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## FUZZY FMEA RISK ASSESSMENT APPROACH FOR IFF SYSTEM IN MILITARY HELICOPTERS USING MATLAB R2022A

FUZZY HIBAMÓD ÉS HATÁSELEMZÉS ALKALMAZÁSA A KATONAI HELIKOPTEREK IDEGEN-BARÁT RENDSZEREINEK ELEMZÉSE SORÁN A MATLAB R2022A SZOFTVER FELHASZNÁLÁSÁVAL

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### **Abstract**

*In this article, the author reviews the fuzzy Failure Mode and Effect Analysis (fuzzy FMEA) as one of the effective methods of risk assessment. Using the fuzzy logic toolbox of the MATLAB R2022a software, the Identification Friend or Foe (IFF) system of military helicopters is analysed in a case study, during which the fuzzy risk priority numbers (F-RPN) for this system of military helicopters is created. Finally, the author of this paper summarizes the results obtained.*

**Keywords:** fuzzy, failure mode and effect analysis, case study, identification friend or foe, military helicopter

### **Absztrakt**

*A cikkben bemutatásra kerül a fuzzy hibamód és hatáselemzés, mint a kockázatelemzés egyik újszerű, hatékony módszere. A MATLAB R2022a szoftver fuzzy logika eszköztárának felhasználásával, egy eset tanulmány keretében elemezzük a katonai helikopterek idegen-barát rendszerét, amely során megalkotjuk a katonai helikopterek idegen-barát rendszerének fuzzy kockázat prioritási számait. Végezetül, a kapott az eredmények összefoglalásra kerülnek.*

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**Kulcsszavak:** fuzzy, hibamód és hatáselemzés, esettanulmány, idegen-barát rendszer, katonai helikopter

## Introduction

Nowadays, the reliability and safety are essential issues in the engineering including aviation. Modern technical systems should meet technical, safety, security, and environmental protection requirements. The risk of failure of technical devices and systems is basically the probability of occurrence, the severity of the consequence, and depends on the detectability of the error or the cause of it.

Increase the reliability of an integrated technical system - even design or during operation - the level of risk of possible failures possible together with the analysis. Failure Mode and Effect Analysis (FMEA) is the purpose of a technical system or process recognizing the potential for failure, the causes of it, and the risk ranking according to level. Description and application of the procedure different standards have been developed. An example is the IEC Standard Publication 60812 – edition 3.0 - Failure modes and effects analysis (FMEA and FMECA)<sup>2</sup>.

FMEA proves to be one of the most important early preventative actions in system, design and processor service which will prevent failures and errors from occurring and reaching the customer. The traditional FMEA determines the risk priorities of failure modes through the risk priority number (RPN), which is the product of the Occurrence (O), Severity (S) and Detectability (D) of a failure. However, the crisp risk priority number (RPN) have been considerably criticized for a variety of reasons <sup>3</sup>.

Fuzzy set theory<sup>4</sup> is a way to deal with exchanging the vulnerability of hypothetical relations into numerical systems. Many of the research-

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<sup>2</sup> IEC Standard Publication 60812 – edition 3.0 - Failure modes and effects analysis (FMEA and FMECA)

<sup>3</sup> Zhen Wang–Jian-Min Gao–Wang Rongxi–Kun Chen–Zhi-Yong Gao–Wei Zheng: Failure Mode and Effects Analysis by Using the House of Reliability-Based Rough VIKOR Approach, IEEE Transactions on Reliability, DOI: 10.1109/TR.2017.2778316, 2017. p. 3.

<sup>4</sup> Zadeh L.A.: Toward extended fuzzy logic — A first step, Fuzzy Sets and Systems, DOI: 10.1016/j.fss. 2009.04.009, 2009. pp-6.

ers assumed that fuzzy FMEA approach is the great foundation for obtaining accurate responses <sup>5</sup>. Most of the current investigations into fuzzy FMEA writing by utilizing "If – Then" rules. A literature review of fuzzy set theory based FMEA approaches was presented by Hu-Chen Liu, Long Liu and Nan Liuc<sup>6</sup>. Since then, some new developments and new applications of the fuzzy FMEA have been showed <sup>7</sup>.

The author has previously illustrated a review of reliability-based methods for risk assessment and their application to electronic warfare self-protection systems (EWSP)<sup>8</sup> and has already demonstrated the use of the fuzzy method in a fuzzy Analytic Hierarchy Process (F-AHP) analysis in previous publications<sup>9</sup>.

This paper presents a possibility of applying fuzzy FMEA to an EWSP such as identification friend or foe devices (IFF) to assess potential risks. Other similar example of applying this method was described by Jakkula Balaraju, Mandela Govinda et al.<sup>10</sup> and by Dino Rimantho and Mochammad Hatta<sup>11</sup>

The paper will be organized as follows: Section 1 shows the applied literatures. Section 1 words a possible evaluation method with Fuzzy Failure Mode Effect Analysis. Section 2 presents the possibility of use of the method by a case study. Section 3 encompasses the most important findings, conclusions, and future works of the author.

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<sup>5</sup> H. Gargama-S.K. Chaturvedi: Criticality assessment models for failure mode effects and criticality analysis using fuzzy logic, IEEE Trans. Reliab., 2011 pp. 102–110, <https://doi.org/10.1109/TR.2010.2103672>.

<sup>6</sup> Hu-Chen Liu-Long Liu-Nan Liuc: Risk evaluation approaches in failure mode and effects analysis: A literature review, DOI:10.1016/j.eswa.2012.08.010, 2013, pp 828-838

<sup>7</sup> Sohag Kabir-Yiannis Papadopoulos: A review of applications of fuzzy sets to safety and reliability engineering, International Journal of Approximate Reasoning, 2008, p. 12

<sup>8</sup> Domán László: Review of reliability-based methods for risk assessment and their application to electronic warfare self-protection systems in military helicopter, Repüléstudományi közlemények, 2021/3., pp. 1-12

<sup>9</sup> Domán László: Katonai helikopterek elektronikai hadviselés (önvédelmi rendszerek) értékelési szempontjaival összefüggő súlyszámok meghatározása Fuzzy AHP módszer felhasználásával, Ludovika Egyetemi Kiadó, 2022, pp. 1-20

<sup>10</sup> Jakkula Balaraju-Mandela Govinda Raj-Chivukula Suryanarayana-Murthy:Fuzzy-FMEA risk evaluation approach for LHD machine – A case study, Journal of Sustainable Mining, 2009, pp. 257-268, <https://doi.org/10.1016/j.jsm.2019.08.002>

<sup>11</sup> Dino Rimantho-Mochammad Hatta: Risk analysis of drinking water process in drinking water treatment using fuzzy FMEA Approach, Journal of Engineering and Applied Sciences, 2018, pp. 1-11

## Evaluation method with Fuzzy Failure Mode Effect Analysis

Fuzzy logic is an appropriate technique which is used to estimate the output response from given input data. There are a wide variety of reasons why fuzzy logic system are used:

- The concept of fuzzy logic is very easy to understand. The basics of math in a fuzzy interface system are also simple.
- It is flexible and tolerates data if there is any inappropriate data in the datasets.
- With this technique, complex nonlinear functions can be modelled in a short time.
- This approach can also enhance the experience of professionals due to the need for further training.
- This technique will work in simple natural language.

According to fuzzy methodology is a significant theory which deals with the breakdown of information. In fuzzy FMEA the risk indexed parameters such as Severity (S), Occurrence (O) and Detectability (D) are fuzzified with suitable membership functions. This is a knowledge-based approach and can be created with proficiency and knowledge in the form of fuzzy "If – Then" rule. More sensible and suitable knowledge-based model can be built using expert knowledge and decisions. The fuzzy conclusion is then de-fuzzified to acquire the fuzzy risk priority number (F-RPN) value<sup>12</sup>.

The three parameters discussed above are the severity of the effect of failure, the probability of occurrence, and the ease of detection for each failure mode. The traditional RPN is calculated by multiplying these three numbers as per the formula below:

$$RPN = S \cdot P \cdot D$$

where: S is the severity of the effect of failure,  
P is the probability of failure,

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<sup>12</sup> Jakkula Balaraju-Mandela Govinda Raj-Chivukula Suryanarayana-Murthy:Fuzzy-FMEA risk evaluation approach for LHD machine – A case study, Journal of Sustainable Mining, 2009, p. 4, <https://doi.org/10.1016/j.jsm.2019.08.002>

$D$  is the ease of detection<sup>13 14</sup>.

The concepts connected with fuzzy logic are shown in Figure 1.

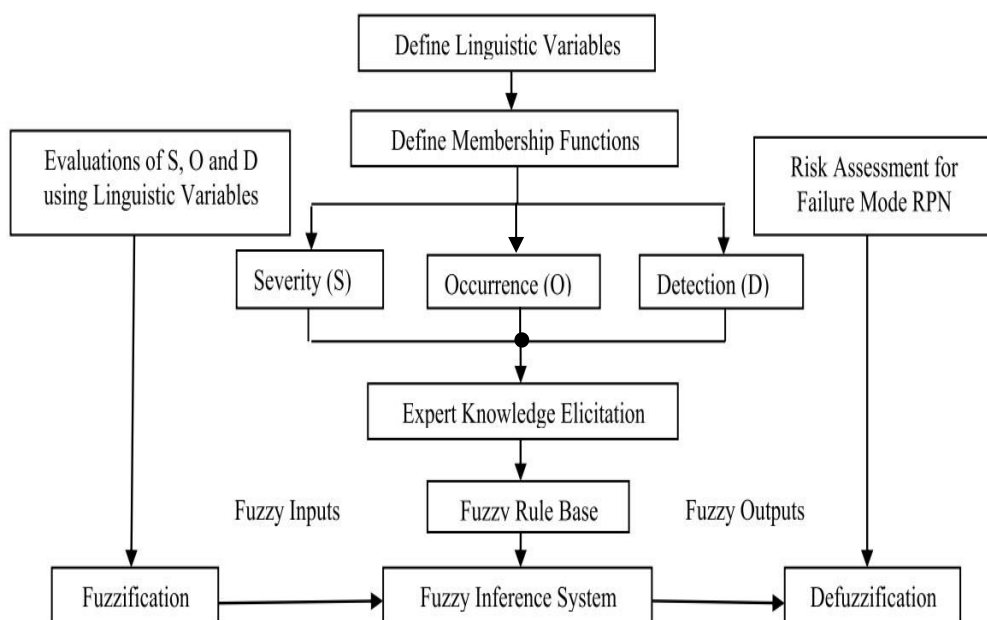


Figure 1. Flow chart of fuzzy FMEA method<sup>15</sup>

Fuzzification is a process used to transform input parameters into membership degree quantities, which express the input parameters in the form of qualitative linguistic terms<sup>16</sup>. Models that are based on fuzzy inference systems use linguistic terms and “If – Then” rules instead of numerical terms. Linguistic variables have their values expressed as words or sentences in a natural language describing degrees of membership. A fuzzy set, which belongs to these linguistic variables, is an extension of a crisp set in which each element can have binary membership, that is, either full membership or no membership.

<sup>13</sup> D.R.Kiran: Failure Modes and Effects Analysis, Total Quality Management, 2017, pp. 373-389, <https://doi.org/10.1016/B978-0-12-811035-5.00026-X>

<sup>14</sup> Dr.Dilber Uzun Ozsahin et al. : Fuzzy logic in medicine, Biomedical Signal Processing and Artificial Intelligence in Healthcare, 2020, pp. 153-182, <https://doi.org/10.1016/B978-0-12-818946-7.00006-8>

<sup>15</sup> Jakkula Balaraju-Mandela Govinda Raj-Chivukula Suryanarayana-Murthy:Fuzzy-FMEA risk evaluation approach for LHD machine – A case study, Journal of Sustainable Mining, 2009, p. 4, <https://doi.org/10.1016/j.jsm.2019.08.002>

<sup>16</sup> Sharma et al.: Systematic failure mode effect analysis (FMEA) using fuzzy Linguistic modelling, International Journal of Quality & Reliability Management, 2005, pp.986-1004, DOI: 10.1108/02656710510625248

The fuzzy rule base explains the level of criticality of a system for each combination of input variables.

In general, the combination of input variables can be created in linguistic form, for example, by using rule-based logic like “If – Then”, “Or – Else” etc. This can be created in two different ways namely, familiarity and proficiency of a specialist and process of the fuzzy based model<sup>17</sup>. Experts’ judgment and experience can be used to define the degree of membership function for a variable.

De-fuzzification is a process of looking at standard results after they have been normally included and that they will be the final output responses of the fuzzy controller <sup>18</sup>.

The characteristic of that group of techniques is that the output fuzzy set membership function is treated as a distribution, for which the average value is evaluated. Due to that heuristic approach, the output has continuous and smooth change for the change of values of input variable.

The most often used defuzzification techniques are grouped according to the basic methods used in them: a group is made of the basic technique and of all techniques extended from that basic technique. Extended techniques differ from the basic ones by introduced additional parameters. A fuzzy system designer defines more precisely the defuzzification process by defining those additional parameters.

- **Distribution methods and derivatives:**

The characteristic of that group of techniques is that the output fuzzy set membership function is treated as a distribution, for which the average value is evaluated.

- *centre-of gravity* technique, COG
  - *mean-of-maxima*, MeOM;
  - *basic defuzzification distributions*, BADD;

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<sup>17</sup> Yang G.: Life cycle reliability engineering. New Jersey, John Wiley & Sons, 2007, 978-0-471-71529-0.

<sup>18</sup> Sharma et al.: Systematic failure mode effect analysis (FMEA) using fuzzy Linguistic modelling, International Journal of Quality & Reliability Management, 2005, pp.986-1004, DOI: 10.1108/02656710510625248

- *generalized level set defuzzification*, GLSD;
- *indexed COG*, ICOG;
- *semi-linear defuzzification*, SLIDE;
- *fuzzy mean*, FM;
  - *weighted fuzzy mean technique*, WFM;
  - *quality technique*, QT;
  - *extended quality technique*, EQT.

- **Maxima techniques methods and derivatives:**

Maxima techniques give because of defuzzification an element from a fuzzy set core. A fuzzy set core consists of elements of a universe of discourse on which that set is defined with the highest degree of membership to the fuzzy set.

- *first-of-maxima technique*, FOM;
- *middle-of-maxima*, MOM;
- *last-of-maxima*, LOM;
- *random-choice-of maxima*, RCOM.

- **Area techniques:**

Area defuzzification techniques use area under the membership function to determine the defuzzification value.

- *centre-of-area technique*, COA;
- The *extended centre-of-area method*, ECOA;

- **Defuzzification techniques in the decision-making systems or miscellaneous methods:**

In the situations in which there are several output fuzzy variables, defuzzification can be considered as decision-making problem under fuzzy constraints.

- Constraint decision defuzzification (CDD);
- Fuzzy clustering defuzzification (FCD)<sup>19</sup>.

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<sup>19</sup> Nikos E Mastorakis et al: Analysis of Basic Defuzzification Techniques, Technical University of Sofia, 2002, pp. 1-7.

## Case study

In this analysis, a team of experts identifies all possible system failures of the subject and their causes. This is precisely the extent severity, occurrence, and detectability of specific causes of the risk. Expert opinions are subject to a degree of uncertainty due to different language categories and concepts. To demonstrate possibility of use of method submitted above in this chapter a case study will be shown. The evaluation was performed in several steps, the process of which was shown in Figure 1<sup>20 21 22 23</sup>.

Firstly, an expert group was set up whose members serve in the fields of aeronautical engineering, helicopter pilot, military operations, and electronic warfare. After that, the group of experts identified the subject all possible system errors and their causes. The degree of risk of the causes thus defined is determined by their occurrence, severity, and detection, usually as a product of the above three factors. As we did not have an adequate statistical data set to determine these factors in case of IFF system, we needed to use estimates based on expert judgment. However, the expert's opinions contain a certain degree of uncertainty due to the differently interpreted language categories and concepts.

In this research the identification of the risk was done by using Ishikawa method (cause and effect analysis). The analysed IFF was classified into five factors: Personnel, Methods, Equipment, Environment, Measurement. The Ishikawa (fishbone) diagram for Root Cause Analysis (RCA) of the IFF system is provided in Figure 2. This method was used by the author in previous research on a similar topic<sup>24</sup>.

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<sup>20</sup> Pokorádi László: Rendszerek és folyamatok modellezése, Debrecen, Campus kiadó, 2008, pp. 198-213

<sup>21</sup> Jakkula Balaraju-Mandela Govinda Raj-Chivukula Suryanarayana-Murthy: Fuzzy-FMEA risk evaluation approach for LHD machine – A case study, Journal of Sustainable Mining, 2009, p. 4, <https://doi.org/10.1016/j.jsm.2019.08.002>

<sup>22</sup> Dino Rimantho-Mochammad Hatta: Risk analysis of drinking water process in drinking water treatment using fuzzy FMEA Approach, Journal of Engineering and Applied Sciences, 2018, pp. 1-11

<sup>23</sup> Sohag Kabir-Yiannis Papadopoulos: A review of applications of fuzzy sets to safety and reliability engineering, International Journal of Approximate Reasoning, 2008, p. 40

<sup>24</sup> Domán László, Pokorádi László, Szilvássy László: Repülésszervezők idegen-barát felismerésének kockázatát befolyásoló tényezők ok-okozati elemzése, Repülés-tudományi közlemények, 2019/3. pp. 15–30., DOI: 10.32560/rk.2019.3.650



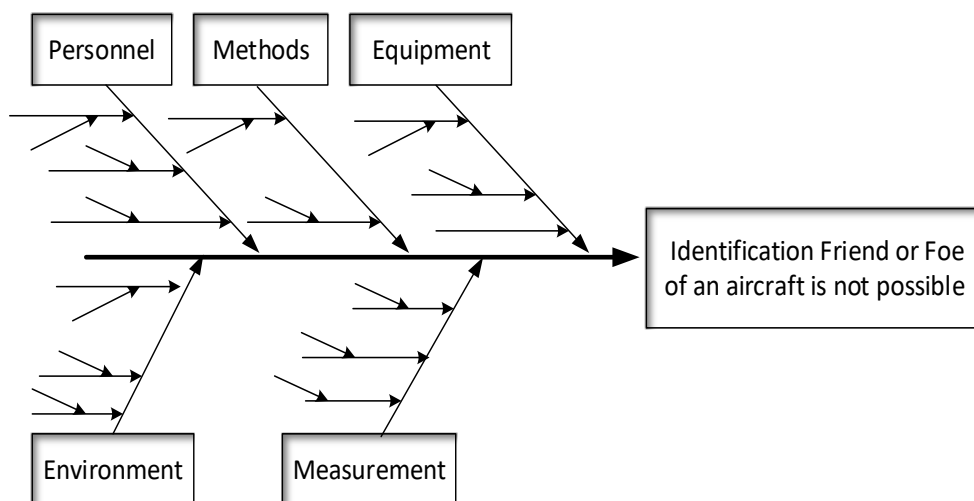


Figure 2. Ishikawa (fishbone) diagram for the Root Cause Analysis of the IFF [Made by author]

Figure 3 shows an example of AN/APX-123/A (V) MARK-XIIA IFF that is also used on military helicopters.



Figure 3. Mark XIIA AN/APX 123/A(V) IFF system<sup>25</sup>

In this research, by way of example, the equipment factor is presented. The Ishikawa diagram of the equipment factor is provided in figure 4.

<sup>25</sup> Keller John, BAE Systems to provide hundreds of aircraft IFF transponders under terms of \$34.3 million contract, Military aerospace, 2014, Online: <https://www.militaryaerospace.com/trusted-computing/article/16719001/bae-systems-to-provide-hundreds-of-aircraft-iff-transponders-under-terms-of-343-million-contract>.

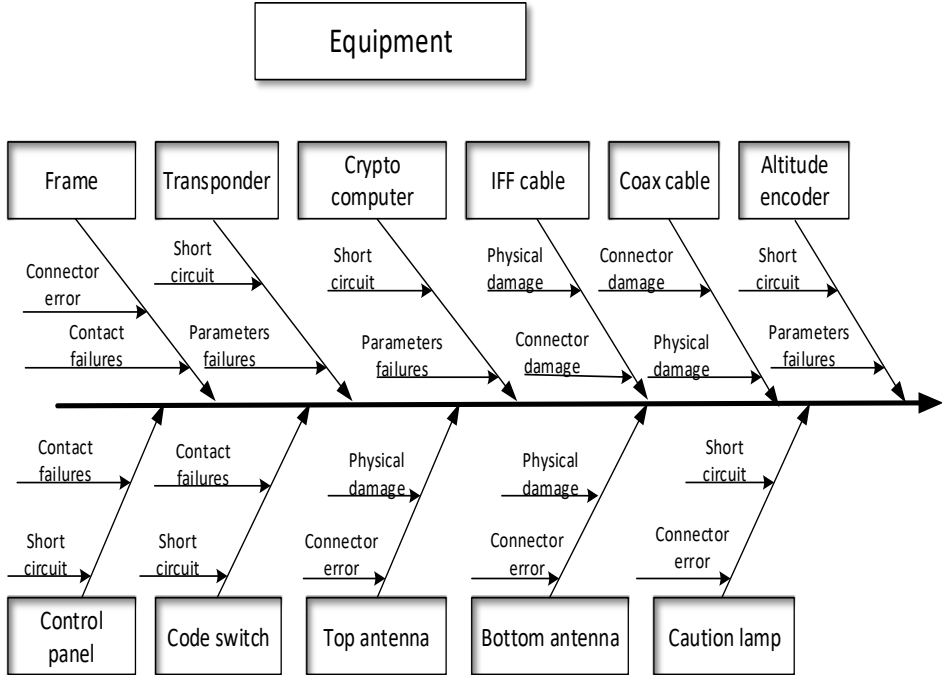


Figure 4. Ishikawa (fishbone) diagram for equipment factor [Made by author]

This factor was divided into 11 subsystems: Frame, Transponder, Crypto computer, Control panel Code switch, Top antenna, Bottom antenna, IFF cable, Coax cable, Caution lamp, Altitude encoder (Table 1).

CAUSE-EFFECT OF THE EQUIPMENT FACTOR

Table 1.

Failure Mode (Risk)	Cause	Effect
Frame Failure	Connector error	no data flow
	Contact failures	no data flow
Transponder Failure	Short circuit	identification not possible
	Parameter's fail-ures	identification not possible
Crypto computer Fail-ure	Short circuit	identification not possible
	Parameter's fail-ures	identification not possible
Control panel Failure	Short circuit	identification not possible
	Contact failures	no data flow

Code switch Failure	Short circuit	no data flow
	Contact failures	no data flow
Top antenna Failure	Physical damage	no data from upper air-space
	Connector error	no data from upper air-space
Bottom antenna Failure	Physical damage	no data from lower air-space
	Connector error	no data from lower air-space
IFF cable Failure	Physical damage	no data flow
	Connector damage	no data flow
Coax cable Failure	Physical damage	no/reduced signal level
	Connector damage	no/reduced signal level
Caution lamp Failure	Short circuit	no signal (feedback)
	Connector error	no signal (feedback)
Altitude encoder Failure	Short circuit	no altitude signal
	Parameter's failures	no altitude signal

[Made by author]

The next step was to define membership functions (Table 2) for the three risk factors Severity, (S), Occurrence (O), and Detectability (D). Once membership functions were defined, each risk factor was represented by linguistic variables. The input variables used were the S, O, and D, with five levels (Hazardous/Very High, High, Moderate, Low and None/Remote).

After that, expert judgement was collected regarding the three risk factors in the form of linguistic terms. Fuzzification process was done by changing the value of RPN into fuzzy risk priority number (F-RPN) using the MATLAB R2022A software Fuzzy Logic Toolbox Mamdani method with MIN implication function. The system is structured in two ways, such as Mamdani method and Sugeno methods. The Mamdani method is the most used method of discussing fuzzy methodology, so this was also used in this research

The results of the S, O and D scores were grouped into five linguistic level categories as in Table 2 and Table 3.

RISK INDEXED PARAMETERS (S, O, D) RANKING FOR RPN  
ESTIMATION<sup>26</sup>

Table 2.

Effect	Severity level (S)	Probability of occurrence (O)	Detection criteria (D)	Rating
Hazardous / Very High	When a potential failure mode effects	Very high: failure is almost unavoidable (>1 in 2)	Control actions are not available	10-9
High	System inoperable due to destructive failure	High: repeated failure, A process that has often failed (1 in 8)	Low possibility of noticing the breakdown	8-7
Moderate	System inoperable with minor or notable	Moderate: infrequent failures with little impact (1 in 80)	Low chance of detecting a possible cause and consequent failure mode	6-5
Low	System operable with relatively few failures	Low: relatively few failures are associated with similar process (1 in 2000)	Reasonably high possibility of noticing the possible reasons for occurrence of breakdown	4-3
None / Remote	No effect	Remote: failure is implausible (1 in 150000)	Required control are available to detect a failure mode	2-1

[Made by author]

All the functional failures of the IFF system with potential failure modes and the conventional RPN ( $RPN=S \times O \times D$ ) were given in Table 3.

<sup>26</sup> Chin K.S., Chan A. and Yang j. B.: Development of a fuzzy FMEA based product design system. International Journal of Advanced Manufacturing Technology, 2008, pp. 633–649.

## ESTIMATED VALUES OF RISK INDEXED PARAMETERS

Table 3.

Failure mode	Cause	Severity (S)	Occurrence (O)	Detectability (D)	RPN
Frame Failure	Connector error	9	1	4	36
	Contact failures	7	2	5	70
Transponder Failure	Short circuit	10	7	2	140
	Parameter's failures	7	6	2	84
Crypto computer Failure	Short circuit	10	5	2	100
	Parameter's failures	8	3	2	48
Control panel Failure	Short circuit	6	4	3	72
	Contact failures	7	2	5	70
Code switch Failure	Short circuit	2	4	3	24
	Contact failures	2	2	5	20
Top antenna Failure	Physical damage	10	1	4	40
	Connector error	7	2	3	35
Bottom antenna Failure	Physical damage	10	4	1	40
	Connector error	7	2	3	35
IFF cable Failure	Physical damage	9	1	7	63
	Connector damage	9	1	5	45
Coax cable Failure	Physical damage	5	1	7	35
	Connector damage	7	1	4	28
Caution lamp Failure	Short circuit	6	3	2	36
	Connector error	7	2	3	35
Altitude encoder Failure	Short circuit	2	6	3	36
	Parameter's failures	2	6	1	12

[Made by author]

Secondly, the selection of the most relevant defuzzification methods for application to IFF system was done with the expert group and proposal of defuzzification methods. The first stage aimed at identifying the various types of defuzzification approaches (associated with the mean, minimum value, etc.), presented above.

The next step was to select the appropriate defuzzification methods (centroid - centre of gravity) and the parameters of the methods chosen were determined.

The membership functions were added using the MATLAB R2022A software Fuzzy Logic Toolbox Fuzzy Interface System (FIS) Editor (Figure 5).

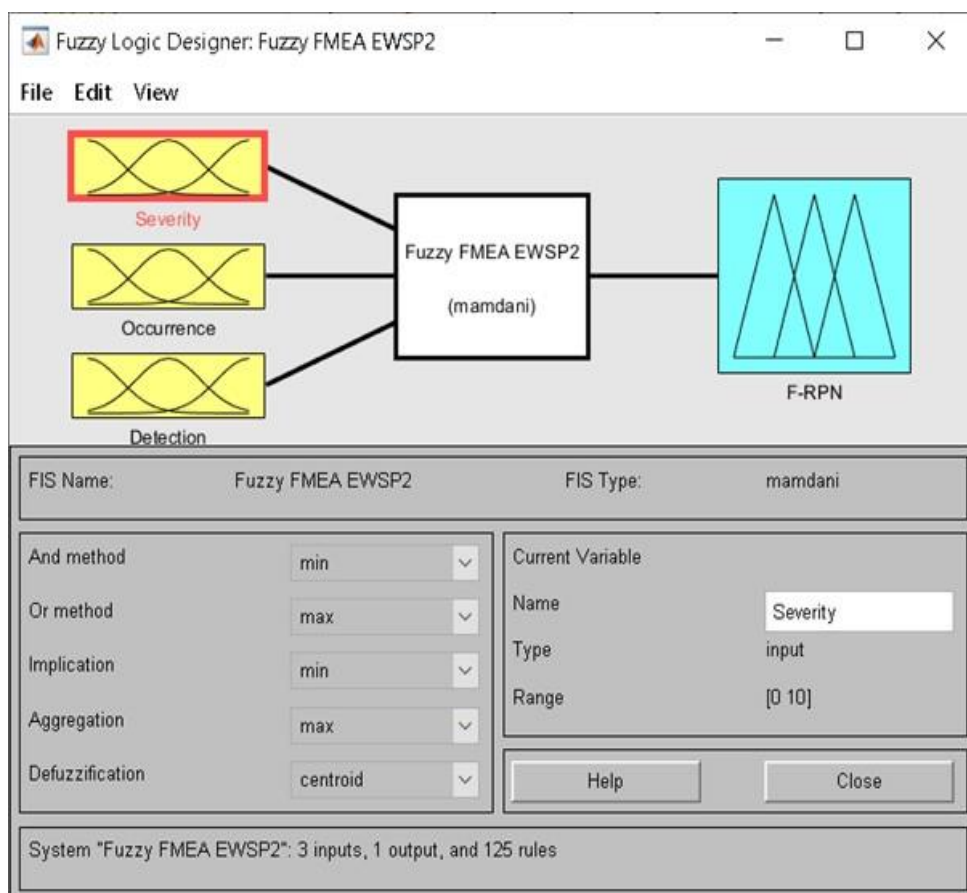


Figure 5. FIS editor [Made by Author]

In general, the term severity describes the severity/risk/hazard level of the failed part/component.

In accordance with the level of significance, the severity ranking was allotted in a 1–10-point scale. The level in this severity scale was estimated based on the familiarity and proficiency of the expert group.

The occurrence is the probability of an exact failure happened during a considered period. This was estimated based on the frequency of the occurrence of a break down. Occurrence ranking was also given a severity ranking using a scale of 1–10. The value 10 represents the highest probability of occurrence and similarly and, 1 the lowest probability of occurrence.

Detectability defines the likelihood of the detection of a failure mode, and it could also be expressed as the ability of a person to detect the potential breakdown mode and its consequence. The detectability was also estimated using a 1–10-point scale. The lowest value of detectability was assigned when there was no current control action for the failure mode. These parameters were used to estimate the fuzzy risk priority number (F-RPN). The criticality of the component was decided based on the prioritization of a failure mode<sup>27</sup>. The method used is fuzzy FMEA, with input used in the form of assessment of S, O and D, and output is an F-RPN. The input membership function (categories, curve type, parameter) for each risk factors are given in Table 4 and shown in Figure 6, 7 and 8.

PARAMETER OF MEMBERSHIP FUNCTION OF INPUT VARIABLE

Table 4

Categories	Curve type	Parameter
Hazardous/Very High	Trapezoidal	[7,75 9,75 10,25 12,75]
High	Trapezoidal	[5,25 7,25 7,75 9,75]
Moderate	Trapezoidal	[2,75 4,75 5,25 7,75]
Low	Trapezoidal	[0,25 2,25 2,75 4,75]
None/Remote	Trapezoidal	[-2,25 -0,25 0,25 2,25]

[Made by author]

<sup>27</sup> Zadeh L. A.–Desoer C.A.: Fuzzy sets. IEEE Information and Control, 1965, pp. 338–353

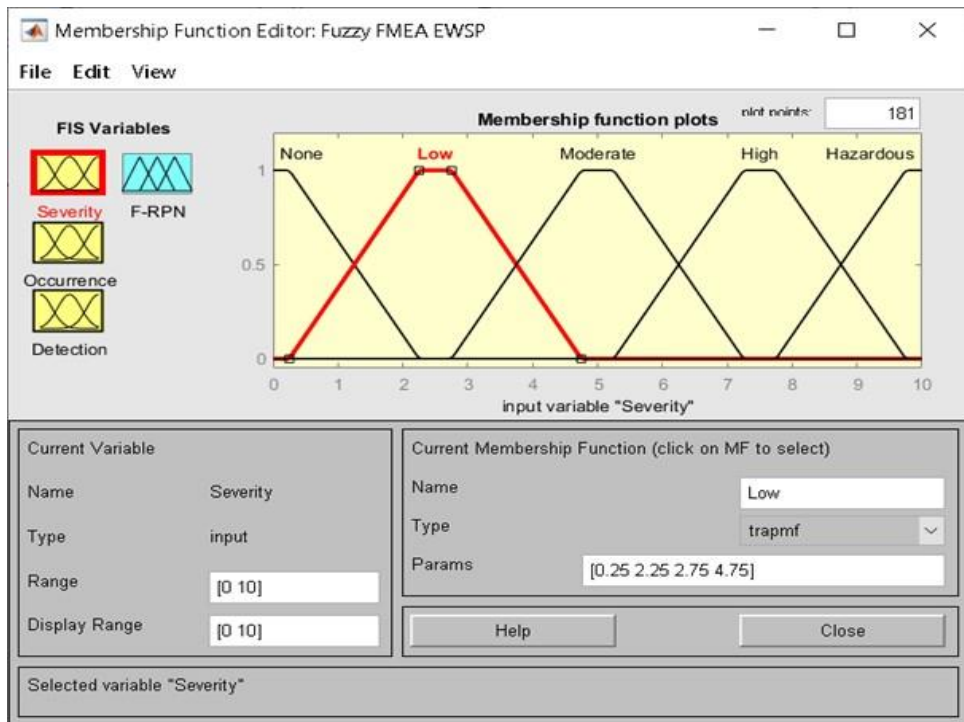


Figure 6. Membership function editor, severity [Made by Author]

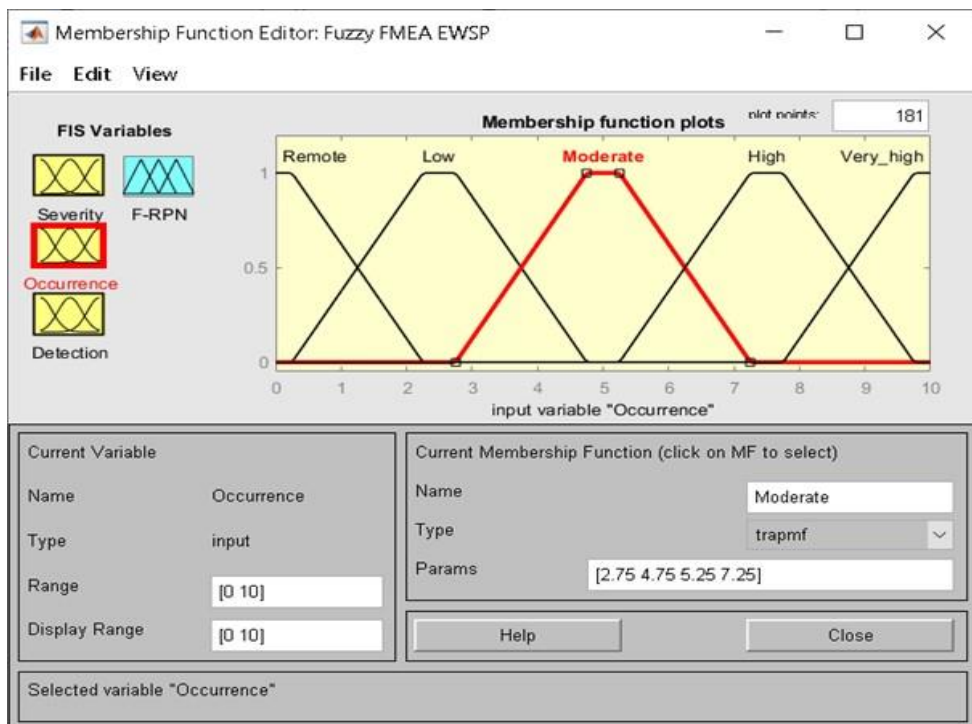


Figure 7. Membership function editor, occurrence [Made by author]



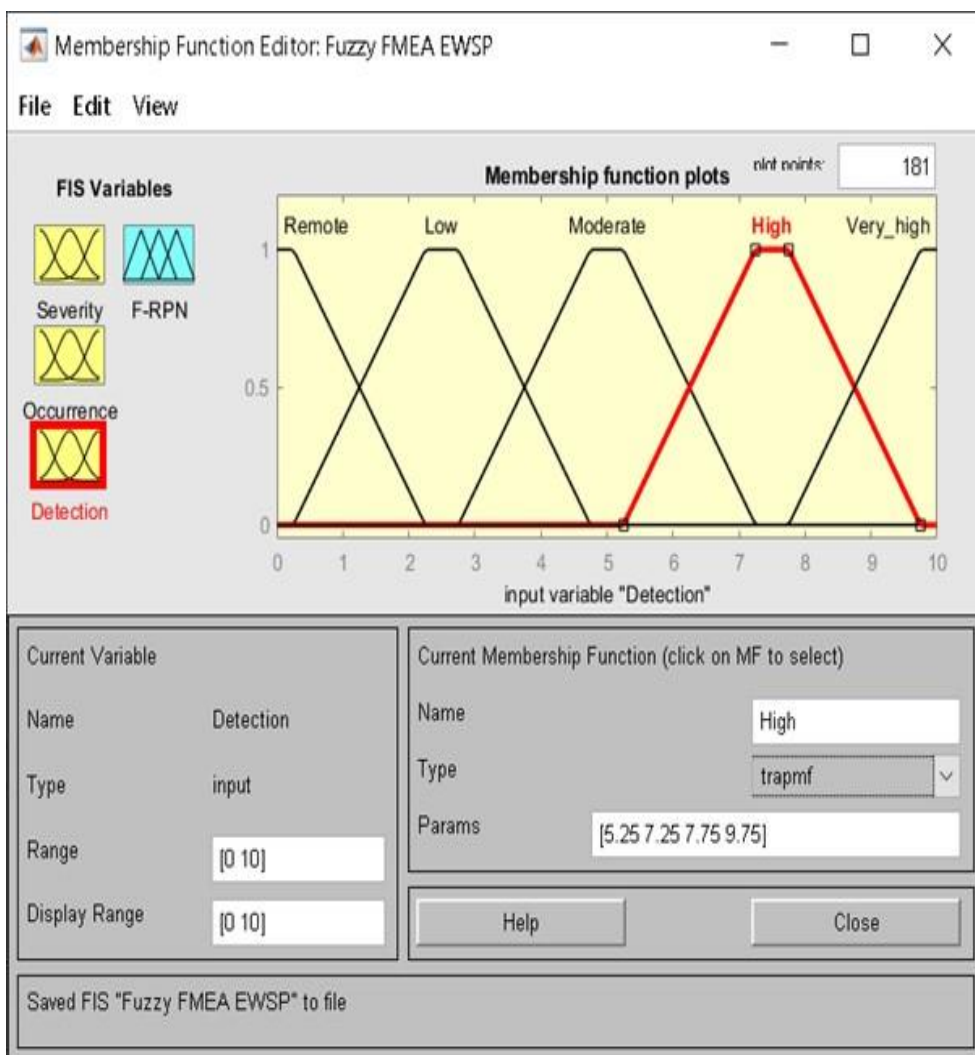


Figure 8. Membership function editor, detection [Made by Author]

Output of value F-RPN applied to represent the priority of corrective action to the rating scale of 1-1000. The F-RPN was categorized in nine interval classes, such as None, Very Low, Low, Low Moderate, Moderate, High Moderate, Low High, High and Hazardous. The categories of output variables are presented in the Table 5<sup>28</sup>. The membership function of the output variable and its parameters was determined based on the type of curve used (Table 6 and Figure 9).

<sup>28</sup> Dino Rimantho-Mochammad Hatta: Risk analysis of drinking water process in drinking water treatment using fuzzy FMEA Approach, Journal of Engineering and Applied Sciences, 2018, pp. 1-11

## CATEGORY OF OUTPUT VARIABLES ON FMEA FUZZY

Table 5.

<b>Output value</b>	<b>Category</b>
None (N)	1-50
Very Low (V_L)	51-100
Low (L)	101-150
Low Moderate (L_M)	151-250
Moderate (M)	251-350
High Moderate (H_M)	351-450
Low High (L_H)	451-600
High	601-800
Hazardous	801-1000

[Made by Author]

## PARAMETER OF MEMBERSHIP FUNCTION OF OUTPUT VARIABLE

Table 6

<b>Categories</b>	<b>Curve type</b>	<b>Parameter</b>
None (N)	Trapezoid	[-50 0 25 75]
Very Low (V_L)	Triangle	[25 75 125]
Low (L)	Triangle	[75 125 200]
Low Moderate (L_M)	Triangle	[125 200 300]
Moderate (M)	Triangle	[200 300 400]
High Moderate (H_M)	Triangle	[300 400 500]
Low High (L_H)	Triangle	[400 500 700]
High	Triangle	[500 700 900]
Hazardous	Trapezoid	[700 900 1000 1200]

[Made by Author]

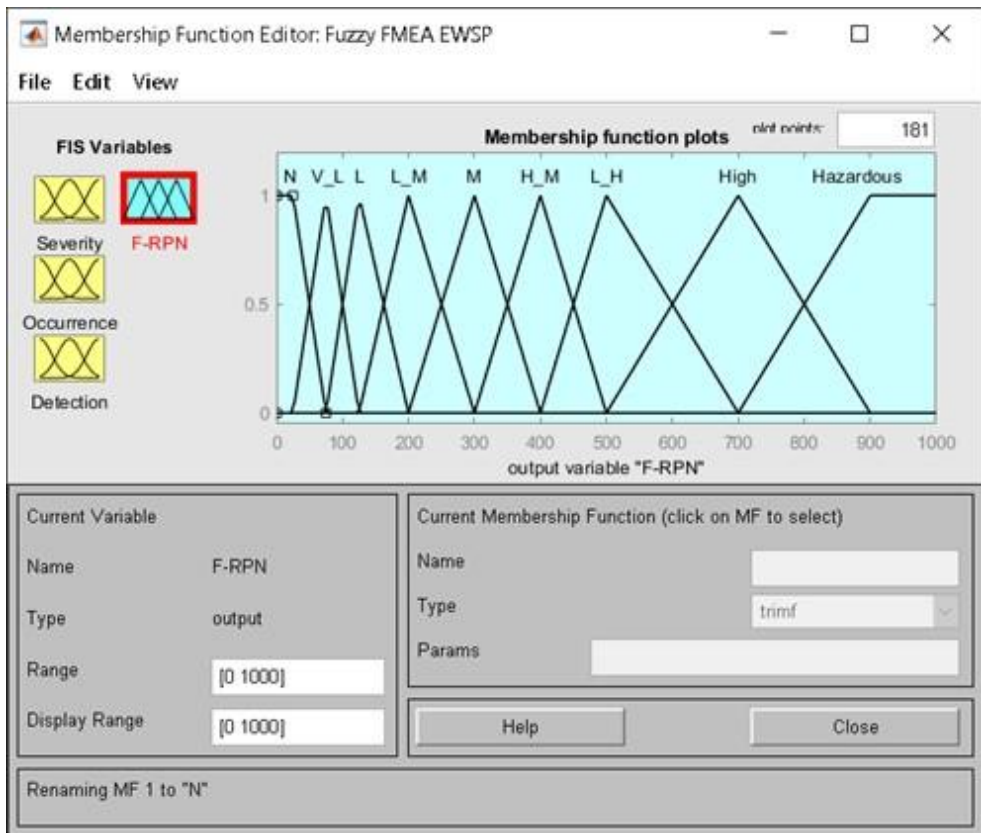


Figure 9. Membership function editor, Fuzzy-RPN [Made by Author]

The next step was to define “If – Then” rules to map the expert judgement regarding failure modes to fuzzy numbers.

The fuzzy inference system is used for the combination “If – Then” fuzzy rules in the rule base and fuzzy consequences.

The minimum inference system uses the min operator for "And" on the “If” side of the fuzzy rule and the max operator for "Or" of the rule. Combined operators were used to aggregate combinations consequences into a single rule. The result of the aggregation was then de-fuzzified to obtain the crisp value.

The input variables used were as follows Severity (S), Occurrence (O), and Detectability (D), five linguistic category levels (None/Remote, Low, Moderate, High, Very high/Hazardous) to get 125 fuzzy rule bases combinations. A combination of this FMEA fuzzy rule the basis is shown in the following example:

- IF Severity is None and Occurrence is Very high and Detection is Moderate THEN F-RPN is Low;

- IF Severity is Low and Occurrence is Moderate and Detection is Very high THEN F-RPN is Low moderate;
- IF Severity is Moderate and Occurrence is Remote and Detection is High THEN F-RPN is Very low;
- IF Severity is High and Occurrence is Remote and Detection is High THEN F-RPN is Low;
- IF Severity is High and Occurrence is High and Detection is Low THEN F-RPN is Moderate;
- IF Severity is Hazardous and Occurrence is Moderate and Detection is Low THEN F-RPN is Low Moderate.

In this analysis, the Rule Editor function of software was used to edit the list of rules, which characterizes the conduct of the framework (Figure 10 and 11).

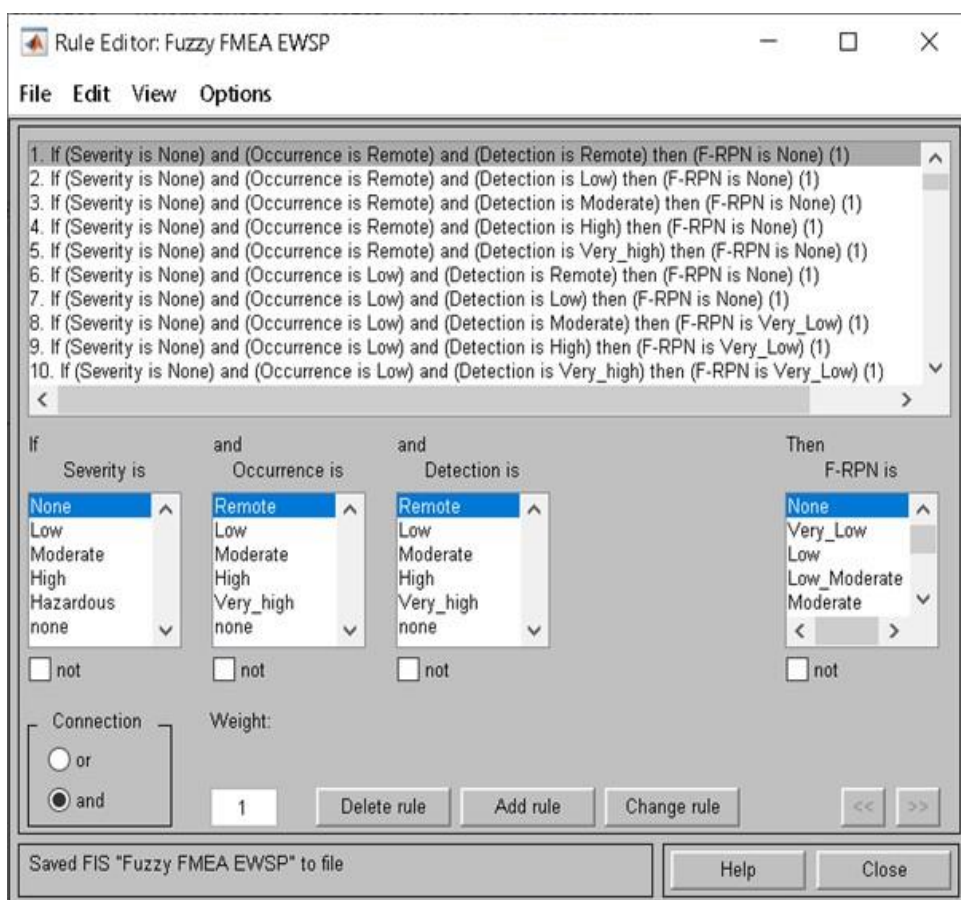


Figure 10. Rule editor [Made by Author]

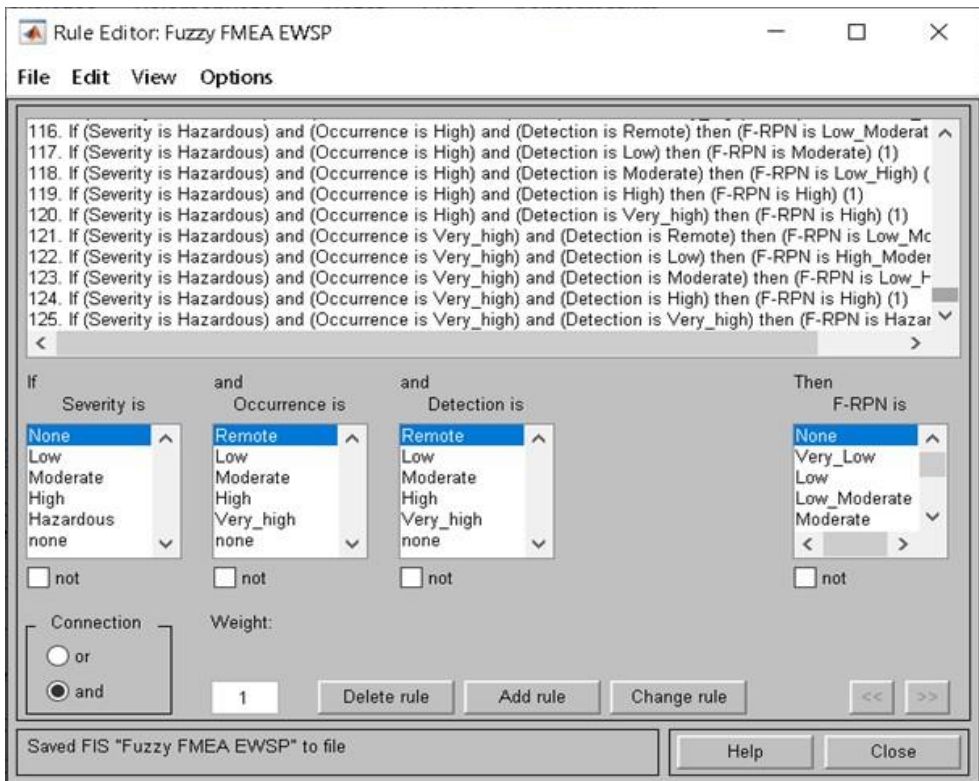


Figure 11. Rule editor [Made by Author]

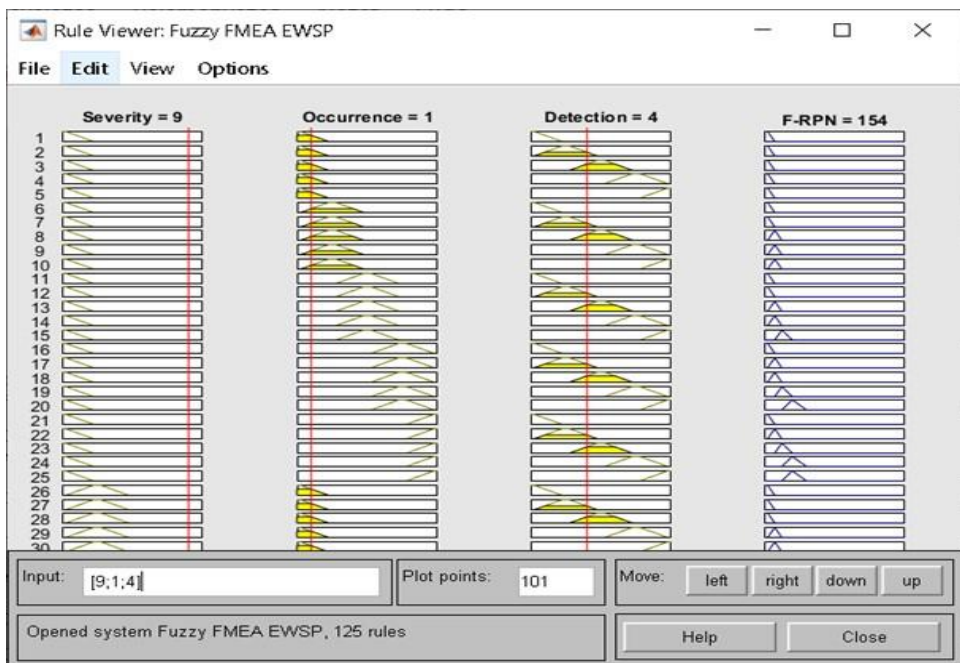
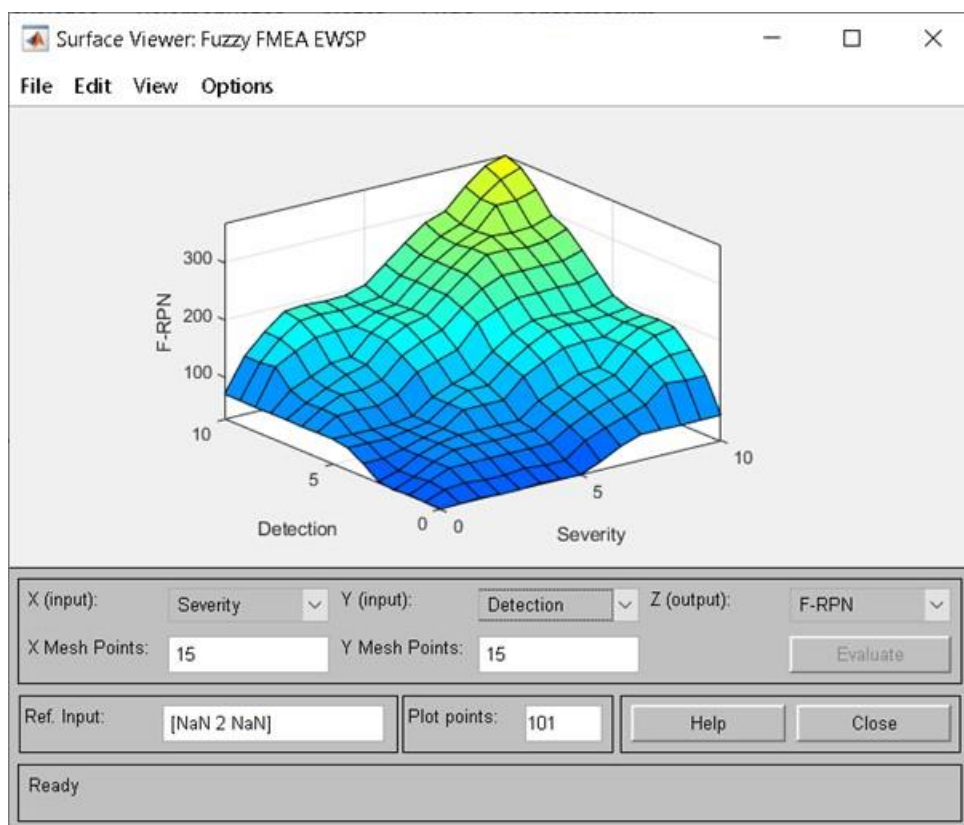


Figure 12. Rule viewer [Made by Author]

The Rule Editor is a MATLAB-based logic unit which helped to add the rules in a linguistic form. The dependency of the output parameter should be dependent upon the given linguistic format input data. The process was performed in MATLAB based fuzzy analysis for the created combination of input rules. Finally, the MATLAB Rule Viewer function was prepared to demonstrate how the rules were fuzzyfied as shown in Figure 12.

The Surface Viewer function of software (Figure 13) helped to view the dependency of the output on one or two of the inputs, such as severity and detection<sup>29</sup>. In this analysis, the presented surface viewer is a three-dimensional mapping view with severity, detection and F-RPN. From the plot it was noticed that the maximum amount of dependency of F-RPN (278) was obtained for the severity (10) and detection (2).



*Figure 13. Surface viewer [Made by Author]*

<sup>29</sup> Rengith V.R.-Madhavan Dilip: Fuzzy FMECA (failure mode effect and criticality analysis) of LNG storage facility. Journal of Loss Prevention in the Process Industries, pp. 537–547. <https://doi.org/10.1016/j.jlp.2018.01.002>.

## Results and discussion

The proposed Fuzzy-FMEA approach provides information on possibility of occurrence of the various potential failure modes with identical F-RPN values (Table 7). MATLAB based F-RPN values were obtained directly from the software fuzzy interface. This helped to reduce the burden of the prioritization of F-RPN rankings.

ESTIMATED VALUES OF RISK INDEXED PARAMETERS AND F-RPN METRICS

Table 7.

Failure Mode	Cause	Severity (S)	Occurrence (O)	Detectability (D)	F-RPN
Frame Failure	Connector error	9	1	4	154
	Contact failures	7	2	5	191
Transponder Failure	Short circuit	10	7	2	278
	Parameter's failures	7	6	2	213
Crypto computer Failure	Short circuit	10	5	2	201
	Parameter's failures	8	3	2	144
Control panel Failure	Short circuit	6	4	3	160
	Contact failures	7	2	5	191
Code switch Failure	Short circuit	2	4	3	83,9
	Contact failures	2	2	5	70,2
Top antenna Failure	Physical damage	10	1	4	154
	Connector error	7	2	3	138
Bottom antenna Failure	Physical damage	10	4	1	154
	Connector error	7	2	3	138
IFF cable Failure	Physical damage	9	1	7	221
	Connector damage	9	1	5	154
Coax cable Failure	Physical damage	5	1	7	150
	Connector damage	7	1	4	143
Caution lamp Failure	Short circuit	6	3	2	98,7
	Connector error	7	2	3	138
Altitude encoder Failure	Short circuit	2	6	3	120
	Parameter's failures	2	6	1	79,6

[Made by author]



### ***Comparison of conventional FMEA and fuzzy FMEA results***

In general, it was assumed that all the risk indexed parameters are equally important. The ranking of S, O, and D were assigned based on expert decisions in a range of 1–10 scale. The traditional RPN values were calculated for each individual potential failure mode with the multiplication of risk indexed parameters, presented above.

The RPN and F-RPN values and the priority ranking of conventional FMEA and Fuzzy based FMEA for the analysed IFF system is shown in Table 8. The failure modes and rankings were ranked based on the calculated RPN results. These were predicted by multiplying risk-indexed parameters such as S, O, and D in the traditional FMEA approach. MATLAB R2022a fuzzy toolbox-based F-RPN values were obtained directly from the interface.

COMPARISON OF CONVENTIONAL FMEA AND FUZZY FMEA RPN VALUES

Table 8.

<b>Failure mode</b>	<b>Cause</b>	<b>Conven- tional RPN</b>	<b>Rank- ing</b>	<b>Fuzzy RPN</b>	<b>Fuzzy ranking</b>
Frame Failure	Connector error	36	14	154	8
	Contact failures	70	5	191	5
Transponder Failure	Short circuit	140	1	278	1
	Parameter's failures	84	3	213	3
Crypto com- puter Failure	Short circuit	100	2	201	4
	Parameter's failures	48	8	144	13
Control panel Failure	Short circuit	72	4	160	7
	Contact failures	70	6	191	6
Code switch Failure	Short circuit	24	20	83,9	20
	Contact failures	20	21	70,2	22
Top antenna Failure	Physical damage	40	11	154	8
	Connector error	35	15	138	15



Bottom antenna Failure	Physical damage	40	10	154	8
	Connector error	35	16	138	15
IFF cable Failure	Physical damage	63	7	221	2
	Connector damage	45	9	154	8
Coax cable Failure	Physical damage	35	17	150	12
	Connector damage	28	19	143	14
Caution lamp Failure	Short circuit	36	12	98,7	19
	Connector error	35	18	138	15
Altitude encoder Failure	Short circuit	36	13	120	18
	Parameter's failures	12	22	79,6	21

[Made by author]

## Conclusion

In general, it can be said that reliable equipment must remain in good condition over time. The main reason for the decrease in the performance of equipment is the occurrence of unexpected failures. These failures occur for several reasons, including inefficient maintenance and operation measures, and a harsh work environment. Therefore, the evaluation and risk analysis are required to improve or eliminate failures before system performance declines.

In this research, the failure behaviour of an IFF system was analysed within each possible failure mode. This analysis provides information on several aspects, such as the current operating status of the system, the causes of the failure modes, and the effect of the failure modes on equipment performance, and so on. These studies also evaluate the prediction of necessary practices or control measures such as possible design changes and replacement of parts to ensure the required level of availability.

From the results of the traditional FMEA (Table 8), it can be observed that the highest level of RPN was achieved by the transponder short-circuit (140) and the crypto computer short-circuit (100). The RPN value provides guidance on prioritizing fault modes and can be used to minimize the severity and occurrence of the fault mode. It can also be helpful to suggest changes needed to improve a plan or process. It was concluded that the higher level of RPN is due to the high severity level and the maximum probability of occurrence of potential failures. If the RPN value is high, the effect of the fault mode is more critical. This effect reduces the life of the equipment. This can be improved by performing preventive maintenance from time to time and by maintenance personnel and raising awareness of each component.

In this article due to a suggestion from previous research<sup>30</sup>, the method used in this risk assessment is fuzzy FMEA (fuzzy failure mode and effect analysis), with input Severity (S), Occurrence (O) and Detectability (D), and output value of fuzzy risk priority number. Based on the brainstorming process of an expert group and FMEA fuzzy analysis results could be concluded that, the main risks in IFF system are equipment, human, measurement, methods, and environment.

In this paper the MATLAB R2022A based software fuzzy toolbox was used to analyse the data. The fuzzy FMEA technique can also help to accurately rank fault modes if two or more are of the same rank. From the results (Table 8), rank 1 (transponder short-circuit – 278) and 2 (IFF cable physical damage –221) were assigned to the highest value of the F-RPN. Failure modes with the highest F-RPN have been treated as a critical component, so it is recommended that the highest F-RPN be monitored, and any necessary repairs or replacements be performed to extend the life of the equipment. In some cases, it may be necessary to replace a part if it is not possible to repair the defective parts at the time of the preventive maintenance.

This technique can also assess the hazards and criticality of IFF system by characterizing the MATLAB database of fuzzy “If-Then” guidelines. This technique considers vague and ambiguous data during the evaluation process. It was concluded that the rule based fuzzy FMEA analysis provides strong evidence that the proposed method is

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<sup>30</sup> Domán László: Review of reliability-based methods for risk assessment and their application to electronic warfare self-protection systems in military helicopter, *Repüléstudományi közlemények*, 2021/3., pp. 1-12

logically useful for ranking F-RPN values. This analysis not only identified the limitations associated with RPN of traditional FMEA approach, but also estimated the reasons for the occurrence of possible failure modes in a complex system that could be repaired. In addition, the fuzzy rule base should be modified or updated if additional failure information will be available.<sup>31</sup>

## References

1. Balaraju Jakkula–Govinda Raj Mandela–Suryanarayana Chivukula Murthy: Fuzzy-FMEA risk evaluation approach for LHD machine – A case study, *Journal of Sustainable Mining*, 2009, pp. 257-268, <https://doi.org/10.1016/j.jsm.2019.08.002>
2. Chin K.S.–Chan A.–Yang j. B.: Development of a fuzzy FMEA based product design system. *International Journal of Advanced Manufacturing Technology*, 2008, pp. 633–649
3. Domán László: Review of reliability-based methods for risk assessment and their application to electronic warfare self-protection systems in military helicopter, *Repüléstudományi közlemények*, 2022/1., pp. 1-12
4. Domán László: Katonai helikopterek elektronikai hadviselés (önvédelmi rendszerek) értékelési szempontjaival összefüggő súlyszámok meghatározása Fuzzy AHP módszer felhasználásával, In Földi László (szerk.) *Szemelvények a katonai műszaki tudományok eredményeiből III.*, Ludovika Egyetemi Kiadó, 2022, pp. 1-20
5. Domán László, Pokorádi László, Szilvássy László: Repülőeszközök idegen-barát felismerésének kockázatát befolyásoló tényezők okozati elemzése, *Repüléstudományi közlemények*, 2019/3. pp. 15–30., DOI: 10.32560/rk.2019.3.650
6. Dr.Dilber Uzun Ozsahin et al.: Fuzzy logic in medicine, *Biomedical Signal Processing and Artificial Intelligence in Healthcare*, 2020, pp. 153-182, <https://doi.org/10.1016/B978-0-12-818946-7.00006-8>
7. Gargama H.–Chaturvedi S.K.: Criticality assessment models for failure mode effects and criticality analysis using fuzzy logic, *IEEE Trans. Reliab.*, 2011 pp. 102–110, <https://doi.org/10.1109/TR.2010.2103672>.

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<sup>31</sup> Jakkula Balaraju-Mandela Govinda Raj-Chivukula Suryanarayana-Murthy:Fuzzy-FMEA risk evaluation approach for LHD machine – A case study, *Journal of Sustainable Mining*, 2009, pp. 257-268, <https://doi.org/10.1016/j.jsm.2019.08.002>

8. Hu-Chen Liu–Long Liu–Nan Liuc: Risk evaluation approaches in failure mode and effects analysis: A literature review, DOI:10.1016/j.eswa.2012.08.010, 2013, pp 828-838
9. IEC Standard Publication 60812 – edition 3.0 - Failure modes and effects analysis (FMEA and FMECA)
10. Kabir Sohag–Papadopoulos Yiannis: A review of applications of fuzzy sets to safety and reliability engineering, International Journal of Approximate Reasoning, 2008, pp. 29-55
11. Keller John: BAE Systems to provide hundreds of aircraft IFF transponders under terms of \$34.3 million contract, Military aerospace, 2014.  
Online: <https://www.militaryaerospace.com/trusted-computing/article/16719001/bae-systems-to-provide-hundreds-of-aircraft-iff-transponders-under-terms-of-343-million-contract> (Downloaded: 31 03 2021).
12. Kiran D.R.: Failure Modes and Effects Analysis, Total Quality Management, 2017, pp. 373-389  
<https://doi.org/10.1016/B978-0-12-811035-5.00026-X>
13. Mastorakis Nikos E. et al: Analysis of Basic Defuzzification Techniques, Technical University of Sofia, 2002, pp. 1-7.
14. Pokorádi László: Rendszerek és folyamatok modellezése, Debrecen, Campus kiadó, 2008, pp. 198-213
15. Rengith V.R.–Madhavan Dilip: Fuzzy FMECA (failure mode effect and criticality analysis) of LNG storage facility. Journal of Loss Prevention in the Process Industries, pp. 537–547.  
<https://doi.org/10.1016/j.jlp.2018.01.002>.
16. Rimantho Dino–Hatta Mochammad: Risk analysis of drinking water process in drinking water treatment using fuzzy FMEA Approach, Journal of Engineering and Applied Sciences, 2018, pp. 1-11
17. Sharma et al.: Systematic failure mode effect analysis (FMEA) using fuzzy Linguistic modelling, International Journal of Quality & Reliability Management, 2005, pp.986-1004.  
DOI: 10.1108/02656710510625248
18. Wang Zhen – Gao Jian-Min –Rongxi Wang – Chen Kun – Gao Zhi-Yong – Zheng Wei: Failure Mode and Effects Analysis by Using the House of Reliability-Based Rough VIKOR Approach, IEEE Transactions on Reliability, DOI: 10.1109/TR.2017.2778316, 2017. p. 3.

19. Yang G.: Life cycle reliability engineering. New Jersey, John Wiley & Sons, 2007, 978-0-471-71529-0.
20. Zadeh L. A.–Desoer C.A.: Fuzzy sets. IEEE Information and Control, 1965, pp. 338–353
21. Zadeh L. A.: Toward extended fuzzy logic — A first step, Fuzzy Sets and Systems, DOI:10.1016/j.fss.2009.04.009, 2009. pp-6.