fuzzy Inference Systems Approach for Risk Evaluation of Dairy Products Manufacturing Systems

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Abstract: - The objective of this Paper is to analyse the risk level of dairy products manufacturing systems at different categories (Physical, Biological, Chemical, and Environmental) of the operation, and the final risk evaluation of the manufacturing system. Five Mamdani Fuzzy Inference System (FIS) models are proposed to solve this problem. Mamdani FIS has been proven to be a great tool to assess risk at different levels. The world is evolving and growing every day and the need for dairy products are becoming more evident and essential to human. Furthermore, the higher consumption rate of dairy products by people of different ages has attracted investors because of its economic values. Considering this growth and its economic benefits, the understanding of the risk involved in dairy products manufacturing processes is highly required. The model provides a deep insight on how to mitigate the risks involved in dairy products manufacturing systems. Models were experimented using experimental data to validate the model.

Key-Words: - Fuzzy, Mamdani Fuzzy Inference System, Linguistic terms, Risk Evaluation, Dairy Products, Failure Mode and Effects Analysis.

1 Introduction

The effective and healthy contributions of the dairy products to the modern-day world are increasing, so the risk associated with it. Dairy products are consumed globally by both the young individuals and adults (cut across all generations). This high rate of consumption (over 6 billion people) is influenced by powerful market demand for dairy products due to its benefits.

The effect of high rate of consumption also contributes to the 4% annual increase of dairy (Milk) production across the globe. Food and Agriculture Organization of United Nations (FAO) statistics show a steady increase in the dairy products consumption for the past decades and that continues with the world total dairy production sitting at 805 million tons in the year 2015. Following this high consumption, investors venture into the business. Thus, it becomes necessary to understand the production processes as well as the associated risks.

The manufacturing processes of dairy production entail a cascaded industrial process which includes extraction, processing, sanitation, storage etcetera. Thus, the need to produce a highly hygienic final product is required since dairy products are perishable. In [1] it is explained that contaminated and infected dairy products had and will continue to cause negative impacts on consumers if the manufacturing processes failures are not properly studied and accessed.

Dairy farming is the main integral of the dairy products manufacturing. Without raw milk, it would be a challenge to manufacture or produce dairy products. The more emphasizes given to the raw milk sourcing, treatment, and handling, the safer and lessen the negative impact on the consumers. [1] stated that the samples of most raw milk from the dairy farm used for dairy products manufacturing in Turkey failed the requirement test which gave birth to dairy products manufacturer owning dairy farm themselves to minimise these unwelcoming results.

In 2007, World Health Organization (WHO) reported that little less than 2 million people lost their lives in 2005 because of diarrheal diseases caused by contaminated foods with dairy products inclusive. These hazardous contaminated foods are causing foodborne diseases globally (both in emerging market and economically strong markets). Around 8.3% of the universe biological related foodborne disease outbreaks are directly caused by dairy products [2].

Therefore, the effective evaluation of the risk in dairy products manufacturing will reduce production of contaminated and infected dairy. The traditional Failure Modes and Effects Analysis (FMEA) Risk Priority Number (RPN) does not promise success in risk evaluation due to its numerous shortcomings like how different arrangement give the same output, the lack of expert's opinion in identifying the failure mode and how a zero value in the criteria indicate no failure or risk.

The need to present a better approach to analyse the risk in dairy products manufacturing is vital. We proposed a five (5) Mamdani FISs using the expert's opinion, quantitative, linguistic terms to rank the FMEA RPN criteria (Occurrence, Severity, and Detectability). This research will undermine failures and risk associated with the dairy products manufacturing to greatly minimize the risks across all categories (Physical, Biological, Chemical, and Environmental), which in turn reduce risks associated with the whole dairy products manufacturing systems.

The remaining sections of the paper are arranged as follows. Section 2 elaborates on the proposed methodology; whereas, section 3 presents the experimental results analysis. In section 4, the conclusion is presented.

2 Proposed Methodology

The proposed model is implemented by two-stage five-FIS systems. The first stage (consist of four FISs) analyse the dairy products risks using the FMEA criteria, the inputs (Occurrence, Severity, and Detectability) with expert's knowledge and opinion. Fig. 1 shows the schematic diagram of the proposed model. The output of each one of the Physical, Chemical, Biological and Environmental Failure from the first stage will be fed as input to the final stage FIS, where the final manufacturing system ranking is done. The parameters are defined and ranked based on FMEA methodology to give equal weight to all the criteria.

In the planning of a manufacturing system, it is of the best interest of operation, maintenance, and plant managers to identify potential failures and develop a Standard Operating Procedure (SOPs) before diving into any task, so it is important to analyse risk by categories since their consequences differ.

The first step of this model required the opinions and inputs from the experts in identifying the failure modes, assign the linguistic terms corresponding to each case of the failure mode in the system based on their occurrences, severities, and degree of detection if the failure occurs. The membership functions (MFs) are assigned appropriately based on the linguistic terms defined by the experts, these linguistic terms were used to design the MFs of the proposed models.

The evaluation criteria between 0 and 100 are used in the proposed model, follows the sequence of the traditional FMEA (O, S, and D) in the ranking of the linguistic term and the MFs evaluation of the failures. The experts were an important component of this work as shown in figure 1, however, their knowledge and opinions are limited to identifying the failure modes for each category and provided information on the occurrence, severity, and detectability of those identified failure modes.

The experts were formed based on their in-depth knowledge of the manufacturing system and a total of six (6) committee is appropriate for a medium problem. The committee (experts) includes the Operation manager, Maintenance manager, two (2) Senior Operators, and two (2) Line leaders (Supervisors).

Fig. 2 shows the Fuzzy Inference System interface of the proposed models. As mentioned earlier, there are five FIS models proposed to have a comprehensive evaluation, taking account of what matters in the dairy products manufacturing. Although fig. 2 shows the final FIS with the Physical, Biological, Chemical, and Environmental risk the inputs to the final FIS to rank dairy products manufacturing system.

Trapezoidal MF min and max (equation 1) was adopted for all the models as a result of continuity and due to it simply formulated and computational easy [3]. The linguistic terms that were used are Very_High, High, Medium, Small, and Very_Small to give the fuzzy rules of five to the power of three (inputs; O, S, and D) each and the final FIS has fuzzy rules of 625 and a total of 1125 rules.

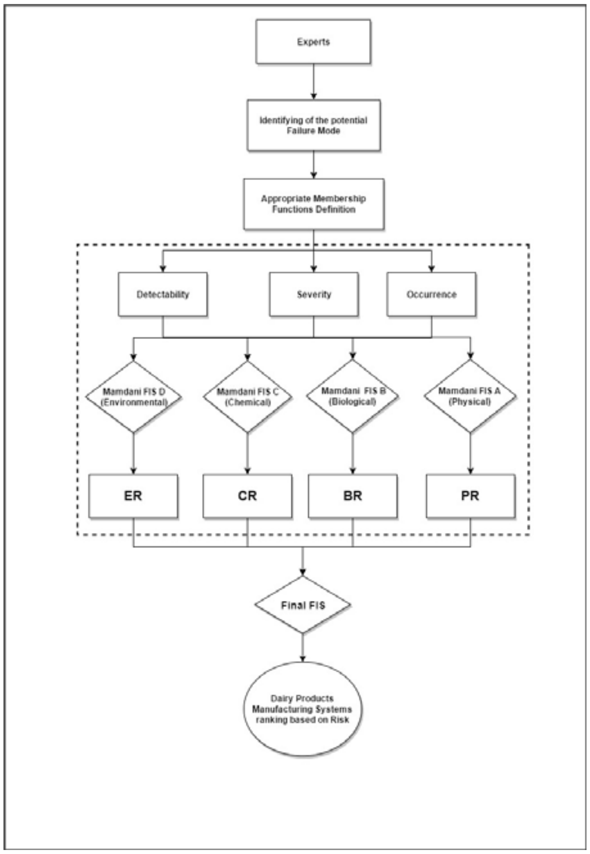

Fig. 1: Proposed Mamdani Fuzzy Inference Systems for Risk Analysis in Dairy Products Manufacturing Systems

Each model of the first four FIS (Physical (P), Biological (B), Chemical (C), and Environmental (E) models) have three inputs (O, S, and D) and the final FIS has four inputs (P, B, C, and E) with one final output to form a cascaded system.

The inputs are fuzzified and go through the Fuzzy engine before being defuzzified to give a crisp output. The defuzzification method was selected for this evaluation is the Centroid of Area because of the even distribution of the expected probability values [3].

Trapezoidal MF (Fig. 3) can be briefly defined by *min* and *max* as thus;

$$trap(x;\alpha,\beta,\gamma,\delta) = \max\left(min\left(\frac{x-\alpha}{\beta-\alpha},1,\frac{\delta-x}{\delta-\gamma}\right),0\right) \quad (1)$$

The equation is valid when $\alpha < \beta \le \gamma < \delta$ is true.

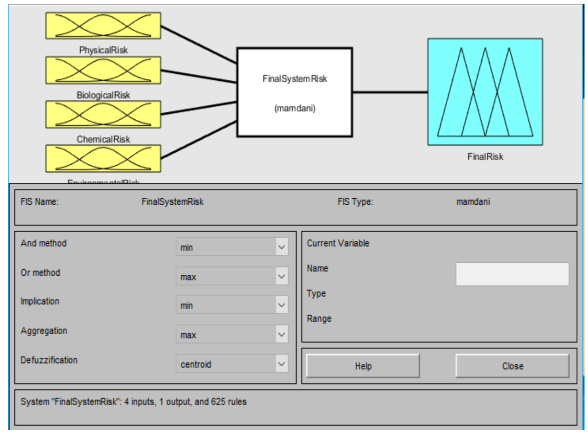

Fig. 2: Risk Analysis in Dairy Products Manufacturing Systems Mamdani FIS interface

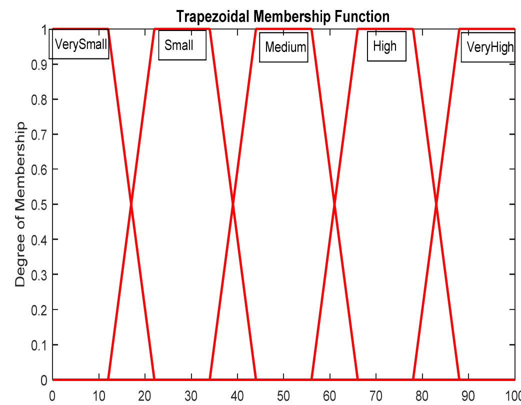

Fig. 3: Trapezoidal Membership Function

Fuzzy rules are generally expressed as "IF-THEN" rule and it could be extended to "IF-AND/OR-THEN" depending on the expert knowledge of the system. "IF-AND-THEN" ('AND' the fuzzy operator) was used to develop the proposed model rules for efficiency and accuracy.

The rule holds the learning as a course of action of guideline for the entire system. Fuzzy rules are developed through human knowledge and expert of the system. It is fair to say the more understanding of the system an expert has, the better the rules developed to solve issues related to that system, and this makes the proposed models suitable and reliable in analysing and evaluating the risk level of the dairy products manufacturing.

Even though [4, 5] have argued the bias nature of giving criteria weight to failures by experts, which sometimes may not truly represent the true state or extent of the issues or failures, the proposed model will help reduce the effect of double standard (biases) in allocating weight to failures due to its novel approach of running each failure through different stages before prioritizing it.

This mechanism allows input of different sets which the outputs are based on proposed model methodology. It analyses dairy products manufacturing systems for benchmarking, which reduces the cost of operation because of less second guesses in the operation, and the proposed models result is general and applicable to any dairy products manufacturing systems if it is applied rightly with few tweaks to the rules.

2.1 Evaluation Criteria for the inputs

The Table 1 below indicates the variables for a linguistic term which defines the term factors and as well as the range to classify the level of the risk. The Table also serves as a reference point to define the membership functions for the proposed model. The range between 0 and 100 are used for easy understanding of the output result so that each person can understand the results irrespective of their educational level or understanding.

Table 1: Evaluation Criteria for the inputs

Rank	Linguistic term
0 - 19	Very Small
20 - 39	Small
40 - 59	Medium
60 - 79	High
80 - 100	Very High

3 Results and Discussion

The finished products of dairy products pass through many processes to make it consumable for the consumer. Thus, making the consumers the paramount element to consider during the processes. Although many approaches have been explored to get to the root-cause of these failures associated with dairy products manufacturing that may affect the intent consumers (which cut a cross all generation due to dairy products nutrient benefits), this research analysed the risk of the failure modes in dairy products manufacturing to provide a well improved failure ranking, which will result in proper channelling of resources to the most important failures which will in turn reduce operation cost, rework time, extract information about risks to mitigate such failures in the future, and most importantly yield safe dairy products to the consumers.

The Occurrence, Severity, and Detectability were used as the fuzzy inputs to the first Four FISs (FIS A-D) to analyze the failure modes in each category (Physical, Biological, Chemical, and Environmental) and give outputs of each risk level. The outputs of the first stage were used as inputs to the second phase FIS to rank the dairy products manufacturing system.

All the results are derived based on the proposed Mamdani FIS model using MATLAB Mamdani Fuzzy Inference Systems toolbox. The experimental result of the proposed Mamdani FIS approach is compared with the traditional FMEA RPN. The ranking of the failure modes shown a well reliable result since the knowledge of the experts is incorporated in the fuzzy rules. It is important to the parameters are optimised to give an accurate and reliable fuzzy set.

Tables 2, 3, 4, and 5, show the experimental results versus FMEA RPN. The important point to notice is when one of the input criteria is zero (0) PFM13, the FMEA RPN methodology gives no risk as the output, but the proposed approach still recognised that there is a risk, though, the risk level is relatively small. This is one of the advantages of the proposed methodology over RPN.

Physical, Biological, Chemical, and Environmental Failure modes are represented with PFM, BFM, CFM, and EFM in Table 2, 3, 4, and 5.

From the results, the biological risk requires more attention because of the higher risk level compared to physical risk. Environmental risk also represents an area for improvement. The weighted average of the output results from the first stage was done twice before used as the inputs to the final stage to give a complete risk analysis of dairy products manufacturing. A comparison between two different organizations was experimented to rank the organization based on the risk level. Table 6 shows the result of the comparison using the proposed final FIS.

Table 2: Prop osed Physical risk output results versus FMEA RPN

Failure Modes	O	S	D	PR	FIS Ranking	FMEA RPN	RPN Ranking
PFM1	68	48	40	72	2	130.56	10
PFM2	60	55	45	59	8	148.5	5
PFM3	50	60	48	59	8	144	6
PFM4	82	40	70	68.8	4	229.6	2
PFM5	60	60	60	65.6	5	216	3
PFM6	30	75	40	50	13	90	13
PFM7	63	60	50	70.4	3	189	4
PFM8	55	60	20	59	8	66	14
PFM9	60	60	40	65.6	5	144	6
PFM10	50	50	55	50	13	137.5	8
PFM11	60	45	50	59	8	135	9
PFM12	50	80	70	74.7	1	280	1
PFM13	40	0	30	9.32	17	0	17
PFM14	48	30	28	28	16	40.32	16

The final FIS result is interpreted in an opposite way to the first four FISs. The lower value means a bad manufacturing system, while h igher output value indicates the best manufacturing system.

4 Conclusions

The objective of this work is t o develop an intelligent system capable of analyzing and evaluating risks i n dairy products manufacturing systems. The traditional risk assessment strategies manage deficient or ambiguous data due to inadequate knowledge of the system and no involvement of the expert s in the risk asses sment and lack of obvious inner failures system to furnish experts with an accurate and dep endable risk ranking.

The proposed intelligent system (Mamdani FIS) is capable of managing these shortcomings of traditional risk assessment strategies and incorporate the expert opinions into the mechanism to give reliable outcomes. To navigate through these hurdles, a r obust model of five Mamdani Fuzzy Inference System was proposed and developed. The models were tested with an experimental data to provide the model's verification and insight on how the model works. One of the advan tages of this approach is to enable industries to benchmark on a good working manufacturing system with lower risk level for the better ment and improvement of the systems with higher risk level. For consolidated consensus methodology for the probabilistic assessment of safe operation, benchmarking practices have been proven to be exception ally effective [6]. Not only will this model be a handful for benchmarking, it is also a reference poi nt to every dairy product manufacturer. The Mamdani Fuzzy MATLAB Toolbox was used to develop and analyse these proposed models.

Acknowledgment

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Table 3: Proposed Biological risk o utput results versus FMEA RPN.

Failure Mode	O	S	D	Biological Risk	FIS ranking	FMEA RPN	RPN ranking
BFM1	60	88	82	90.7	7	432.96	2
BFM2	40	90	70	90.7	7	252	9
BFM3	88	70	50	91.5	1	308	4
BFM4	40	80	44	66	16	140.8	18
BFM5	50	70	73	91.5	1	255.5	8
BFM6	75	70	62	90.7	7	325.5	3
BFM7	80	80	48	91.1	4	307.2	5
BFM8	55	60	40	59	20	132	19
BFM9	60	70	60	77.7	13	252	9
BFM10	60	60	40	65.6	17	144	17
BFM11	50	80	70	91.1	4	280	7
BFM12	40	60	65	68.8	15	156	15
BFM13	80	92	93	91.1	4	684.48	1
BFM14	68	70	60	90.7	7	285.6	6
BFM15	70	90	40	81.3	12	252	9
BFM16	70	70	30	91.5	1	147	16
BFM17	40	70	44	63	19	123.2	20
BFM18	60	72	50	77.7	13	216	13
BFM19	60	60	50	65.6	17	180	14
BFM20	70	80	40	84.5	11	224	12

Table 4: Proposed Chemical risk output result s versus FMEA RPN

Failure Mode	O	S	D	CR	FIS ranking	FMEA RPN	RPN ranking
CFM1	60	80	65	87	6	312	2
CFM2	50	78	76	91.5	3	296.4	3
CFM3	40	70	90	90.7	1	252	5
CFM4	40	50	15	41	11	30	11
CFM5	38	75	60	65.6	7	171	7
CFM6	25	95	50	91.5	8	118.75	9
CFM7	57	70	40	73.7	9	159.6	8
CFM8	30	65	40	46.7	9	78	10
CFM9	50	80	70	91.1	5	280	4
CFM10	40	75	80	81.4	2	240	6
CFM11	68	80	73	91.1	4	397.12	1

Table 5: Proposed Environmental risk output results versus FMEA RPN

Failure Mode	O	S	D	ER	FIS ranking	FMEA RPN	RPN ranking
EFM1	65	70	60	87	3	273	2
EFM2	40	85	10	64.4	6	34	7
EFM3	70	80	60	90.7	1	336	1
EFM4	40	50	20	50	7	40	6
EFM5	80	60	45	77.7	4	216	3
EFM6	75	70	40	90.7	1	210	4
EFM7	70	40	25	72	5	70	5

Table 6: Experimental final outp ut dairy products manufacturing systems risk of company A versu s (Vs) B ranking.

Final Result Company “A” Vs Company “B”		
Categories	Company A	Company B
Physical Risk	59.6	44
Biological Risk	81	51.2
Chemical Risk	77.4	28
Environmental Risk	76.1	56.3
Final Output Result	9.23	49.2