Applying tThe Fuzzy FMEA tTo Rank Risks in the Monthong Durian Supply Chain Applying the Fuzzy FMEA to rank risks in the Monthong Durian Supply Chain

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ABSTRACT

Thai raw durians and processed durian products has gained popularity among both domestic and international consumers. The demands of these goods were dramatically increased over the past several years. However, there are risks occurred in the production of raw durians and durian products. In this study, the supply chain of Monthong durian was diagnosed and categorized. It was found that there were 4 main stakeholders in the chain consisted of the supplier, the manufacturer, the distributor, and the retailer. The processes responsible by each stakeholder and risks associated to each process were gathered using the classical FMEA technique. There were total of 64 risks in this supply chain. To relax the limitations of traditional FMEA, fuzzy FMEA technique and FRPNs were used to evaluate the collected data. The risks were finally classified into 3 types as high, intermediate, and low. There were 7 risks identified as high risks. Those concluded "insufficient fresh water", "fluctuated durian price", "storms", "too much rain", "clogged drainage", "pest diseases", and drought.

Keywords
Durian, FMEA, fuzzy, reliability, risk analysis

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Introduction

Durian is one seasonal kind of fruits that has gained popularity among the Asian consumers. The durian plantation areas in Thailand (especially the Monthong cultivar) have been consistently increasing due to large demand domestically and internationally. Durian price has been increasing every year. In the years 2015-2019, the average price of durian had increased 18.83% per year (from 46.96 Baht/kg to 99.86 Baht/kg).

With the support from the Thai Government, MonThong durian has been pushed as one of the successful "value-added" agricultural products in Thailand (Thomya & Taotagoo, 2019). Some well-known durian processed products among Thais and the Asian tourists are such as durian paste, fried durian and durian candies.

Due to the potential of the crop, the supply chain of the MonThong durian has been greatly enlarged over the past decades. Not only local farmers are interested in successfully planting durian trees, but many businesspeople have also been interested in investing in MonThong durian plantation. Furthermore, there are those along the supply chain who can earn their livings on Monthong durian related businesses.

However, to start a business related to Monthong durian, there are some risks that should be considered. Many new farmers have failed to plant durian trees perhaps due to the lack of knowledge and the understanding of how to solve problems properly when facing with problems and/or crisis.

For example, in the years 1995 and 2011, the floods damaged almost all durian farms in Nonthaburi (Nonthaburi (Thongdara et al., 2013). In 2020, the COVID-19 virus had prevented

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durian exportation causing the price to drop significantly (National, 2020).

Failure Mode Effect Analysis (FMEA) technique is one of the most widely used methods in identifying risks in a system. For example, FMEA technique was also used in service industry (Geum et al., 2011). Haur et al. (2013) performed FMEA risk analysis of the bird nest production process. Voltarelli et al. (2018) applied the technique to analyze the risks of sugar cane harvesting.

However, there were two drawbacks of using the FMEA technique alone. First, the risk assessment of products or systems based on Risk Priority Number (RPN) values could cause real-world problems Since in real life events, not all factors were equal. Second, the FMEA technique was too dependent on the experience of the experts (Liu & Zhou, 2014). Therefore, FMEA technique has been widely merged with fuzzy techniques to overcome the limitations of the traditional FMEA technique.

There have been many studies that adopted the fuzzy FMEA techniques. Wessiani and Sarwoko (2015) used the fuzzy FMEA technique to assess the risk of the poultry feed industry. It was found that the traditional FMEA technique identified 89 risks in animal feed production. But when using the fuzzy technique, it was found that there were only 39 risks that should be dealt with. Yin et al. (2019) used fuzzy algorithms to control the speed and degrees of unmanned machinery that was used to grow rice, resulted in an improvement in accuracy and a reduction of errors in the path of rice cultivation that may occur. Moreover, fuzzy FMEA techniques were applied in various applications such as planning risk management evaluating organic rice risks in the supply chain (Rohmah et al., 2015), and evaluating marine supply chain risk (Wan et al., 2019). The used of fuzzy technique FMEA provided reasonable results for arranging ~~these risk priority~~this risk priority.

To our knowledge, there has not been any study that attempt to rank risks of any agriculture commodity crop during the plantation stage. Even as of now, there are still some countries whose economy rely heavily on agricultural commodity crop like Thailand. This research can still potentially provide some useful knowledge or benefits to those under developed and developing countries.

In this research, a fuzzy FMEA technique was used to identify the potential risk in the supply chain process of the Monthong durian. The analysis was made to the entire supply chain of durian related business. The focus was on durian plantation stage.

Literature Review

At present, the trend of a healthy and environmentally friendly is becoming more and more popular with consumers and manufacturers. The world was becoming more aware of food, health, and safety, making organic food more popular. In Thailand, one of the most popular organic products was rice. Unfortunately, organic rice has very low productivity compared to normal farming and there are many several risks. Whether it is the characteristics of the species, seasons changing. All of these factors are difficult to control for agricultural products (Paveerat & Thammanoon, 2020). In general, the agro-product industry was already very risky compared to other industries, regardless of the weather. fluctuation of agricultural object prices, and financial uncertainty in investment of this industry. Several studies have been conducted to assess and identify risks in the industry by using FMEA tool (Peyman et al., 2020). The agricultural technology management system has certain role in promoting the development of agriculture (Yu et al., 2020) whether it is a matter of raise agricultural productivity or increase agricultural demand for land (McGowan & Vasilakis, 2019).

A widely used risk management tool in engineering was the Failure Mode and Effect Analysis (FMEA) as it was a technique that could identify and eliminate potential failures in systems (Ahmet & Mehmet, 2012). In addition, FMEA can be applied in a wide variety of industries, such as in agriculture, the FMEA technique was used to prioritize the risks that might affect the cultivation of oyster mushroom (Andriansyah et al., 2019).

The fuzzy FMEA model is the most popular approach that assesses the shortcomings

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of RPN. Several fuzzy FMEA techniques have been widely used to overcome the problems of traditional FMEA (Khuankrue et al., 2017). The obvious benefit of the fuzzy FMEA in this study was to take care of imprecise and vague judgement (Srivastava et al., 2018).

Methodology

In this research, the entire supply chain of Monthong durian was established. Stakeholders along the supply chain were interviewed to identify functions and risks of durian-related business starting from the plantation stage based on (Wessiani & Sarwoko, 2015).

Once the risks were identified, the values of Severity (S), Occurrence (O) and Detectability (D) were assessed by stakeholders. Then, the calculation of the fuzzy risk priority numbers was done following (Gan et al., 2011). Stakeholders' weights were assessed and the Fuzzy Risk Priority Number (FRPN) for each risk was calculated. The defuzzified values were calculated using the Mean of Maxima method (MOM) selected out of the three types of the Maxima method including the First of Maxima Method (FOM), the Last of Maxima Method (LOM), and the MOM. The MOM had the advantage of better covering all the data and valuations than the FOM and the LOM (Ozdemir, 2010).

The defuzzified values were calculated by using Maxima method which categorized into 3 types which including first of Maxima Method (FOM), last of Maxima Method (LOM), and mean of Maxima Method (MOM). In this research, the Mean of Maximum technique (MOM) was chosen to be used as tool to analyse the data due to this technique had the advantage of covering all the data and valuations. In contrast of FOM and LOM which covered only low and high value respectively.

Results and Discussion

Supply Chain of Monthong Durian Products

There were typically four main stakeholders in the supply chain of Monthong durian. Those were consisted of the supplier, the manufacturer, the distributor and the retailer. The roles for each stakeholder were described below:

1. Supplier

In this stage, the most relevant stakeholders were the farmers who grow durian trees. Their responsibility was categorized into 4 main duties consisted of surveying the area to plant the Monthlong durian, planting the durian, caring and maintenance, and harvesting the durian.

2. Manufacturer

The main function of the manufacturer was to add the value to the durian bought from the supplier by processed them to increase product value. Moreover, products had to be certified by acquiring safety standard in order to be able to export them to foreign countries.

3. Distributor

In Thailand, the stakeholder who bought durians from the farmers was called "Long". Longs were the middlemen in this supply chain. They made advanced contracts with farmers before harvesting durians to ensure that they had sufficient durian supply for their customers. They were required to pass the safety standard before exporting any good internationally.

4. Retailer

Retailers can range from traditional markets such as flea markets, department stores, and even in the form of durian truck stalls (wandering around and usually stop at any busy street, village, or inside any local market). Most of them received durians from the distributors.

The functions for these stakeholders were listed in Tables 1-4. According to the FMEA technique, risks and their associated potential impacts were also listed for each function as shown in Tables 1-4.

Ratings based on Gan et al. (2011) were assessed by interviewing stakeholders in the supply chain. The stakeholders who got interviewed were the owners of durian farms/manufacturers/distributors/ and small-scaled retailers in Chumphon and Chanthaburi provinces. Both provinces were ranked the first and the second in terms of durian plantation areas in Thailand.

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Table 1. FMEA analysis of the suppliers (farmers)

Function	Risk Code	Risk	Potential Effect
Survey the area to plant the Monthong Durian.			
Survey for water supply	R1	Insufficient fresh water	Unable to grow durian until harvestable
	R2	Poor water quality or toxic water	May cause the durian tree to die or may affect the fruit, resulting in poor quality durian
Pick the plantation area with suitable weather	R3	The weather for planting is too hot	Burning or falling leaves causing the durian tree to die or grow slowly
	R4	The weather for planting is too cold	Burning or falling leaves causing the durian tree to die or grow slowly
	R5	Drought in the plantation area	Unable to grow durian until harvestable
	R6	Too much rain in the plantation area	Excessive rainfall may cause waterlogging or flooding, especially when there is a lack of well-prepared drainage management. This will cause the durian tree to die or grow slowly.
	R7	Storms in the plantation area	May cause damage to the durian tree or even kill the tree
	R8	Earthquake in the plantation area	May cause damage to the durian tree or even kill the tree
Pick the plantation area with suitable soil conditions	R9	The soil condition is too acidic	Can be toxic to durian tree
	R10	The soil condition is too alkaline	Can be toxic to durian tree
	R11	There are toxic contaminants in the soil	The soil lacks nutrients that are not suitable for cultivation
Planting Monthong durian			
Pick the suitable plantation period	R12	Planting in the inappropriate season	Water may not be sufficient for cultivation or there may be an unfavorable environment for the growth of durian tree
Prepare the planting of durian tree (plow the plantation area)	R13	Weeds are still leftover on the field	Weeds steal for food from the durian tree, causing the durian tree to grow slowly.
	R14	No drainage or clogged drainage	May cause waterlogging resulting in the roots to rot

Function	Risk Code	Risk	Potential Effect
Specify the planting spot	R15	The clearance between the trees are too narrow	Not convenient to use additional equipment/machines in the area
	R16	The clearance between the trees are too wide	Too costly/not cost effective
	R17	The actual plantation does not locate in the specified spot	May not get sufficient water supply and also may cause a problem to the drainage system
Choose plantation method	R18	The chosen plantation method is not suitable for the area	Waste too much water
Care and maintenance			
Maintenance before the harvesting period (years 1-3)	R19	Losing the money due to the fall of supplementary crop price (crops planting on the empty space around the durian plantation area hoping to gain additional income)	Lose money from the fallen price of the supplementary crop
	R20	The existing durian tree dies or gets diseases	Lose money re-planting and repairing the durian, resulting in not being able to sell during early in the market
	R21	Too little water	Can cause the durian tree to grow slowly due to the lack of nutrients or the durian tree may die
	R22	Too much water	Waterlogging for a long period of time can cause the durian roots to rot and may cause the durian tree to die
	R23	Improper pruning	Slow down flowering and fruiting processes
	R24	Got insect or pest diseases	Damage the durian tree and also cost more to eradicate the insects or pests
	R25	Too much sunlight	Can cause the leaves of the durian tree to burn
	R26	Too much fertilizer	Can cause the durian tree to become pale and die and cost more to buy chemical fertilizer
	R27	Too little fertilizer	Can cause the durian to grow slowly because of the lack of nutrients
Care just before getting	R28	Too little water	The leaves of the durian tree

Function	Risk Code	Risk	Potential Effect
the durian fruit (years 4-5)			were pale and the buds will not grow out
	R29	Too much water	May turn the fruit back to the leave
	R30	Too much fertilizer	Can cause the durian tree to become pale and die and cost more to buy chemical fertilizer
	R31	Too little fertilizer	Can cause the durian tree to come out fruiting slowly and the taste of the durian fruit was not good
	R32	Trim too many flowers	May lose some durian fruits
	R33	Trim too much fruit	May lose some durian fruits
	R34	Trim too little fruit	May have too many durian fruits resulting in the smaller-size durians than expected
	R35	Durian fruit was stolen	Lose profit
	R36	Excessive durian weight	Durian branches were broken causing damage to all durian fruits
		Harvesting	
Harvest durians	R37	Miscount the age of the durian fruit	This causes the durian to be cut too soon resulting in the poor taste
	R38	Accidentally cut unripe durian	Unripe durians cannot be sold resulting in the loss of income
	R39	Durian is accidentally fallen on the ground	Durian fruit will be damaged and cannot be sold or can be sold at a very cheap price
	R40	Accidentally leave the durian on the ground after harvesting	Can cause the durian to become infected and spoil the durian
	R41	Durian prices are fluctuated	May lose money due to the unstable income

Table 2. Risk of durian processing manufacturer

Process	Risk Code	Risk	Potential Effect
		Certificate acquisition	
Get certified by the Department of Agriculture to be able to export durian products	R42	Fail to get a certificate	Cannot export products
	R43	The process of getting the certificate takes too much time	Lose sales opportunities
		Acquire durian fruits from farmers	
Locate durian fruit	R44	Cannot obtain sufficient durian	Unable to sell durian

Process	Risk Code	Risk	Potential Effect
suppliers		fruits for the demand	products
	R45	Durian fruit has a high price	Lose profit
	R46	Buy poor quality durian	May not be able to process the durian or may get bad quality of the final products
	R47	Sorting durian grade in a wrong category	May result in high production cost or high raw material cost
		Marketing	
Identify the customers	R48	May have too little demand	Lose profit or too much inventory
	R49	Get cheated by the buyer or get the money late	Lose profit or loss of opportunity

Table 3. Risk of distributor

Process	Risk Code	Risk	Potential Effect
		Registered certification	
Get certified by the Department of Agriculture to be able to export durian products	R50	Fail to get a certificate	Cannot export products
	R51	The process of getting the certificate takes too much time	Lose sales opportunities
		Acquire durian fruits from farmers	
Locate durian fruit suppliers	R52	Cannot obtain sufficient durian fruits for the demand	Unable to sell durian products
	R53	Durian fruit has a high price	Lose profit
Distribute products	R54	Not enough products to deliver to various stores within the network.	Lose credibility and profit
	R55	Order cancel from the store	Lose profit
	R56	Accidents during the logistic process	The products are damaged and cannot be sold
		Marketing	
Identify the customers	R57	May have too little demand	Lose profit or too much inventory

Table 4. Risk of retailer

Process	Risk Code	Risk	Potential Effect
		Received products from Distributor	
Gather products from the distributors	R58	Distributor has insufficient supply	Lose sales opportunities
	R59	Distributor is unreliable and sometimes may not deliver products on time	Lose sales opportunities
		Retail the products in the market	
Identify possible distribution channels	R60	No connections	Lose profit due to unable to sell products
	R61	Too many retailers resulting in the tense competition	Market share and profit are decreased
Retail the products	R62	Too little demand	Unsold durians are spoiled, resulting the loss of income

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Process	Risk Code	Risk	Potential Effect
	R63	Too much demand	Lose sales opportunities
	R64	Products are sold with bad quality	Lose credibility

Calculation of FRPN Values

Linguistic Term and fuzzy numbers in this study were assessed as criteria in triangular distribution forms. The assessment was made only for the severity and occurrence factors as shown in Table 5. The detection factor was assumed to be 1 since in this study it was assumed that once the even occurred, it was automatically detected.

After the respondents assessed risk scores (from 1 to 5; 1 = very low, 2 = low, 3 = intermediate, 4 = high, 5 = very high), FRPNs were calculated. We assumed the weights of experts as h_i , i = 1,…,4, shown in Table 6. In Table 6, TM_i, i = 1,..,4, represented each respondent. TM_2 and TM_3 received the highest weights since both responders were specialized and worked in all processes in the supply chain. TM_4 received the lowest weight since the respondent had relatively smaller expertise in management and distribution of product both domestically and internationally. Columns 3 and 4 in Table 6 represented the fuzzy factor weights of severity and occurrence which were based on the FMEA technique. The fuzzy factor weight of each *TM* was assessed by evaluating the questionnaire answered by each respondent. The numbers were in triangular fuzzy form (*a*, *b*, *c*), where *a* represents the lower bound, *b* represents the most likely value, and *c* represents the upper bound of the assessment.

The calculation of the rating factors and weight factors followed the steps similar to Gan et al. (2011). The FRPN values were then calculated. The resulting FRPNs for all stakeholders are shown in columns 1-4 in Tables 7. Additionally, the defuzzied values by the Mean of Maxima (MOM) method were shown in the fifth column of Tables 7. Finally, the rankings of risks were shown in the last column of the same table.

Table 5. Linguistic terms and fuzzy numbers for severity and occurrence

Score	Linguistic Term	Fuzzy Number for Severity			Fuzzy Number for Occurrence		
1	Very low	0	0	0.05	0	0.05	0.10
2	Low	0.05	0.08	0.10	0.10	0.15	0.20
3	Intermediate	0.10	0.15	0.20	0.20	0.30	0.40
4	High	0.20	0.30	0.50	0.40	0.50	0.60
5	Very high	0.50	0.75	1.00	0.60	0.80	1.00

Table 6. Weighs of the respondents and the corresponding fuzzy factor weights for severity and occurrence

h_i	Fuzzy Factor Weight for Severity	Fuzzy Factor Weight for Occurrence
TM_1	0.25	(0.2,0.3,0.5) (0,0.05,0.1)
TM_2	0.30	(0.2,0.3,0.5) (0.2,0.3,0.4)
TM_3	0.30	(0.2,0.3,0.5) (0.4,0.5,0.6)
TM_4	0.15	(0.05,0.08,0.10) (0.1,0.15,0.2)

Table 7. Defuzzified value

Risk Code	Min	Most Likely	Max	Defuzzied	Ranking
R1	4.43	4.44	4.47	4.45	1
R2	3.28	3.31	3.40	3.33	18
R3	3.53	3.54	3.57	3.55	12
R4	3.37	3.37	3.38	3.38	16
R5	3.66	3.66	3.69	3.67	7
R6	3.89	3.89	3.91	3.90	4
R7	4.02	4.02	4.04	4.02	3

Risk Code	Min	Most Likely	Max	Defuzzied	Ranking
R8	2.07	2.09	2.16	2.11	60
R9	3.14	3.15	3.16	3.15	27
R10	2.74	2.75	2.79	2.76	49
R11	2.89	2.89	2.91	2.90	41
R12	3.13	3.14	3.19	3.15	28
R13	2.86	2.86	2.89	2.87	44
R14	3.82	3.83	3.87	3.84	5
R15	3.05	3.05	3.03	3.04	34
R16	2.74	2.74	2.76	2.75	51
R17	2.82	2.81	2.76	2.79	48
R18	3.64	3.65	3.66	3.65	8
R19	2.83	2.84	2.89	2.86	45
R20	3.13	3.13	3.12	3.12	30
R21	3.40	3.42	3.49	3.44	13
R22	3.34	3.36	3.42	3.37	17
R23	3.21	3.23	3.27	3.24	22
R24	3.69	3.69	3.71	3.70	6
R25	2.71	2.71	2.74	2.72	52
R26	2.86	2.88	2.99	2.91	40
R27	2.91	2.94	3.05	2.97	37
R28	2.73	2.75	2.81	2.76	50
R29	2.58	2.60	2.66	2.61	56
R30	3.04	3.06	3.13	3.08	33
R31	2.64	2.66	2.73	2.67	54
R32	2.87	2.88	2.92	2.89	43
R33	2.78	2.79	2.84	2.81	47
R34	2.38	2.40	2.48	2.42	58
R35	3.54	3.56	3.65	3.58	10
R36	2.99	3.00	3.01	3.00	36
R37	2.97	3.00	3.15	3.04	35
R38	3.38	3.41	3.55	3.44	14
R39	3.28	3.31	3.40	3.33	19
R40	2.89	2.91	2.96	2.92	39
R41	4.04	4.04	4.07	4.05	2
R42	3.50	3.53	3.66	3.56	11
R43	3.26	3.29	3.37	3.31	20
R44	2.62	2.62	2.64	2.62	55
R45	3.18	3.18	3.17	3.17	25
R46	3.08	3.09	3.16	3.11	32
R47	2.86	2.88	2.95	2.90	42
R48	2.91	2.94	3.04	2.96	38
R49	3.06	3.09	3.20	3.12	31
R50	3.26	3.28	3.34	3.29	21
R51	3.22	3.22	3.24	3.22	24
R52	3.62	3.64	3.70	3.65	9
R53	3.18	3.18	3.17	3.17	26
R54	3.36	3.38	3.44	3.39	15

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Risk Code	Min	Most Likely	Max	Defuzzied	Ranking
R55	3.21	3.22	3.29	3.24	23
R56	3.11	3.13	3.22	3.15	29
R57	2.82	2.84	2.93	2.86	46
R58	1.71	1.75	1.87	1.78	64
R59	2.39	2.42	2.54	2.45	57
R60	2.22	2.25	2.38	2.29	59
R61	2.07	2.09	2.17	2.11	61
R62	2.62	2.65	2.78	2.68	53
R63	1.84	1.84	1.86	1.85	63
R64	2.00	2.00	2.00	2.00	62

Figure 1 contains the plot of the defuzzified values versus their rankings. In this figure, the defuzzified values could be grouped into three risk levels. The first risk level was the one from the highest ranking until the graph started to flatten (at around the ranking number 7). The second risk level was the flatten zone between ranking numbers 8-56. Finally, the last risk level was the steep downward trend between ranking numbers 57-64.

Table 8 contains risks in the first risk level (high-risk group). The risk of insufficient fresh water (ranked the first) can be reduced by the new farmers since they can try to search for the plantation location where fresh water is available. Some risks were in fact related to each other. For example, not enough fresh water is related to drought. Also, some risks in this table were from the heavy rainstorms which are unavoidable. This is similar to the risk of insect or pest diseases or price fluctuation. On the other hand, the risk of no drainage (ranked number 5) can be relatively easier to mitigate.

The risks ranked middle or low could be considered if mitigation approach was cost-effective. This paper also illustrates when applying technology into agriculture, it could help farmers to better manage their production efficiently.

Table 8. High risk group

Ranking	Risk Activity	Value
1	Insufficient fresh water	4.45
2	Durian prices are fluctuated	4.05
3	Storms in the plantations	4.02
4	Too much rain in the plantation area	3.90
5	No drainage or clogged drainage	3.84
6	Got insect or pest diseases	3.70
7	Drought in the cultivation area	3.67

Conclusion

Stakeholders in the supply chain of Monthong durian were the supplier, the manufacturer, the distributor and the retailer. Our results identified 64 risks using the classical FMEA technique. However, when considering the risks using the FRPNs, it was suggested that there were only 7 risks posed as high-risk using the fuzzy FMEA technique. Insufficient fresh water came up as the first rank in the analysis. Other high ranks were related to drought, no drainage, rainstorms, pest diseases, and price fluctuation.

We believe that the results of our study could be used not only as a guideline for Monthong durian farmers, but also for other types of farmers in the tropical climate similar to Thailand. The technique used in this study can also be adapted to classified risks in other applications.

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References

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[1] Ahmet, K. C., & Mehmet, E. (2012). Fuzzy failure modes and effects analysis by using fuzzy TOPSIS-based fuzzy AHP. Expert Systems with Applications, 39(1), 61-67.

[2] Andriansyah, S. S., Evita, H. S., & Luh, S. P. (2019). Risk Management Of Oyster Mushroom Agribusiness Jember District. International Seminar Series on Regional Dynamics, pp. 169-174.

[3] Gan, L., Pang, Y., Liao, Q., Xiao, N. C., & Huang, H. Z. (2011). Fuzzy criticality assessment of FMECA for the SADA based on modified FWGM algorithm & centroid deffuzzification. IEEE International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering, pp. 195-202.

[4] Geum, Y., Cho, Y., & Park, Y. (2011). A systematic approach for diagnosing service failure: Service-specific FMEA and grey relational analysis approach. Mathematical and Computer Modelling, 54(11-12), 3126-3142.

[5] Haur, J. C., Tay, K. M., & Lim, C. P. (2013). Application of the fuzzy Failure Mode and Effect Analysis methodology to edible bird nest processing. Computers and Electronics in Agriculture, 96, 90-108.

[6] Khuankrue, I., Kumeno, F., Ohashi, Y., & Tsujimura, Y. (2017). Improving Fuzzy FMEA Model for Student Projects. IEEE Joint 17th World Congress of International Fuzzy Systems Association and 9th International Conference on Soft Computing and Intelligent Systems, pp. 1-6.

[7] Liu, J., & Zhou, Y. (2014). Improved FMEA Application to Evaluation of Supply Chain Vulnerability. IEEE Seventh International Joint Conference on Computational Sciences and Optimization, pp. 302-306.

[8] McGowan, D., & Vasilakis, C. (2019). Reap what you sow: Agricultural technology, urbanization and structural change. Research Policy, 48(9), 103794.

[9] Özdemir, M. (2010). A probabilistic schedule delay analysis in construction projects by using fuzzy logic incorporated with relative importance index (RII) method, Master thesis, Middle East Technical University.

[10] Paveerat, P., & Thammanoon, H. (2020). Supply chain risk management of organic rice in Thailand. Uncertain Supply Chain Management, 8(1), 165-174.

[11] Peyman, Z., Mohammad, R., Mojtaba, K., & Amir, M. (2020). Agricultural Risk Management Using Fuzzy TOPSIS Analytical Hierarchy Process (AHP) and Failure Mode and Effects Analysis (FMEA). Agriculture, 10(11), 504.

[12] Rohmah, D. U., Dania, W. A., & Dewi, I. A. (2015). Risk Measurement of Supply Chain Organic Rice Product using Fuzzy Failure Mode Effect Analysis in MUTOS Seloliman Trawas Mojokerto. Agriculture and Agricultural Science Procedia, 3, 108-113.

[13] Srivastava, P., Khanduja, D., & Agrawal, V. P. (2018). Mitigation of risk using rule based fuzzy FMEA approach. 8th International Conference on Cloud Computing, Data Science & Engineering, pp. 26-30.

[14] Thomya, C., & Taotagoo, N. (2019). Riding the Durian Belt and Road: Risky Times for Thai Agriculture. Earth Journalism Network, 17.

[15] Thongdara, R., Tanachaikhan, P., Kulpradit, K., & Tibkaew, A. P. (2013). The Urban Expansion to Durian Orchard in Nonthaburi. Asian Conference on Remote Sensing, pp. 2745-2753.

[16] Voltarelli, M. A., Paixão, C. S., Zerbato, C., da Silva, R. P., & Gazzola, J. (2018). Failure mode and effect analysis (FMEA) in mechanized harvest of sugarcane billets. Engenharia Agrícola, 38(1), 88-96.

[17] Wan, C., Yan, X. P., Zhang, D., Qu, Z., & Yang, Z. (2019). An advanced fuzzy Bayesian-based FMEA approach for assessing maritime supplychain risks.

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Transportation Research Part E Logistics and Transportation Review, 125, 222-240.

[18] Wessiani, N. A., & Sarwoko, S. O. (2015). Risk analysis of poultry feed production using fuzzy FMEA. Procedia Manufacturing, 4, 270-281.

[19] Yin, J., Zhu, D., Liao, J., Zhu, G., Wang, Y., & Zhang, S. (2019). Automatic Steering Control Algorithm Based on Compound Fuzzy PID for Rice Transplanter. Applied Sciences, 9(13), 2666.

[20] Yu, L., Qin, H., & Xiang, P. A. (2020). Incentive mechanism of different agricultural models to agricultural. Sustainable Computing: Informatics and Systems, 28, 100423.

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