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# Development of Fuzzy Failure mode effect analysis (FFMEA) model for Risk Priority Number (RPN) analysis

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**Abstract**

Failure mode effect analysis (FMEA) is one of the well known and widely used technique of Quality Management. The purpose of FMEA is to examine failure modes in different products, designs, business processes/services. Traditional FMEA technique involves the determination of Risk Priority Number (RPN) which was obtained by multiplication of three risk factors i.e. Occurrence (O), Severity (S) and Detection (D). In this study we have treated the risk factors as fuzzy variables and evaluate them using fuzzy linguistic terms and fuzzy ratings. This paper presents a way to evaluate FMEA parameters using fuzzy sets. Modelling and Simulation has been done using Matlab-Simulink using fuzzy logic toolbox and results are also shown.

**Keywords: FMEA, RPN, Matlab Simulink, FIS, MF's**

## 1.0 Introduction

Rule of business is that any increase in customer expectation, growth in technology and real participation in International markets leads to the real competition requiring the management a true attention. Under such circumstances, the management tries to improve the quality of the products, reduce costs, enhance the service level, and eliminate any kind of deficiency/faults associated with the product. To make sure that the wanting results would be obtained as needed, companies use Failure Modes and Effects Analysis (FMEA) as a tool to make that possible [1].

FMEA first emerged from studies done by NASA in 1963, Very soon it was used to improve safety in the processes involved in chemical industries [2]. Then in 1977 it was similarly used and promoted by Ford Motor Company where it served to quantify and order critical defects at the design stage of a product so that they were not passed on to the customer [3]. The objective of FMEA is to prevent unacceptable failures and to assist management in a more efficient allocation of resources. [4]

FMEA is one of the well known techniques of Quality Management and it is widely used in Techno-Management environment. FMEA is highly applicable for defining, identifying and eliminating Potential failures, problems, errors and so on from system, design, process, business services etc before they the customer [5]. FMEA involves the determination of Risk Priorities of the failure modes that have been identified. The traditional FMEA methodology determines the risk priorities of failure modes through the risk priority number (RPN), which is the product of the Occurrence (O), Severity (S) and Detection (D) of a failure [6] i.e.

$$RPN= O\times S\times D$$

Where O and S are the frequency and seriousness (effects) of the failure and D is the ability to detect the failure before it reaches the customer. In the traditional approach the three risk factors occurrence, severity and detection are considered equally important. FMEA is usually carried out by a team of people with direct knowledge of the procedures or process concerned[7]. After determining the risk number, the RPN team provides recommended actions, which should reduce the risk numbers [8].

In this study Stage-wise Fuzzy Inference System (FIS) was incorporated to aggregate S, O, and D ratings (namely an FIS-based RPN model), instead of a simple product function [9]. This paper has been divided into five parts. Part I gives the General Introduction of FMEA. Part II Defines the Fuzzy Reasoning Approach to FMEA. Part III comprises of Modelling and Simulation of FMEA model in Matlab. Part IV gives Results. Part V comprises of Conclusion and future outlook. Part VI comprises of References.

## 2.0 Fuzzy Approach to FMEA

Fuzzy concept was incorporated to FMEA methodology to allow uncertainty and imprecise information to be included [10]. Fuzzy FMEA has been widely used in many industrial applications as in marine industry [11], engine systems [12] and auxiliary feed water system in nuclear power plants [13]. The advantages of the proposed stage-wise fuzzy inference system are manifold. Firstly, it allows expert knowledge and experience to be incorporated [14,15]. Secondly, It is robust against uncertainty and vagueness [16]. Thirdly, It allows a non-linear relationship between the RPN score and the three risk factors to be formed [17]. Lastly, the three risk factors can be captured qualitatively, instead of quantitatively. In Fuzzy FMEA approach the three risk factors are further fuzzified with the help of Linguistic variables. The crisp ratings for the risk factors i.e. Occurrence, Severity and Detection are shown in table 1.0, table 1.1 and table 1.3 respectively [5].

| Rating | Probability of Occurrence | Failure Probability |
|---|---|---|
| 10 | Almost certain (AC) | >1 in 2 |
| 9 | Very high (VH) | 1 in 3 |
| 8 | High (H) | 1 in 8 |
| 7 | Moderately high (MH) | 1 in 20 |
| 6 | Moderate (M) | 1 in 80 |
| 5 | Low (L) | 1 in 400 |
| 4 | Very low (VL) | 1 in 2000 |
| 3 | Remote (R) | 1 in 15,000 |
| ≤ 2 | Very remote (VR) | 1 in 150,000 |

Table 1.0 Crisp ratings for occurrence of a failure

| Rating | Effect | Severity of effect |
|---|---|---|
| 10 | Hazardous without warning (HWW) | Very high severity ranking when a potential failure mode effects safe system/design/process operation without warning |
| 9 | Hazardous with warning (HW) | Very high severity ranking when a potential failure mode affects safe system/design/process operation with warning |
| 8 | Very high (VH) | System/design/process inoperable with destructive failure without compromising safety |
| 7 | High (H) | System/design/process inoperable with equipment damage |
| 6 | Moderate (M) | System/design/process inoperable with minor damage |
| 5 | Low (L) | System/design/process inoperable without damage |
| 4 | Very low (VL) | System/design/process operable with significant degradation of performance |
| 3 | Minor (MI) | System/design/process operable with some degradation of performance |
| ≤ 2 | Very minor (VMI) | System/design/process operable with minimal interference |

Table 1.1 Crisp ratings for severity of a failure

| Rating | Detection | Likelihood of detection by design control |
|---|---|---|
| 10 | Absolute uncertainty (AU) | Design control cannot detect potential cause/ mechanism and subsequent failure mode |
| 9 | Very remote (VR) | Very remote chance the design control will detect potential cause/mechanism and subsequent failure mode |
| 8 | Remote (R) | Remote chance the design control will detect potential cause/mechanism and subsequent failure mode |
| 7 | Very low (VL) | Very low chance the design control will detect potential cause/mechanism and subsequent failure mode |
| 6 | Low (L) | Low chance the design control will detect potential cause/mechanism and subsequent failure mode |
| 5 | Moderate (M) | Moderate chance the design control will detect potential cause/mechanism and subsequent failure mode |
| 4 | Moderately high (MH) | Moderately high chance the design control will detect potential cause/mechanism and subsequent failure mode |
| 3 | High (H) | High chance the design control will detect potential cause/mechanism and subsequent failure mode |
| $\leq 2$ | Very high (VH) | Very high chance the design control will detect potential cause/mechanism and subsequent failure mode |

Table 1.2 Crisp ratings for detection of a failure

### 2.1 Design of Stage-wise Fuzzy FMEA Model

In this study we have used stage-wise fuzzy reasoning approach [18] which reduces fuzzy if-then rules by dividing the whole system into fuzzy inference stages [19]. As shown in figure 1.0 two Fuzzy Inference Systems (FIS) namely 'FIS-1' and 'FIS-2' are created in Matlab using Fuzzy logic toolbox [20].

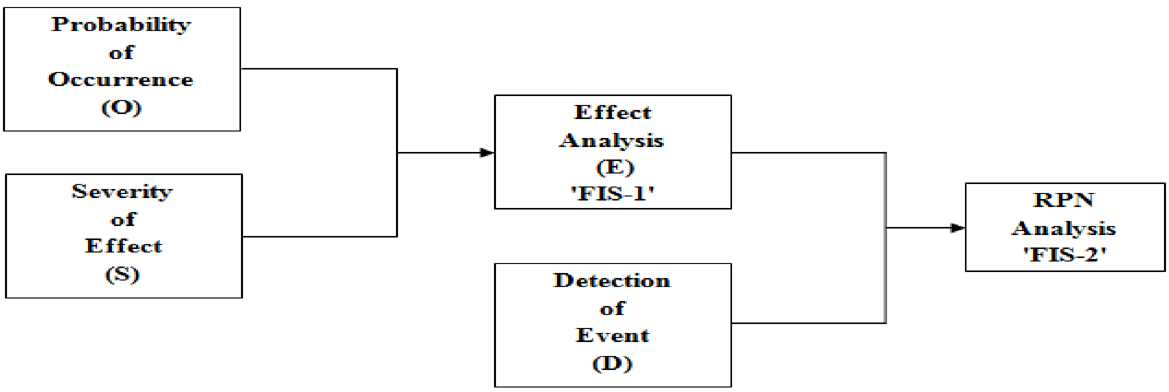


Figure 1.0 Stage-wise Fuzzy FMEA model

If we look at the figure 1.0 then we can see that in the first stage the inputs 'Probability of Occurrence ' and 'Severity of Effect' are combined to build 'Effect Analysis'. Similarly in the second stage 'Effect Analysis' is further combined with 'Detection of Event' to build RPN Analysis.

**2.2 Defining Universe of Discourse (UOD), Fuzzification of critical attributes and MF's:**

Each of the input parameters (Critical attributes: Occurrence, Severity, Effect and Detection) have been given a UOD of [1 10] where as the output parameter i.e. RPN has been given a UOD of [0 1]. All these parameters are been fuzzified with nine linguistic variables using triangular membership functions [18].

Examples of fuzzified input/output for 'FIS-1' and 'FIS-2' are shown in figure 1.1 to figure 1.5

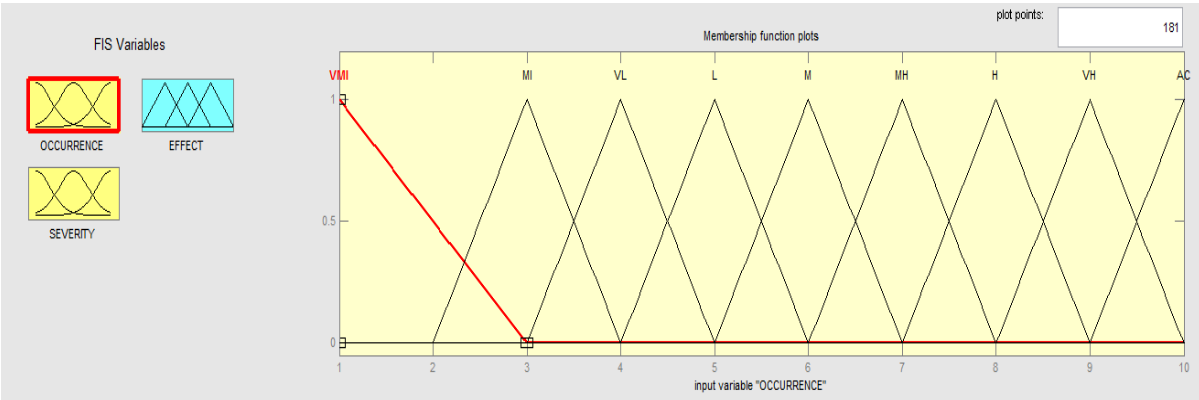


Fig 1.1 Fuzzified input parameter-'Occurrence'

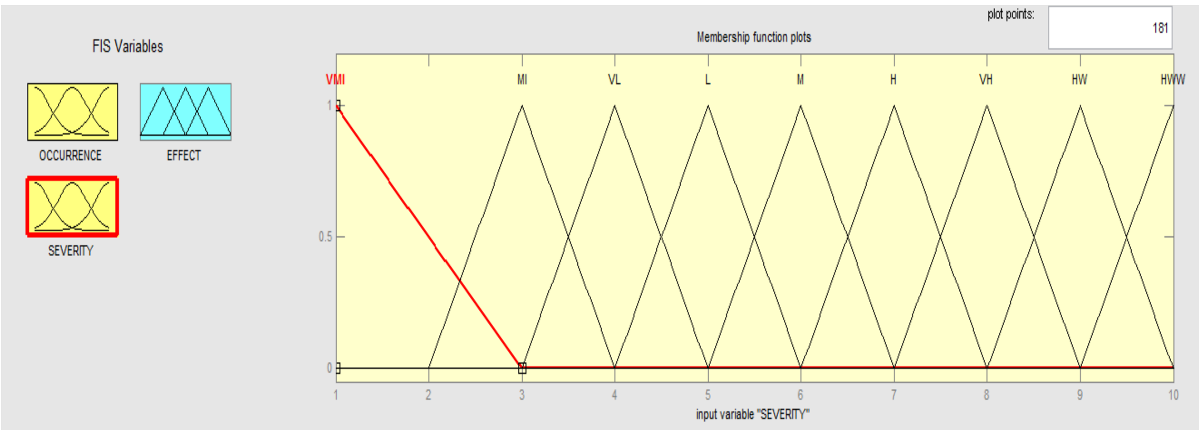


Fig 1.2 Fuzzified input parameter-'Severity'

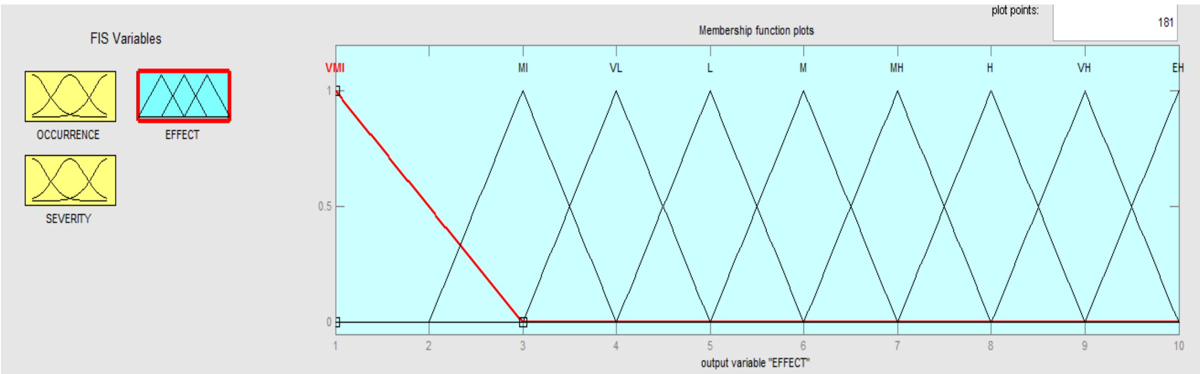


Fig 1.3 Fuzzified output parameter-'Effect'

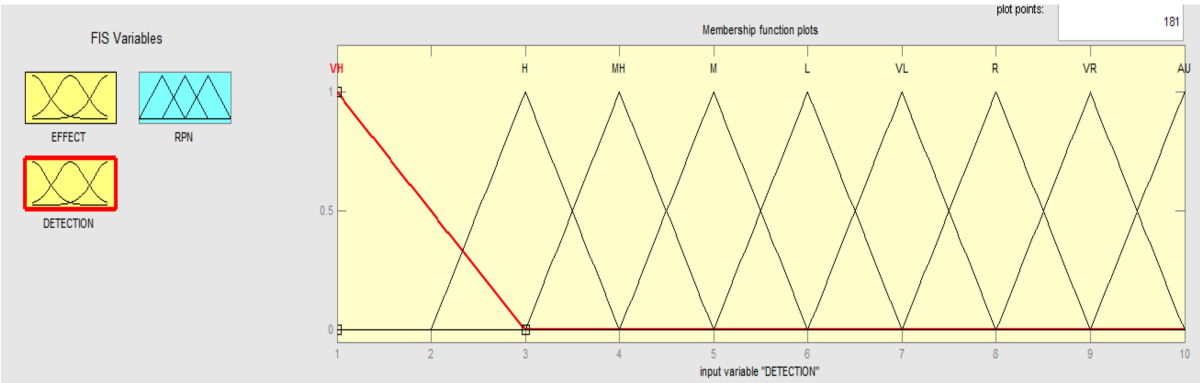


Fig 1.4 Fuzzified input parameter-'Detection'

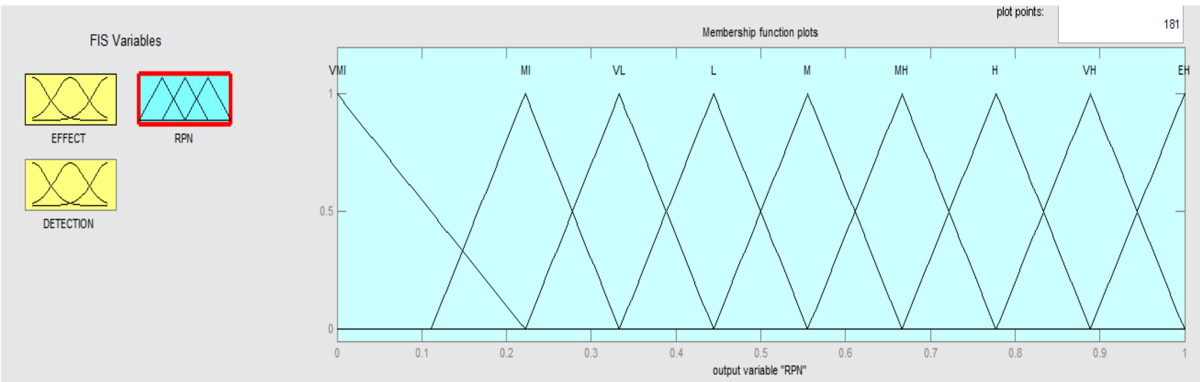


Fig 1.5 Fuzzified output parameter-'RPN'

### 2.3 Defining fuzzy control rules

### (a) Fuzzy controller 'FIS-1' (refer to fig 1.0)

Fuzzy control rules [18] for the fuzzy controller can be seen from table 1.3

| | | Probability of Occurrence (O) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Effect Analysis (E)** | **AC** | **VH** | **H** | **MH** | **M** | **L** | **VL** | **MI** | **VMI** | **EMI** |
| **Severity Of Effect (S)** | **HWW** | EH | EH | VH | VH | H | H | MH | MH | M | M |
| | **HW** | EH | VH | VH | H | H | MH | MH | M | M | L |
| | **VH** | VH | VH | H | H | MH | MH | M | M | L | L |
| | **H** | VH | H | H | MH | MH | M | M | L | L | VL |
| | **M** | H | H | MH | MH | M | M | L | L | VL | MI |
| | **L** | H | MH | MH | M | M | L | L | VL | MI | MI |
| | **VL** | MH | MH | M | M | L | L | VL | MI | MI | VMI |
| | **MI** | MH | M | M | L | L | VL | MI | MI | VMI | VMI |
| | **VMI** | M | M | L | L | VL | MI | MI | VMI | VMI | EMI |
| | **EMI** | M | L | L | VL | MI | MI | VMI | VMI | EMI | EMI |

Table 1.3 Fuzzy control rules-'FIS-1'

Probability of Occurrence(O) and Severity of Effect(S) are the input variables, Effect Analysis is the output. As can be seen from the table there are total hundred rules e.g. if the rating for ‘Probability of Occurrence' of event is ‘High’ and rating for ‘Severity of effect' is ‘Hazardous without warning' then the rating for associated ‘Effect Analysis’ is ‘Very high’. The fuzzy rules are defined and based on personal experience of expert and varies from one expert to other.

A surface viewer for 'FIS-1' is shown in figure 1.6 which demonstrates relationship among ‘Probability of Occurrence’, ‘Severity of Effect’ and associated ‘Effect’. To achieve the surface we have used the fuzzy rule bases and the MF’s of the FIS controller.

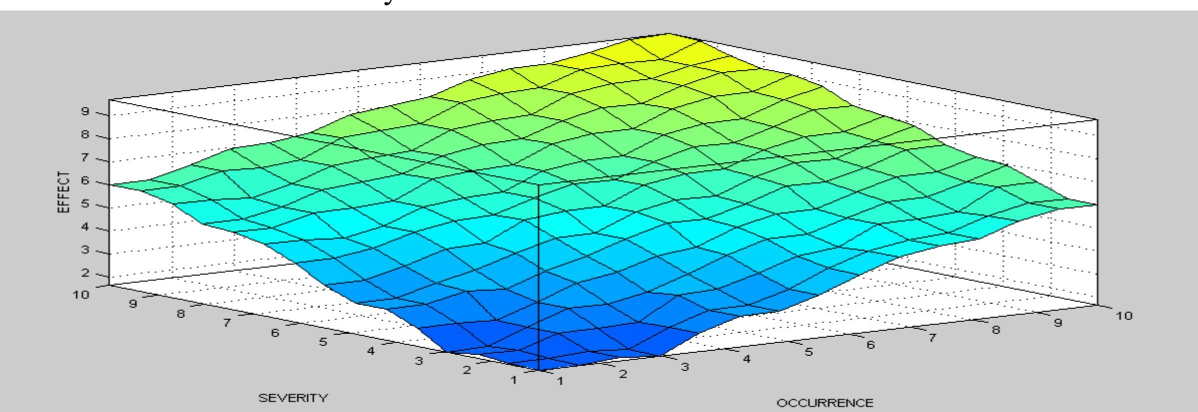


Fig 1.6 A surface viewer for 'FIS-1'

**(b) Fuzzy controller 'FIS-2' (refer to fig 1.0)**

Fuzzy control rules for the fuzzy controller can be seen from table 1.3

| | Effect Analysis (E) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **RPN Analysis** | **EH** | **VH** | **H** | **MH** | **M** | **L** | **VL** | **MI** | **VMI** | **EMI** |
| **Detection Of Event (D)** | **EH** | EH | EH | VH | VH | H | H | MH | MH | M | M |
| | **VH** | EH | VH | VH | H | H | MH | MH | M | M | L |
| | **H** | VH | VH | H | H | MH | MH | M | M | L | L |
| | **MH** | VH | H | H | MH | MH | M | M | L | L | VL |
| | **M** | H | H | MH | MH | M | M | L | L | VL | MI |
| | **L** | H | MH | MH | M | M | L | L | VL | MI | MI |
| | **VL** | MH | MH | M | M | L | L | VL | MI | MI | VMI |
| | **MI** | MH | M | M | L | L | VL | MI | MI | VMI | VMI |
| | **VMI** | M | M | L | L | VL | MI | MI | VMI | VMI | EMI |
| | **EMI** | M | L | L | VL | MI | MI | VMI | VMI | EMI | EMI |

Table 1.4 Fuzzy control rules-'FIS-2'

Effect Analysis and Detection of Effect are the inputs, RPN Analysis is the output. A surface viewer for 'FIS-2' is shown in figure 1.6 which demonstrates relationship among ‘Effect analysis’, ‘Detection of Event’ and associated ‘RPN analysis’. To achieve the surface we have used the fuzzy rule bases and the MF’s of the FIS controller.

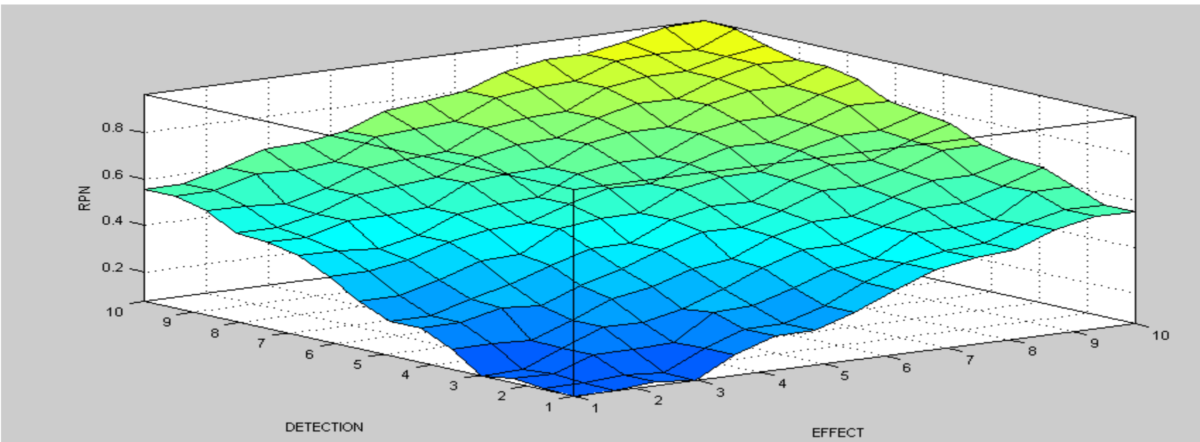


Fig 1.7 A surface viewer for 'FIS-2'

## 3.0 Modelling and Simulation

The proposed stage wise fuzzy reasoning model for FMEA was developed in Matlab-Simulink software (fuzzy logic toolbox) as shown in figure 1.8. Fuzzy logic controller was used to link both the FIS's together.

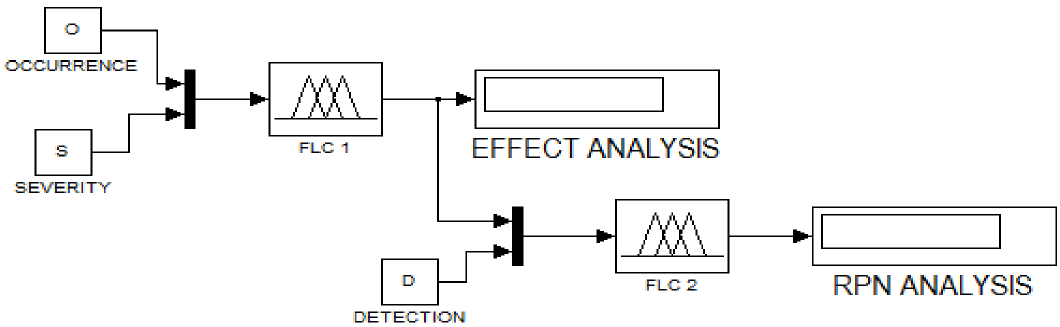


Figure 1.8 Fuzzy reasoning Simulink model

## 4.0 Simulation results

Results of various simulations for different set of inputs i.e. Occurrence (O), Severity (S) and Detection (D) are shown below.

**Set 1:**

**O=8; S=7; D=9;**

The simulation (t=2 sec) results are shown in figure 1.9

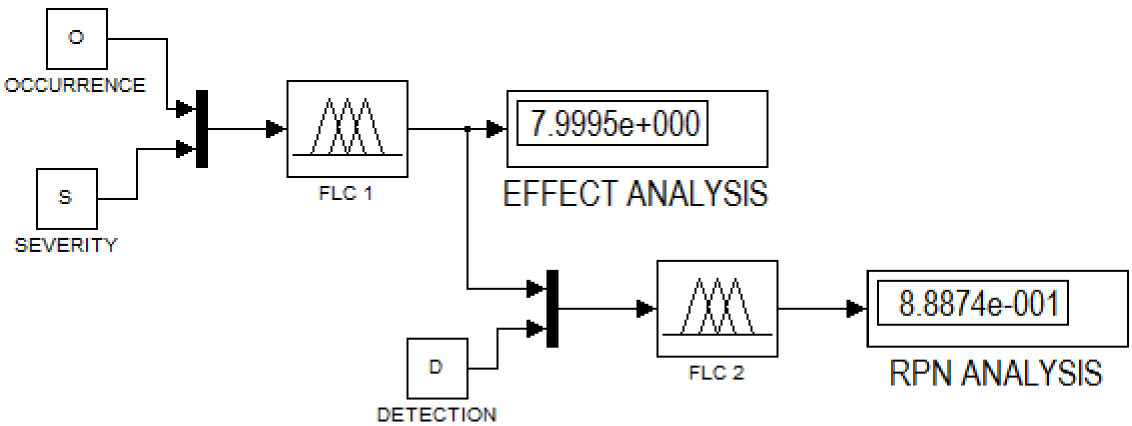


Figure 1.9 Simulation Results

**Set 2:**

**O=4; S=3; D=5;**

The simulation (t=2 sec) results are shown in figure 1.9

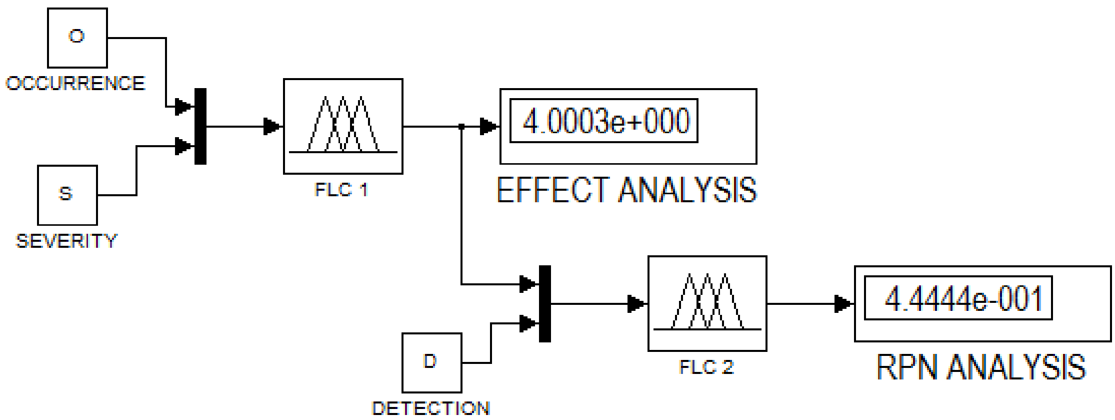


Figure 2.0 Simulation Results

**Set 3:**

**O=9; S=3; D=3;**

The simulation (t=2 sec) results are shown in figure 1.9

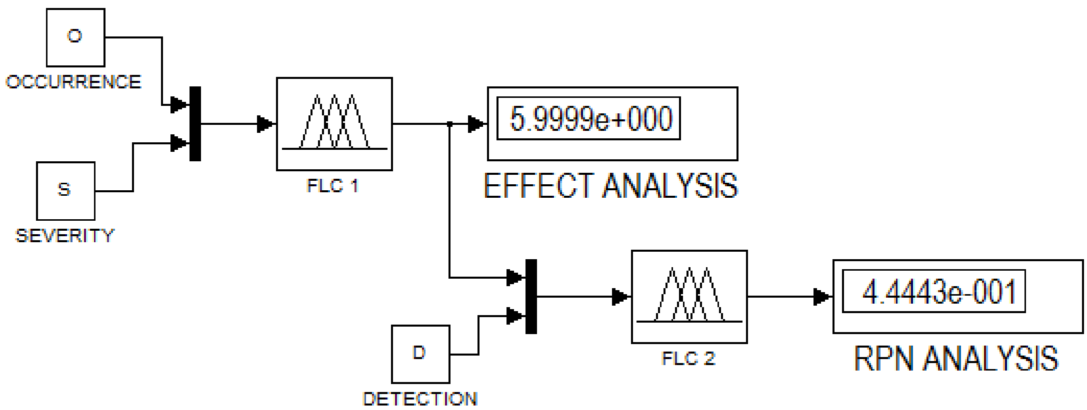


Figure 2.1 Simulation Results

## 5.0 Conclusion & Future outlook

Fuzzy FMEA methodology helps in providing effective information for risk management and decision making under uncertainty. It is a widely used technique in Techno-Management environment. In literature the traditional method of evaluating the crisps values of RPN's have been considerably criticised for a many reasons such as ignoring relative importance among the risk factors, imprecisely evaluations, questionable multiplication procedure and obtaining the RPN values etc. Due to criticism for RPN calculations, a fuzzy FMEA approach is considered which proves to be more realistic as compared to the traditional non-fuzzy approach.

In this study a new Stage-wise fuzzy reasoning approach for evaluation of RPN has been proposed which provides a logical approach to FMEA analysis. The Stage-wise fuzzy reasoning approach was employed as it serves two purposes (i) for determining Effect Analysis based on Occurrence and Severity. (ii) for determining RPN analysis based on Effect analysis and Detection. A Matlab Simulink model for FMEA has been developed and the results are shown. The proposed framework develops a model that optimises the constraints. As an extension for future work a fuzzy ordinal approach for FMEA can also be employed which provides an effective methodology if the number of input parameters are quite large.

## 6.0 References


[1] Y. Zare Mehrjerdi, "*A Chance Constrained Multiple Objective Goal Programming Model of Fuzzy QFD and FMEA: Model Development*", International Journal of Applied Operational Research Vol. 2, No. 1, pp. 41-53, Spring 2012.

[2] Mahdi Shaghaghi, Kamran Rezaie, " *Failure Mode and Effects Analysis Using Generalized Mixture Operators*", Journal of Optimisation in Industrial Engineering 11 (2012) 1-10.

[3] Javier Puente García , David de la Fuente García , Paolo Priore Moreno , Raúl Pino Diez, " *Artificial intelligence tools for applying failure mode and effects analysis (FMEA)",* E.T.S. Ingenieros Industriales de Gijón. Universidad de Oviedo. Depto. Administración de Empresas y Contabilidad. Organización de Empresas. Campus de Viesques s/n 33204 Gijón. Asturias. Spain

[4] Ahsen, A.V., "*Cost-oriented failure mode and effects analysis*", International Journal of Quality & Reliability Management, Vol. 25, No. 5, pp. 466-476, 2008.

[5] Ying-Ming Wang, Kwai-Sang Chin, Gary Ka Kwai Poon, Jian-Bo Yang, " *Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean*", Expert Systems with Applications 36 (2009) 1195–1207

[6] Ahmet Can Kutlu, Mehmet Ekmekcioglu, " *Fuzzy failure modes and effects analysis by using fuzzy TOPSIS-based fuzzy AHP*", Expert Systems with Applications 39 (2012) 61–67

[7] Hadi Shirouyehzad, Mostafa Badakhshian, Reza Dabestani, Hamidreza Panjehfouladgaran, " *Fuzzy FMEA Analysis for Identification and Control of Failure Preferences in ERP Implementation*", The Journal of Mathematics and Computer Science Vol .1 No.4 (2010) 366-376

[8] Petra Halfarová, Tatiana Ustyugova, David Vykydal, " *The application of fuzzy FMEA*", 15. - 17. 5. 2013, Brno, Czech Republic, EU

[9] Bowles, J.B., Pelaez, C.E., *" Fuzzy logic prioritization of failures in a system failure mode, effect and criticality analysis*", Reliab. Eng. Syst. Safe. 50, 203-213 (1995).

[10] Xu, K., Tang, L.C., Xie, M., Ho, S.L., Zhu, M.L ,"*Fuzzy assessment of FMEA for engine systems*", Reliab. Eng. Syst. Safe. 75, 17-29 (2002).

[11] J. Wang A. Pillay, "*Modified failure mode and effects analysis using approximate reasoning*", Reliability Engineering and System Safety, (79):69–85, 2003.

[12] M. Xie S.L. Ho M. L. Zhu K. Xu, L.C. Tang.," *Fuzzy assessment of FMEA for engine systems*", Reliability Engineering and System Safety, (75):17–29, 2002.

[13] C.M.F. Lapa A.C.F. Guimares, " *Fuzzy FMEA applied to power chemical and volume control system*", Progress in Nuclear Energy, (44(3)):191–213, 2004.

[14] Tay, K.M., Lim, C.P., "*Fuzzy FMEA with a guided rules reduction system for prioritization of failures*", Int. J. Qual. Reliab. Manag. 23, 1047 – 1066 (2006).

[15] Guimarães, A.C.F., Lapa, C.M.F, " *Fuzzy FMEA applied to PWR chemical and volume control system*", Progr. Nucl. Energ. 44, 191-213 (2004).

[16] Pillay, A., Wang, J," *Modified failure mode and effects analysis using approximate reasoning*", Reliab. Eng. Syst. Safe. 79, 69-85 (2003).

[17] Bowles, J.B., Pelaez, C.E, "*Fuzzy logic prioritization of failures in a system failure mode, effect and criticality analysis*", Reliab. Eng. Syst. Safe. 50, 203-213 (1995).

[18] Adnan Shaout and Jaldip Trivedi, "*Performance Appraisal System Using a Multistage Fuzzy Architecture*", International Journal of Computer and Information Technology (ISSN: 2279 – 0764) Volume 02– Issue 03, May 2013.

[19] Adnan Shaout and Minwir Al-Shammari, "*Fuzzy logic modelling for performance appraisal systems A framework for empirical evaluation*", Journal of Expert Systems with Application, issue 14 (1998), pages 323-328.

[20] Fuzzy Logic Toolbox: User's Guide Math Works, www.mathworks.com/help/pdf_doc/fuzzy/fuzzy.pdf