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Integrated FMEA-MCDM For Prioritizing Operational Disruption in Production Process

Muqimuddin^{1,3}, M. L. Singgih^{2,4}

^{1,2}Department of Industrial Engineering Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

³Muqimuddin03@gmail.com, ⁴Moseslsinggih@ie.its.ac.id

Abstract. The more complex the production system of a company, definitely makes it sensitive of change or known as disruption. Disruptions always occur in production process and also cause productivity decrease. If there are any kind of disruptions occur, so the decision maker have to prioritize it appropriately. The risk is going to be greater as a consequence when the priority made is false. FMEA is one method that is often used for evaluation and prioritization, especially failure as one type of disruption to minimize risk which can be adopted to assess and evaluate disruptions. The FMEA has some shortcomings including it is not considering the importance of each factor, not considering uncertain information from expert, not considering the cost as one of the criterion considered, and the level of severity is hard to measure, because on different objects can be measured by different aspect. Therefore, this research aims to develop FMEA model for prioritizing disruptions in production process. The model can improve some shortcomings of conventional FMEA. In achieving this goal, several methods are integrated including Analytical Hierarchy Process (AHP) which aims to determine the importance weighting of RPN element factors. In addition, this study uses the Technique for Order Preference by Similarity to an Ideal Solution for prioritizing disruption. Rough set also uses as a method for aggregating opinion of experts, and also uses for improving uncertain information. The model also considers loss revenue as aspect to measure severity level of disruption in determining prioritization.

Keywords: FMEA, Loss Revenue, Uncertain Information, Operational Disruption

1. Introduction

Production process is sensitive of change called disruption. Therefore, the disruptions always occur in production process and create loss for manufacturing company. Loss as an risk of disruptions on the company are difference because it is influenced by duration of disruption [1]. If the disruption occurs, the amount of production produced will decrease. The risk is going to be greater when prioritize disruption is false. If there is an error in prioritizing the disruption, it will certainly have consequences for the manufacturing company. The consequences is the risk of another disruption unselected will occur more severe in the production process. As an illustration where prioritizing disruptions without considering loss revenue, then the disruption with low loss revenue is selected as priority than others disruption. However, each disruptions have a different amounts of loss revenue per unit time. And so, it makes the loss revenue of the disruption can't be reduced significantly high. In the other hand, unselected disruption with high loss revenue, can increase greater than the loss revenue of disruption selected. If the priority handling is done on unselected disruption, the reduction of loss revenue would significantly



be high. Therefore, in determining priorities it is necessary to consider the correct RPN so that they do not create a greater risk.

Failure Mode and Effect Analysis (FMEA) is one of the methods often used by many researchers, especially in evaluating failure as a type of disruption for risk management. This method can also be used to determine failure priorities. However, some researchers criticize this method because it still has some shortcomings including:

1. In determining the value of RPN, it doesn't consider the weight of importance of RPN elements [2] [3]
2. In determining the RPN by multiplying the RPN element will be very possible to produce the same RPN value and it is not reliable for determining the priority of failure [4].
3. RPN elements with likert scoring will be possibly contained uncertain information from experts [4].
4. If only considering 3 elements of RPN as RPN including severity, occurrence and detection, it has not provided a good decision result in prioritizing, and needs others RPN for instance cost as a RPN to consider [5].

Some researchers have done to improve FMEA shortcomings to produce better prioritization such as adding cost aspects [6] and use the DEA method to determine risk priorities [7]. In addition to adding cost aspects, it also accommodate uncertain information from expert opinion and has considered the importance weight of each RPN by integrating BWM and GRA to FMEA [4]. Another research have accommodated uncertain information by aggregating expert assesment using the rough set and integrating BWM and TOPSIS for prioritizing risk in grup decision-making [8]. These previous research, the researcher assume each experts have no importaces in determining the most importance of RPN to consider. In fact, they actually have different opinion regarding it. This situation can be shown which each experts have different opinion regarding the most important and the less important RPN to consider. Therefore, to improve this situation, this research aims to propose FMEA method by integrating some method to acomodate FMEA shortcomings. The proposed method is hopefully able to prioritize disruption in production process. the hierarchy of diruption priority is shown as Figure 1.

2. Methods

The proposed architectural model is shown in Figure 2. The proposed model consists of 4 stages. The first stage is identifying disruptions which occur in production process. Second stage is determining the evaluation scale each RPN (occurrence and detection), while severity is measured by calculating loss revenue each disruptions occurred. Third stage is determining the optimal importance weight of each RPN. In this paper, AHP is chosen as method to determine the weight. This method is also able to accommodate difference of expert's opinion regarding the most importance RPN to be considered in prioritizing disruptions without ignore uncertain information from expert. Fourth stage is determining disruption priorities. In proposed model, TOPSIS is also used as method, because it is effective and suitable to determine all priorities. In additional, uncertain information accomodation of expert's opinion, in this model is also used rough set to aggregate expert's assesment of each input of method.

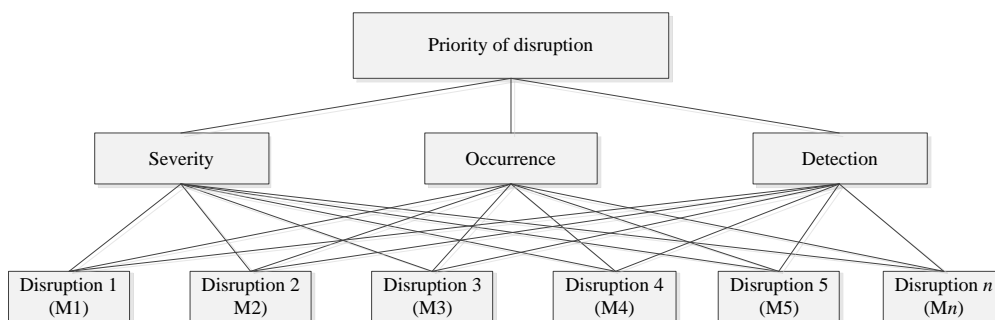


Figure 1. Hierarchy of operational disruption priority

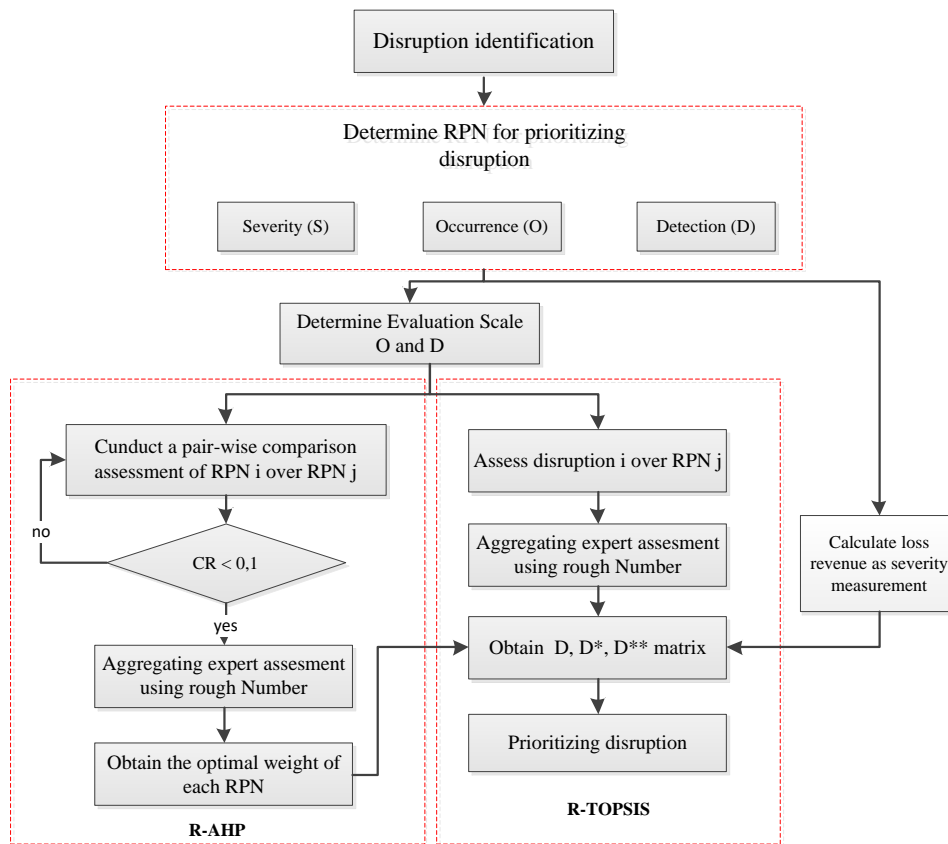


Figure 2. Architectural model

2.1 Loss revenue calculation as severity measurement

In determining the amount of revenue experienced by a company can be calculated based on multiplying the selling price of the product by amount of demand [9]. Meanwhile, if the company produces the same amount of production (Q) with amount of demand (D), the equation becomes as follows:

$$Revenue = S_x \times Q \tag{1}$$

In calculating Q is by multiplying the average production (P_y) and production time (T_p) [10]. Whereas if there is disruption time during T_d then Q 'is produced with the following equation:

$$P_y \times (Tp - Td) = Q' \tag{2}$$

Loss revenue is a decrease in the amount of revenue generated by a company, so that it can be generated by multiplying the selling price of type x products (S_x) and amount of decreasing production (Q - Q ') so equation 2 can be simplified to:

$$Loss\ revenue = S_x \times P_y \times Td \tag{3}$$

2.2 Rough Number

Proposed by Professor Pawlak in 1982, rough set theory is a mathematical method that can acomodate imprecise, incosistent, and incomplete information or knowledge [17]. The steps of determining the rough number value are as follows [8]:

- 1) Determine lower dan upper approximations

There is a U that represents all sets containing all objects and R represents a set of t class (e₁, e₂, ..., e_t) which covers all the objects inside U. R = {e₁, e₂, ..., e_t}, e₁ < e₂ < ..., < e_t. Whereas Y is an arbitrary object of U. $\forall Y \in U, e_v \in R$ dan $1 \leq r \leq t$. Lower and upper bound approximation value [$\underline{apr}(e_v), \overline{apr}(e_v)$] of rough number can be obtained using the following equation:

$$Lower\ approximation : \underline{apr}(e_v) = \cup \{Y \in U / R(Y) \leq e_v\} \tag{4}$$

$$\text{Upper approximation : } \overline{\text{apr}}(e_v) = \cup \{Y \in U/R(Y) \geq e_v\} \tag{5}$$

Based on equation (4) will produce element a_t dan and equation (5) will produce element b_t . While the number of elements a_t shown with N_L and number of elements b_t shown with N_U Thus it can be calculated Lower and upper limit ($\underline{\text{lim}}(e_v), \overline{\text{lim}}(e_v)$) based on following equations:

$$\underline{\text{lim}}(e_v) = \frac{\sum_{i=1}^{N_L} a_t}{N_L} \tag{6}$$

$$\overline{\text{lim}}(e_v) = \frac{\sum_{i=1}^{N_U} b_t}{N_U} \tag{7}$$

2) Determine interval value of rough number

Rough Number (RN) is represented by $[\underline{e}_v, \overline{e}_v]$ or $[\underline{\text{lim}}(e_v), \overline{\text{lim}}(e_v)]$.

2.3 Analytical Hierarchy Process (AHP)

AHP is one of the popular methods used by many decision makers for various problems, one of them, for determining the importance weight of RPN. This method is also able to measure the consistency of preferences, manipulate multiple decision makers, handle tangible and intangible RPN, and manage decision making that involves subjective judgment [11] and steps as follows:

1) Determine RPN

At this step, researchers determine the RPN that will be assessed by the expert.

2) Conduct assessment by comparison of each RPN.

At this stage one or several decision makers determine the value of the importance of each criterion over other RPN in pairs. The assessment is conducted by expert based on a rating scale 1 - 9. The results of expert assessment then it sorted into following matrix B:

$$B^k = \begin{bmatrix} \mathbf{1} & B_{12}^k & \dots & B_{1m}^k \\ B_{21}^k & \mathbf{1} & \dots & B_{2m}^k \\ \dots & \dots & \ddots & \vdots \\ B_{n1}^k & B_{n2}^k & \dots & \mathbf{1} \end{bmatrix} \tag{8}$$

Where B_{ij}^k shows the comparison value of criterion i over j by respondent k.

3) Calculate the consistency ratio value (CR)

Before calculate the CR value, it is necessary to determine the maximum value of the eigenvalue (λ_{max}^k) from the assessment results of each expert. The value is used for calculating consistency index (CI) with the following equation:

$$CI = (\lambda_{max}^k - a) / (a - 1) \tag{9}$$

Where a is the number of RPN assessed by the expert. After the CI value is obtain, the CR value can be obtained based on calculating the ratio of the CI value and the random consistency index (RI)

$$CR = CI/RI \tag{10}$$

The RI value is shown in Table 1 below:

Table 1. Random consistency index (RI)

a	3	4	5	6	7	8	9	10
RI	0,52	0,89	1.11	1,25	1,35	1,4	1,45	1,49

4) Obtain the initial rough matrix.

The determination of the value of this rough number aims to aggregate the results of the assessment of experts. The aggregation uses equation (1) – (4) and the results are sorted into the following matrix C:

$$C = \begin{bmatrix} [1, 1] & \tilde{C}_{12} & \dots & \tilde{C}_{1n} \\ \tilde{C}_{21} & [1, 1] & \dots & \tilde{C}_{2n} \\ \dots & \dots & \ddots & \vdots \\ \tilde{C}_{m1} & \tilde{C}_{m1} & \dots & [1, 1] \end{bmatrix} \tag{11}$$

If there are more than 1 rough number $[C_{ij}^e, \bar{C}_{ij}^e]$ I can be aggregated using the following equation:

$$\underline{C}_{ij} = \frac{C_{ij}^1 + C_{ij}^2 + \dots + C_{ij}^s}{s}; \bar{C}_{ij} = \frac{\bar{C}_{ij}^1 + \bar{C}_{ij}^2 + \dots + \bar{C}_{ij}^T}{T} \tag{12}$$

Where \tilde{C}_{ij} is a obtained rough number value from the rough set method which is including lower bound value (\underline{C}_{ij}) and upper bound value (\bar{C}_{ij}).

5) Obtain the optimal weight each RPN

As for determining the optimal weight, you can use the following equation:

$$\tilde{W}_j = \left[\sqrt[m]{\prod_{j=1}^m \underline{C}_{ij}}, \sqrt[m]{\prod_{j=1}^m \bar{C}_{ij}} \right] \tag{13}$$

then the optimal weight is normalized to produce 0-1 using the following equation:

$$\hat{W}_j = \tilde{W}_j / \max \bar{C}_{ij} \tag{14}$$

2.4. Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

TOPSIS was first proposed by Hwang and Yoon in 1981. The main concept of this method is to determine the best alternative closest to the positive ideal solution (optimal solution) and the farthest from the negative ideal solution (inferior solution). [12]. TOPSIS used by some researchers in decision making because the concept is simple, easy to understand, efficient calculation, and has ability to measure the relative performance of alternative decisions. [13]. The TOPSIS steps are as follows [4]:

1) Determine initial matrix

The initial matrix contains the results of k expert assessment for each failure mode i over the RPN element j. Assessments are based on scale 1 - 10 evaluation scale used in research. The initial matrix is represented into Y matrix as follows:

$$Y = \begin{bmatrix} Y_{111}, Y_{112}, \dots, Y_{11t}, & Y_{121}, Y_{122}, \dots, Y_{12t}, & \dots & Y_{1m1}, Y_{1m2}, \dots, Y_{1mt} \\ Y_{211}, Y_{212}, \dots, Y_{21t}, & Y_{221}, Y_{222}, \dots, Y_{22t}, & \dots & Y_{2m1}, Y_{2m2}, \dots, Y_{2mt} \\ \dots & \dots & \ddots & \vdots \\ Y_{n11}, Y_{n12}, \dots, Y_{n1t}, & Y_{n21}, Y_{n22}, \dots, Y_{n2t}, & \dots & Y_{nm1}, Y_{nm2}, \dots, Y_{nmt} \end{bmatrix} \tag{15}$$

Where Y_{ijk} is the assessment result of failure mode i over RPN j by expert k, $i = 1, 2, \dots, n$; $j = 1, 2, \dots, m$; $k = 1, 2, \dots, t$.

2) Determine the initial rough number matrix (D)

This step aims to aggregate the assessment of experts using the rough set method. the aggregation uses equation (1) – (4) and the results are sorted into the following matrix D:

$$.D = \begin{bmatrix} \tilde{G}_{11} & \tilde{G}_{12} & \dots & \tilde{G}_{1n} \\ \tilde{G}_{21} & \tilde{G}_{22} & \dots & \tilde{G}_{2n} \\ \dots & \dots & \ddots & \vdots \\ \tilde{G}_{m1} & \tilde{G}_{m1} & \dots & \tilde{G}_{mn} \end{bmatrix} \tag{16}$$

if there are more than 1 rough number $[G_{ij}^e, \bar{G}_{ij}^e]$ I can be aggregated using the following equation [11]:

$$\underline{G}_{ij} = \frac{G_{ij}^1 + G_{ij}^2 + \dots + G_{ij}^s}{s}; \bar{G}_{ij} = \frac{\bar{G}_{ij}^1 + \bar{G}_{ij}^2 + \dots + \bar{G}_{ij}^T}{T} \tag{17}$$

Where \tilde{G}_{ij} is a obtained rough number value from the rough set method which is including lower bound value (\underline{G}_{ij}) and upper bound value (\bar{G}_{ij}).

3) Obtain the normalized matrix (D*)

This matrix contains the normalized matrix D in order to produce the value 0 - 1. The normalization with a minimum value can be calculated by the following equation:

$$\tilde{G}_{ij}^* = \left[\frac{G_{ij}}{G_j^{\max}}, \frac{\bar{G}_{ij}}{G_j^{\max}} \right], \text{ where } G_j^{\max} = \max_{1 \leq i \leq m} \{G_{ij}\} \tag{18}$$

Then obtained data can be sorted into the following matrix D*:

$$D^* = \begin{bmatrix} \tilde{G}_{11}^* & \tilde{G}_{12}^* & \dots & \tilde{G}_{1n}^* \\ \tilde{G}_{21}^* & \tilde{G}_{22}^* & \dots & \tilde{G}_{2n}^* \\ \dots & \dots & \ddots & \dots \\ \tilde{G}_{m1}^* & \tilde{G}_{m2}^* & \dots & \tilde{G}_{mn}^* \end{bmatrix} \tag{19}$$

Where \tilde{G}_{ij}^* is normalized preference value of failure mode *i* over RPN *j* which is including upper bound value (\bar{G}_{ij}^*) and lower bound value (G_{ij}^*). G_j^{\max} is represented the maximum preference value of the upper preference value of RPN *j*.

4) Determine weighted normalization matrix (D**)

Matrix D is then normalized again into a matrix D** by multiplying (\tilde{w}_j) and normalized matrix and denoted by (\tilde{G}_{ij}^*) and it can be calculated by the following equation:

$$\tilde{V}_{ij} = [(\tilde{G}_{ij}^*) \times (\tilde{w}_j)] \tag{20}$$

And the result can be sorted into matrix D** as follows:

$$D^* = \begin{bmatrix} \tilde{V}_{11} & \tilde{V}_{12} & \dots & \tilde{V}_{1n} \\ \tilde{V}_{21} & \tilde{V}_{22} & \dots & \tilde{V}_{2n} \\ \dots & \dots & \ddots & \dots \\ \tilde{V}_{m1} & \tilde{V}_{m2} & \dots & \tilde{V}_{mn} \end{bmatrix} \tag{21}$$

where \tilde{V}_{ij} are value of weighted normalization matrix of failure mode *i* over RPN *j* which is including lower and upper bound value [$\underline{V}_{ij}, \bar{V}_{ij}$].

5) Obtain PIS and NIS

The next step is determining PIS and NIS. PIS is a positive ideal solution, while NIS is a negative ideal solution. For determining PIS and NIS can be obtained using the following equation:

$$PIS = (r_1^*, r_2^*, \dots, r_m^*); \text{ where } r_j^* = \max_i \{\bar{V}_{ij}\} \tag{22}$$

$$NIS = (r_1^-, r_2^-, \dots, r_m^-); \text{ where } r_j^- = \max_i \{\underline{V}_{ij}\} \tag{23}$$

6) Calculate the separation distance of PIS and NIS

These distance is calculated based on the following equation:

$$d_i^* = \sum_{j=1}^m \sqrt{\left(\frac{(r_j^* - \underline{V}_{ij})^2 + (r_j^* - \bar{V}_{ij})^2}{2} \right)} \quad ; \quad d_i^- = \sum_{j=1}^m \sqrt{\left(\frac{(\underline{V}_{ij} - r_j^-)^2 + (\bar{V}_{ij} - r_j^-)^2}{2} \right)} \tag{24}$$

7) Calculate closeness coefficient

The last step in this method is calculating the value of closeness coefficient (CCi) which is the index value as a reference in determining the priority of failure mode. For calculating CCi, can be obtained using the following equation:

$$CC_i = w^+ (d_i^- / \sum_{i=1}^n d_i^-) - w^- (d_i^* / \sum_{i=1}^n d_i^*) \tag{25}$$

Where w^+ is a given weight for PIS. And w^- is a given weight for NIS. When CCi value is higher than 0, it indicate the disruption is close to positive ideal solution (PIS). The priority will selected based on the CCi value is close to 1.

3. Discussion

FMEA model is modified by integrating R-AHP and R-TOPSIS for qualitative research. As explanation in first section, FMEA model has 4 shortcomings. It make the desicion result is not reliable in prioritization. Hence, these method is intagrated so that the prioritization is more reliable than FMEA traditional. Each decision maker certainly has a different view of the RPN that is important to consider. Therefore, this model also uses the AHP method which aims to produce the importance of each criterion. Whereas TOPSIS is used for prioritizing disruption where the determination of the ideal solution is based on the PIS and NIS values which then calculate the CCI value to determine the disruption rating. As for the types of disruption that have the highest positive CCI values are the priority in handling. each expert as a decision holder certainly has a different insight about the type of disorder, so the results of the assessment will be different. Therefore, this model also aggregates the results of the assessment using the rough set method to accommodate uncertain information from the results of expert assessments. Another advantage of developed FMEA model can be used for evaluating risk which the number of experts have a different opinion regarding the most importance RPN to consider although number of expert equal to number of criteria. And it definitely still accomodates uncertain information of experts assessment. This modified FMEA is able to use for prioritizing disruption as one of risk management generally in production process.

4. Conclusion

The FMEA model has been carried out by integrating any methods such as R-AHP and R-TOPSIS and has accommodated the level of uncertain information from experts, the level of importance of RPN, and considering the cost aspects in determining priorities. Our proposes model is effective to prioritize disruption in production process and able to make decision better than FMEA traditional. Although the proposed model can improve the shortcoming of FMEA traditional method, it still have a lot of limitation. The proposed will take a long time to implement if there are many RPN to consider. The optimal weight of each RPN will be obtained by much pair-wise comparison using AHP method.

Appendix A

Table A1

Linguistic Scale for AHP

Scale	Linguistic	Description
1	<i>Equal</i>	<i>The importance of RPN i is equal to RPN j</i>
3	<i>Moderate</i>	<i>RPN i is moderately important to RPN j</i>
5	<i>Important</i>	<i>RPN i is important to RPN</i>
7	<i>Very Important</i>	<i>RPN i is very important to RPN</i>
9	<i>Extreamly Important</i>	<i>RPN i is extreamly important to RPN</i>
2,4,6,8	<i>Value between scale</i>	<i>The value if there is vague between scale</i>

Table A2

Preference Scale for TOPSIS

Value	Occurrence (O)	Detection (D)
10	<i>Disruption Almost Inevitable (FI)</i>	<i>Absolute Uncertainty (AU)</i>
9	<i>Very High (VH)</i>	<i>Very Remote (VR)</i>
8	<i>Repeated Failure (RF)</i>	<i>Remote (R)</i>
7	<i>High (H)</i>	<i>Very Low (VL)</i>
6	<i>Moderately High (MH)</i>	<i>Low (L)</i>
5	<i>Moderate (M)</i>	<i>Moderately (M)</i>
4	<i>Relatively Low (RL)</i>	<i>Moderately High (MH)</i>
3	<i>Low (L)</i>	<i>High (H)</i>
2	<i>Remote (R)</i>	<i>Very High (VH)</i>
1	<i>Nearly Impossible (NI)</i>	<i>Almost Certain (AC)</i>

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