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Integrated Risk Assessment Analysis with Fuzzy Logic

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Abstract: In a developing business, it has a very important to share in terms of competitive advantage by detecting and directing the errors before occur. There are many methods in the literature for the early detection and prioritization of these failures. Failure modes and effects analysis (FMEA) is also a common method of choice. The uncertainty and flexibility problem arising from error types analysis has been eliminated by integrating fuzzy FMEA. The probability, severity, and discoverability values determined for each error were examined with error types, effects and fuzzy logic methods. Probability, severity, and discoverability values are considered and analyzed. Each method was listed according to the determined risk process network values and expert opinion, and comparisons were made between the methods.

1. Introduction

Developing technology makes it unavoidable for companies to ensure such improvement efforts and customer satisfaction in order to survive. The markets are huge, and customers can easily access and reach the better option. At this point, companies examine their own processes and identify potential errors. This requires prioritization along with the detection of errors. FMEA includes the probability, severity, and discoverability values which are given to potential errors determined by using expert opinions and numerical data, and the values of the risk priority number (RPN) that are calculated [1]. This method may yield non-objective results. At this point, the deficiencies that occurred were wanted to be met with other methods. The fuzzy logic approach preferred for the analysis of the data in flexibility [2-4]. Comparisons were made between the methods as a result of the application in terms of advantages. These comparisons were made using statistical methods. The application area of the study is a facility that produces cables. During cable production, all processes of a cable were examined. Errors encountered after the examination were determined [5-8]. Probability, severity, and discoverability values were given to these errors and RPN values were calculated. A comparison was made between the RPN values calculated and compared with FMEA and fuzzy FMEA. It has been examined whether there is an advantage between these methods.

2. Literature Survey

By making the analysis more comprehensive, it considers the probability, severity and discoverability values, which are lacking in traditional error types and effects, are all of the same importance and eliminate the possibility of being relative. In order to increase the efficiency and market share of a fertilizer producing company, error types and effects analysis were applied[9-12]. In order to eliminate the points where the error types and their effects are insufficient as a result of the application, the gray relational method was also used and the relationship between the error types and each other was examined by compatibility analysis[13-16]. The automotive sector is one of the sectors with the most significant investment share. Manufacturing processes are also a very long and extensive process. There are many risky events and operations in this process. Since there is a lot of risk in the process, it is normal to have errors in the cars given to the customer[17-19]. In the first part of the study, error types and effects analysis was applied. Error types are then prioritized with gray relational and fuzzy logic. In today's conditions, where everything is more interconnected and intertwined, it is insufficient to prioritize using only error types. The use of fuzzy logic and gray relational method makes it more effective and flexible[20-21].

Product reliability quality has a large share in terms of customer satisfaction in today's conditions. It is important to make a risk analysis to ensure this reliability. It is aimed to identify hazards, rank risks, and take precautions with risk analysis with the rapid population growth, the consumption of energy resources has increased considerably. There are difficulties in meeting these large consumption amounts with limited resources. Human characteristics, data, experiences are processed into programs and machines are given the ability to work with fuzzy logic. Linguistic expressions are expressed mathematically in a computer environment. There are differences between fuzzy logic and classical logic. In classical logic, there are 2 values as values for these differences. FMEA focuses on the prevention of risks in products and processes and documents. It is used when detecting potential errors, determining their severity, degree, detectability, and classifying errors. The aim is to ensure quality by taking precautions.

3. Error Types and Effects

Table 1: Probability Rating Table

Possibility of Error	Defect Parts Rate	Degree
VERY HIGH	Each 200 products ≥	10
	Each 200 products ≥	9
HIGH	Each 200 products ≥	8
	Each 200 products ≥	7
MIDDLE	Each 200 products ≥	6
	Each 200 products ≥	5
	Each 200 products ≥	4
LOW	Each 200 products ≥	3
	Each 200 products ≥	2
FAR	Each 200 products ≥	1

Faults are removed from the system by identifying the situations which cause the error, or to minimize their effects, and to improve processes by minimizing failure. It aims to detect and prevent potential errors that may occur. After the detection of errors, it provides the necessary test and application methods and their control. The product to be produced in the next future aims to positively affect the success of the service that is the rating of the impact of risk. Reducing the severity of the risk prevents its course from worsening. The definition of severity is the effect on the end user of the risk of error occurring. The greater the severity of the error bad effect the greater the degree. While determining the degree of severity, it is determined by the influence of previous experiences and expert opinions with scaling 1 to10 (in Table 1 and Table 2).

In other words, the probability of the error occurring means the probability of occurrence indicates how often a possible error occurs. The probability value is used to show the frequency of occurrence of the error. It allows determine the probabilities of occurrence of errors using the table below. It aims to detect as early as possible and the team should review potential risk scores after scoring (in Fig.1). It allows the detection of potential errors and malfunctions that may occur before the product or service reaches the user. The cost of continuous discoverability is high and definite.

Table 2: Discoverability Rating Chart

DISCOVERABILITY	CRITERIA	Degree
undiscoverable	Discoverability is out of the question.	10
Very far	The discoverability of potential bugs that could occur is probably too far away.	9
Far	The detectability of the potential error that may occur is remote.	8
Very low	The detectability of the cause of the potential failure and the subsequent failure is very low	7
Low	Potential error detectability is low	6
Middle	Discoverability of potential error that may occur is medium, discoverable	5
Medium High	The detectability of the potential error that may occur is high.	4
High	High detectability of potential error that may occur	3
Very High	The detectability of the error is almost 100%	2
Definite	The cause of the error is certain to be discoverable.	1

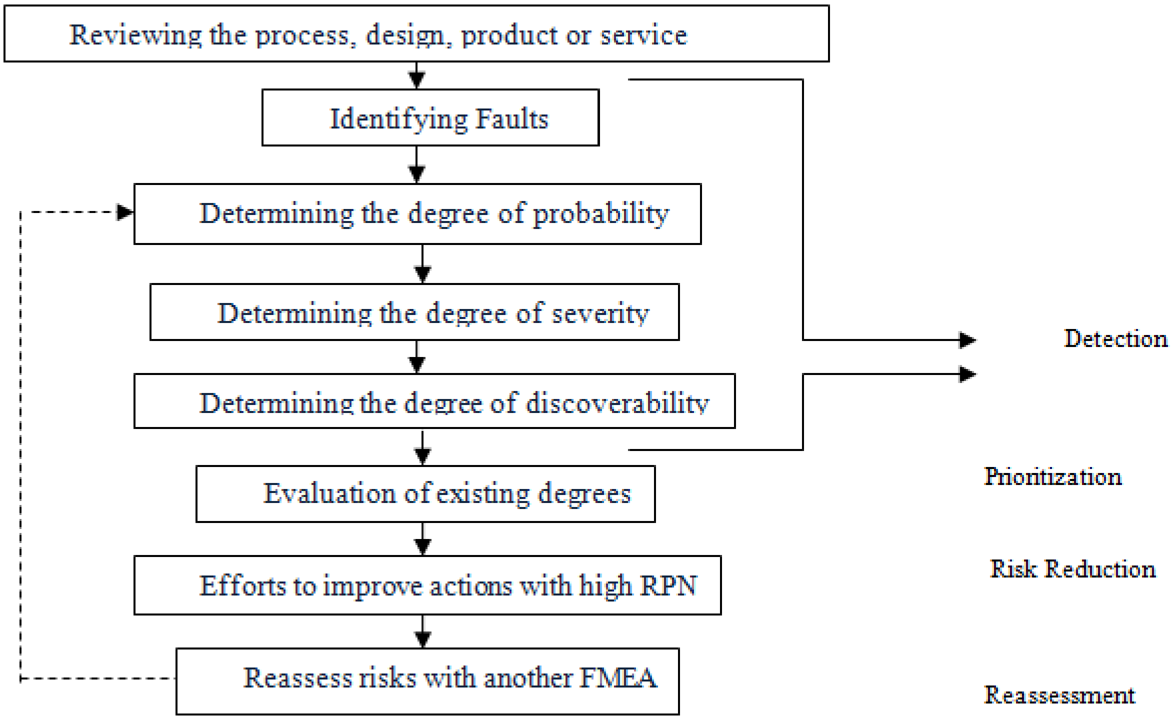


Figure 1: FMEA Process Flow Chart

RPN value is an abbreviation for risk priority order. It occurs by multiplying the probability, severity, and discoverability values. RPN value is not a standard value which are prioritized the errors with the RPN value. The maximum value for RPN is 1000. (10*10*10.) The threshold value should be determined. This threshold value may change in each risk analysis. Various criteria are involved in the determination of this threshold value.

4. Fuzzy Logic and Fuzzy Systems

Fuzzy logic introduced by LoftiZadeh in 1965. The most basic member of fuzzy logic is fuzzy set. A set that has elements with a degree of belonging is called a fuzzy set. Fuzzy sets can give their elements values between 0 and 1. The element is either included or not included in the set. Suppose a universal set X whose elements are x. The characteristic function determines whether these elements belong to the subset or not. It determines the characteristic function of x at {0,1}. Here, the belongingness of the elements to the cluster is graded.

$$\mu_A(X) = \begin{Bmatrix} 1, if\ x \in A \\ 0, if\ x \notin A \end{Bmatrix} \quad (1)$$

Fuzzy systems have systems based on decision making inferences in fuzzy logic. It consists of four parts. These are fuzzification, fuzzy rule base, inference engine, and defuzzification interface (in Figure 2).

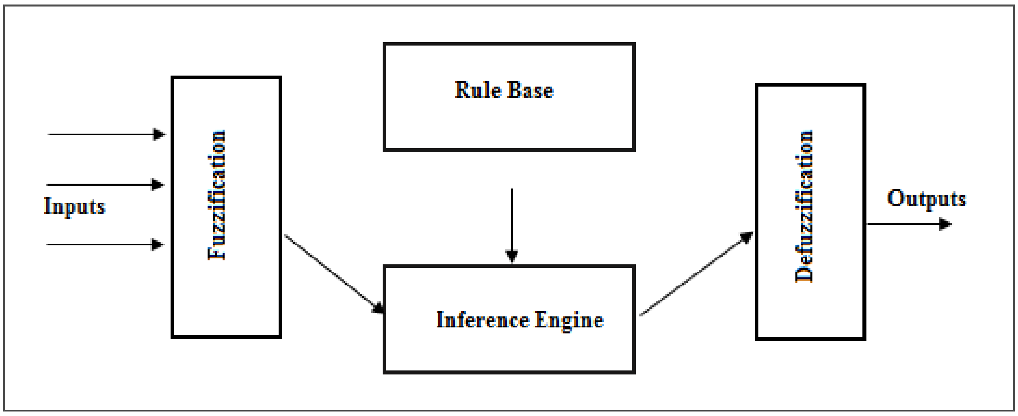


Figure 2: Fuzzy System

Fuzzification is the first step of the fuzzy system process. It takes the transformation of the information which entered through the system into symbolic data. Fuzzy sets are created by a scale change on the input variables. Labels are defined in linguistic scale degree. It covers the process of assigning linguistic variables such as large, small, medium to the inputs, which entered numerical data. The process transformed into verbal variables and constitutes the first step in the fuzzy logic system. With the help of membership functions, linguistic expressions are assigned to input values. Value ranges to be given are selected to scaling for performance. The fuzzy data is transformed into a verbal variable, which is ready to be used in other stages. The value range to be given to the input values is selected. Performance scaling is done to the inputs. Linguistic variables compatible with the scale are assigned to the input values and fuzzy data is prepared to be transferred to the next steps. Membership functions consist of three parts. These are core (self), support and limits. Elements with a membership degree of 1 form the nucleus in that cluster. Elements without membership degrees of 0 and 1 form the boundaries. The fuzzy sets represented by A'. $M_{A'}$ represents the membership degree of the point x in the fuzzy set function. $M_A(x) < 0$ indicates that the value is not included A' in the fuzzy set. $M_A(x) = 0$ shows that x is a definite element in the fuzzy set. If its $M_{A'}$ value is between 0 and 1, 0< $M_A(x)$ < 1. Each value in this value range represents the indeterminate, uncertain values of the membership of x in the fuzzy set. Non crisp values are expressed by fuzzy sets specified by membership functions. There are various membership functions. The most important types of membership functions are the triangular membership function, the trapezoidal membership function, and the gaussian membership function (in Figure 3).

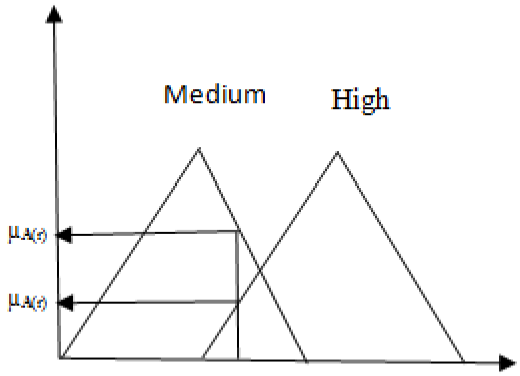


Figure 3: Fuzzification Graph

5. Application of Fuzzy FMEA Analysis

In order to determine the error types, first of all, a very detailed examination was made. Cable production is generally project-based and may vary according to the customer's demand. The occurrence of variability is determined according to the orders. Detecting the errors that cause the most time, energy and cost loss will have a positive effect on many issues such as customer satisfaction and efficiency. Error types and effects were determined by brainstorming with the team. The severity, probability and discoverability values of the errors were determined. In the analysis of error types and their effects, the value is obtained by multiplying the severity, probability, and discoverability. This value is called the RPN value. The RPN value is important to use when sorting errors among themselves. By ordering the RPN value from the largest to the smallest, the order of importance of the errors is also made. By ordering the detected and evaluated errors, it becomes easier to list the preventive actions to be taken. The highest value should be prioritized then the first precaution should be taken in order to prevent this error from occurring. After giving severity, probability, and discoverability values to each error value, RPN values were obtained by multiplying these and prioritization was made. The prioritization is given in the table below. Brainstorming with the analysis team consisting of 2 quality specialists, 2 planning specialists, 1 production specialist and 1 sales specialist in the company and examining the historical data, defective productions, their effects and customer opinions were determined by the steps specified. The rating process was carried out with the method of error type and effects analysis, taking advantage of customer feedback and the opinions of the quality teams. 17 errors were detected. The reasons for the 17 detected errors are also included.

The probability value of the error of cutting the length long while dimensioning the cable lengths is given as 8, the severity value is 6, and the detectability value is 7. The RPN value of 336 was calculated. The reasons that cause this error are; the carelessness of the personnel, the incorrect measurements in the technical drawing of the project, the inaccuracy of the calibration of the measuring instrument used, the insufficient inspection of the measurement tools. The probability value of the error of cutting the length short while measuring the cable lengths is 8, the severity value is 7, and the discoverability value is 7. The RPN value is calculated as 392. By causing this error; The carelessness of the personnel, entering the dimensions incorrectly in the technical drawing of the project, not calibrating the measuring instrument used, insufficient inspection of the measuring instruments, and incorrect calculation of the twisted share of the cable are shown as the reasons in Table 3. The probability value of the wrong braiding and splicing error of the cable branches is 3, the severity value is 6, and the discoverability value is 6. The RPN value of 108 was calculated. The reasons for this error are personnel carelessness, incorrect technical drawing, and incomprehensible line diagrams. The probability value of the cable insulation burnt error is 4, the severity value is 5, and the discoverability value is 4. RPN value was calculated as 80. By causing this error; It is not known at what degree, at what distance, for how long. The probability value of the error of not using a cable with the appropriate cross-section is given as 4, the severity value is 6, and the discoverability value is 5. The RPN value was calculated as 120.

Table 3: FMEA RPN values

Fault No	Faults	Probability	Severity	Discoverable	RPN Values
F1	Cutting the length of the cable long while dimensioning	8	6	7	336
F2	Cutting the length of the cable short while dimensioning it	8	7	7	392
F3	Incorrect braiding and splicing of cable branches	3	6	6	108
F4	Cable insulation burnt	4	5	4	80
F5	Failure to use cables of appropriate cross-section	4	6	5	120
F6	Damage to the cable insulation	6	5	4	120
F7	Damaged hammered adapter	3	7	6	126
F8	Not tightening the adapters well, opening the torques	7	5	6	210
F9	The adapter code is faint	4	6	3	72
F10	Using the wrong adapter	3	6	5	90
F11	Unreadable or blurred marking process	4	4	4	64
F12	Label not heated	3	3	6	54
F13	No marking	4	5	6	120
F14	Use of marking operations on the wrong branches	4	6	5	120
F15	Insertion of the reading direction of the marking sleeves in the wrong direction and fixation by heating	3	5	4	60
F16	Lack of transparency in the marking process	3	5	3	45
F17	Mislabeling	4	5	5	100

Many studies have been conducted with traditional error types and their effects. The healthy data have not been obtained as a result of these studies. These unreliable results revealed the need for more different analyzes. In order to make these data healthier, fuzzy logic was used. The application was made using the fuzzy logic tool box on Matlab. Probability, severity, and discoverability used in the analysis of error types and effects are considered as 3 inputs, and RPN value is considered as an output. The process steps start with entering the fuzzy input data first, then membership entries are made. A fuzzy rule base is created and output data is obtained.

5.1. Linguistic Variables and Definition of Linguistic Variable

Probability, severity and discoverability values were used as inputs. The relationship between the states of these input values and linguistic variables was determined with the contributions of expert opinions. Input values were determined as very little, low, medium, high, very high (in Table 4). The definition of the risk factors of these linguistic variables and the linguistic expressions of their levels were determined with the help of expert opinion (in Table 5). Risk verbal expressions corresponding to linguistic variables were also determined.

Table 4: Risk Faktörlerinin Sözel Olarak İfadesi- Linguistic Expression of Risk Factors

Linguistic Variables	Severity (S)	Occurence (O)	Discoverable (KD)
Very Little	Ineffective	Almost no errors	Almost certain the discoverability of the error
Little	Bug that partially affects performance	Very rare errors.	High detectability of error
Middle	Low damage bug	Few errors.	Error detectability is medium
High	Error causing high damage	Frequent errors.	Error detectability is low
Very High	Error causing project to stop	Almost inevitable mistake.	Discoverability of the error is uncertain

Table 5: Lingusitic Expressions of Risk Levels

Linguistic Variables	Risk Definitions
Very Few (VF)	Almost no risk
Few(F)	There is a small risk, but there is no need to intervene.
Medium (M)	Risk is moderate, intervention may be required
High (H)	The risk is high and it is necessary to take precautions for error.
Very High (VH)	The error requires immediate intervention.

Table 6: Fuzzy Values Corresponding to Input and Output Values in the Established Model

Fuzzy Values Corresponding to Input Values (O, S, K)	Linguistic Variables	Fuzzy Value Corresponding to Output Values (O, S, K)
0-1-3	Very little	0-10-25
1-3-5	Little	0-25-50
3-5-7	Middle	25-50-75
5-7-9	High	50-75-100
7-9-10	Very High	75-90-100

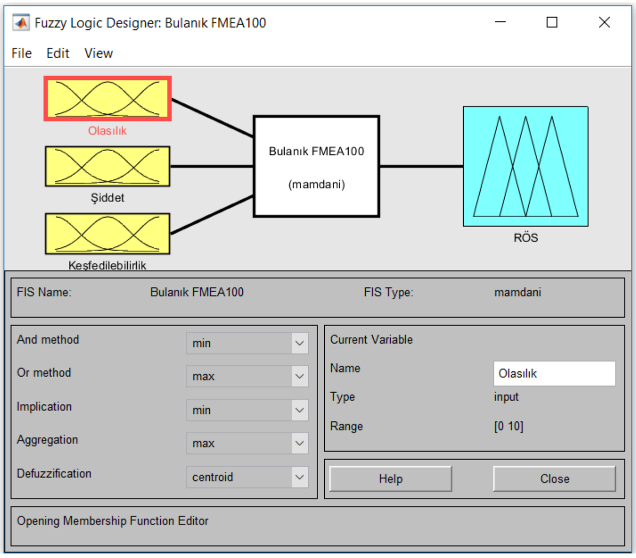


Figure 4: Fuzzy Model Established in Matlab

Fuzzy values were created for all of the probability, severity and discoverability parameters that constitute the inputs of the base, and for all the linguistic variables that were determined to be used as output. While determining the values corresponding to the input variables and output variables in the model, the classical FMEA input range between 0-10 is taken as a basis. 0-100 scale is taken as a basis for output variables (in Table 6). These values were determined with the contribution of expert opinions.

The fuzzy model was created by mamdani fuzzy inference method. Probability, severity, and discoverability values were used as inputs. The model set for its output also includes the risk priority number. The model built on Matlab is shown in Figure 4.

5.2. Defining membership entries

The fuzzy logic membership occured with entries, using expert opinions and experiences, probability, severity and discoverability values that were formed as very little, little, medium, very, very high. The model is being built, it is divided into 5 different sections with a decimal point. The definition of separately created membership entries for probability, severity, discoverability values is shown in Figure 5 and listed in below.

Rule 5; If the probability is very high, the severity is very low, and the discoverability is very high, the RPN will be medium.

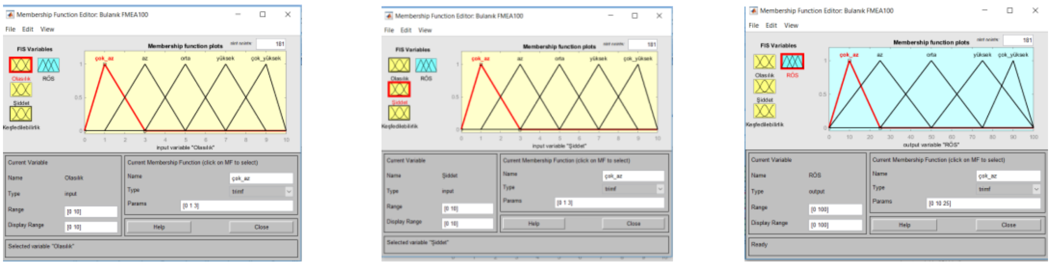
Rule 25; If the probability is very high, the severity is very high, and the discoverability is very high, the RPN value will be very high.

Rule 50; If the probability is high, the severity is very high, and the discoverability is very high, the RPN value will be very high.

Rule 75; If the probability is moderate, the severity is very high, and the discoverability is very high, the RPN value will be high.

Rule 100; If the probability is low, the severity is very high, and the discoverability is very high, the RPN value will be high.

Rule 125; If the probability is very low, the severity is very high, and the discoverability is very high, the RPN will be medium.



a. Probability Variable Membership b. Severity Variable Membership c. Output Variable Membership

Figure 5: FMEA Variables Membership Functions

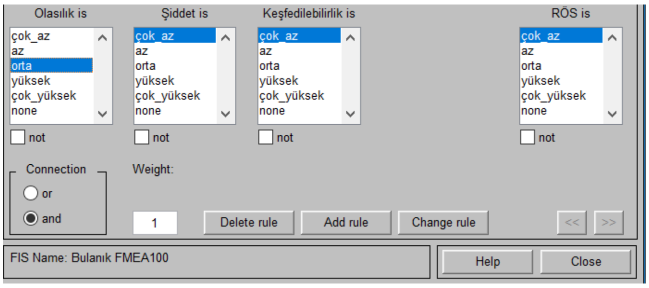


Figure 6: Rule Base Interface

The interface of the model created for the rule base is as in Figure 6. The weight of each 1 is linked to the selected membership functions.

5.3. Obtaining Fuzzy Outputs

In the created model, first the fuzzy inputs and then the membership functions and the rule base are established. RPN values created using 125 rule bases were determined. The RPN values obtained fuzzy outputs which are used in the Matlab program (in Fig. 7). As indicated in the figure 4.8, the probability value is 3, the severity is 5, and the detectability is 3, the detected RPN value is 25 (in Table 7). By using FuzzyLogic, the probability, severity and discoverability values of the error were entered using the matlab program, and fuzzy error types and their effects were reached.

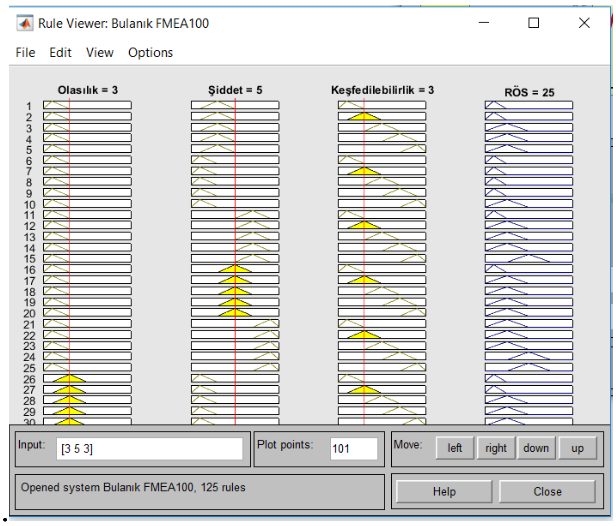


Figure 7: Fuzzy Outputs

6. Conclusion

Errors are caused by different reasons in all sectors. These mistakes cause both material and moral damage. In order to prevent and reduce these damages, it is critical to detect errors and their causes. Errors lead to scrap and cause labor, energy, time and waste. In this study, the errors that occur in various processes during the production of the cable in a cable production facility and the points that cause the errors are emphasized. In the literature, there are various methods aimed at preventing and prioritizing errors. Failure modes and effects analysis is one of these methods. It prioritizes by calculating the RPN value, but recently, inadequacies in the calculation of the RPN value have been observed and criticized. Error types and effects need numerical data, and in cases where these numerical data are insufficient, expert opinions are used. Since the opinions of experts or groups do not contain precise data, fuzzy logic is included in the study. Linguistic variables and expert opinions are included.

After the applied normalization process, all of the values took a value between 0-1. The normalization method used is the min-max method. When the errors are examined, it has been determined that the most important error is the error with the code F16, which has the smallest risk value in the three methods used. The error with the code F16 is the lack of transparency in the marking process. While ranking the errors with the same value, expert opinions were used and the ranking was made accordingly. Statistical tests were applied to evaluate the results obtained from the methods. The fuzzy logic has a significant difference with FMEA, will be healthier and more successful in terms of detecting and preventing the problems that may occur in the evaluation of risks.

Table 7: Fuzzy FMEA Table

Fault No	Faults	O	Ş	K	RPN Values	Fuzzy FMEA
F1	Cutting the length of the cable long while dimensioning	8	6	7	336	75
F2	Cutting the length of the cable short while dimensioning it	8	7	7	392	75
F3	Incorrect braiding and splicing of cable branches	3	6	6	108	50
F4	Cable insulation burnt	4	5	4	80	37,5
F5	Failure to use cables of appropriate cross-section	4	6	5	120	50
F6	Damage to the cable insulation	6	5	4	120	50
F7	Damaged hammered adapter	3	7	6	126	50
F8	Not tightening the adapters well, opening the torques	7	5	6	210	62,5
F9	The adapter code is faint	4	6	3	72	37,5
F10	Using the wrong adapter	3	6	5	90	50
F11	Unreadable or blurred marking process	4	4	4	64	37,5
F12	Label not heated	3	3	6	54	25
F13	No marking	4	5	6	120	50
F14	Use of marking operations on the wrong branches	4	6	5	120	50
F15	Insertion of the reading direction of the marking sleeves in the wrong direction and fixation by heating	3	5	4	60	37,5
F16	Lack of transparency in the marking process	3	5	3	45	25
F17	Mislabeling	4	5	5	100	50

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