

INTEGRATING FUZZY INFERENCE AND FMEA TO PRIORITIZE SERVICE FAILURE RISK

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Abstract: Many firms conduct satisfaction surveys of their customers, with the analyzed results to identify areas of potential improvement. However, it is a recovery action for service failure. This study integrates the fuzzy inference and FMEA to provide a active service failure risk assessment model. Through assess the potential risk activities severity, occurrence and detection to obtain the risk priority number (RPN). With the results of RPN to prioritize the risks, further can be used to determine the sequence of improvement activities. A distribution center case was used to demonstrate the proposed model. The results shown that the high RPN existed in receiving, order picking and shipping activities. Finally, there are some suggestions are proposed for practical application and academic research directions.

Keywords: Fuzzy inference, Failure mode and effects analysis, Service failure, Distribution center

1. INTRODUCTION

The service industries with multi-dimensional nature creates an uncertain environment. A service failure occurs when customers' expectations are not met (Weber and Sparks, 2004). Service failure is commonly defined as a mistake, problem or error that occurs in the delivery of the service (Hoffman et al., 1995). Service failures can lead to negative word of mouth (Spreng, 1995) dissatisfaction, and defection (Richins,M.L., 1987), behaviors adversely affecting the profitability of the company (Muller et al., 2003). Risk management can be defined as the process of identification, analysis and either acceptance or mitigation of uncertainty in decision making. Therefore, organizations have to understand service failures antecedents and control it before occurred.

Many researches tries to reduce the service failure risk by means of customer satisfaction survey. However, that are post-action when service failure have occurred. Failure Modes and Effects Analysis (FMEA) is a systemized group of activities that intent to recognize and evaluate the potential failure of a product or process, identify actions that could eliminate or reduce the likelihood of the potential failure and document the entire process (Johnson, 2002). The goal of FMEA is to predict how and where systems that were designed to detect errors and alert staff might fail. To evaluate the criticality of a cause of a possible defect, the risk priority number(RPN) for the failure is calculated as the product of three indexes; (1) the occurrence probability index "P" reflecting the likelihood of the failure occurring, (2) the severity index "S", reflecting how serious the failure is, (3) the detection index "D", reflecting the likelihood of a possible defect not being detected.

The RPN ranking has been well accepted for risk analysis in FMEA. However, it suffers from several shortcomings. It has been pointed out that the same RPN can be obtained from a number of different score combinations of severity, occurrence, and detect (Pillay and Wang, 2003). Although the same RPN is obtained, the risk can be different. Besides that, the relative significance of the three indexes is neglected in the typical way of calculating the RPN. In other words, the three indexes are assumed to be of equal importance, but this may not be the case in practice (Pillay and Wang, 2003). Indeed, the relative significance of the three factors varies based on the nature of a process or a product.

To overcome the above shortcomings, this study aims at integrate the uses of fuzzy inference and FMEA to provide a active service failure risk assessment model. The integrated model can provide more precise assessment in prioritizing the critical potential failure modes.

2. LITERATURE REVIEW

2.1 Typical FMEA Procedure

Failure Modes and Effects Analysis is a structured, systematic analysis tool widely used in the manufacturing sectors,

such as the automotive, aerospace, and electronics industries, to identify, prioritize and eliminate known potential failures, problems and errors from systems under design before the product is released (Toeh and Case, 2004; Xu et al., 2002). Though FMEA is widely used in the manufacturing sector, literature regarding FMEA in service industries are not widely found, with few on medical surgery, health related industries (Chuang, 2007).

Although there are some differences between the operational procedure. The procedure can be arranged as figure 1 and described as follows (Pillay and Wang, 2003):

- (1) Study about the process/product and divide the process/product to sub-process/components
- (2) Identify all potential failure modes of the service system.
- (3) Determining the causes, potential effects and current control method for each failure modes.
- (4) Rating the index for Severity, Occurrence and Detection
- (5) Calculating the Risk Priority Number (RPN) for each effect
- (6) Prioritize failure modes for corrective actions
- (7) Take suitable actions to reduce the high risk failure modes .
- (8) Continual improvement

In the analysis process, the FMEA table (table 1) can be a useful tool to recording all the process. Senol(2007) propose a RPN threshold (equation 1) to determine whether to take corrective action for potential failure modes. If the RPN is over 100 or individual index exceed 9, that is high risk.

$$\text{If } RPN = \begin{cases} < 40 \\ \geq 40, < 100 \\ \geq 100 \end{cases} \begin{matrix} \\ \text{No Risk} \\ \text{Imperceptible Risk} \end{matrix} \tag{1}$$

$O \geq 9$
 $S \geq 9$ } Risk
 $D \geq 9$

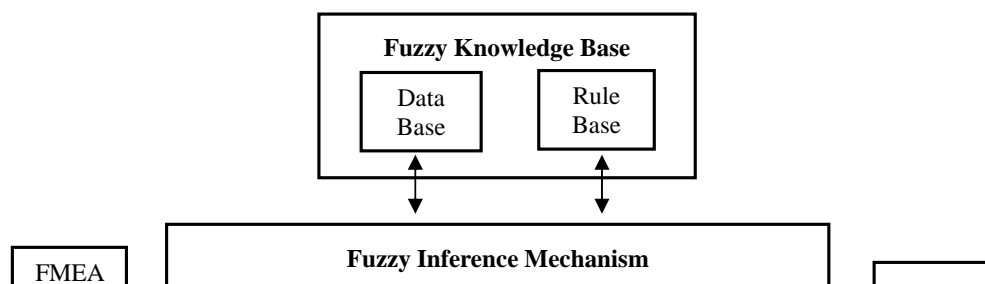
Table 1: FMEA analysis template

Prepared by:					Owner:				
Project team:					Responsibility:				
					FMEA date:				
					Original:				
Service/ process feature	Potential failure mode	Potential effects of failure	Severity rating	Potential cause of failure	Occurrence rating	Detecting rating	Risk priority number	Recommen d action	Action taken

3. RESEARCH METHOD

3.1 Fuzzy Risk Assessment Method

The fuzzy risk assessment methodology is based on fuzzy sets theory, which developed by Zadeh in 1965. It provides a more flexible and meaningful method to assess risk associated with sub-system/process/products failure modes. The three inputs, i.e. S , P and D which are used in FMEA are fuzzified using triangle membership function to determine degree of membership in this study. The resulting fuzzy inputs are evaluated in fuzzy inference engine, which makes use of well-defined rule base consisting of If-Then rules and fuzzy logic operations to determine criticality level of the failure. The fuzzy conclusion is then defuzzified to get risk priority number (RPN). Higher the value of RPN, greater will be the risk. The fuzzy linguistic assessment model was developed using toolbox platform of MATLAB 6.5 R.14. The basic system architecture consists of three main modules, (1)FMEA inputs (2) fuzzy knowledge base (3) fuzzy inference mechanism. The figure 2 demonstrates framework of fuzzy system. The following paragraphs will discuss each of them briefly.



(1) Fuzzification

The goal of fuzzification is to transform the crisp inputs into a membership degree, which expresses how well the linguistically defined terms. In this study, using the toolbox simulator of Matlab(2004) membership functions for both inputs and outputs. The three inputs are severity, occurrence, and detect. To represent the fuzzification of inputs in fuzzy FMEA, triangular membership functions(Figure 3) are used which are consistent with the definitions of probability of failure occurrence, severity and non-detectability used in the study as depicted in tables(2-4).

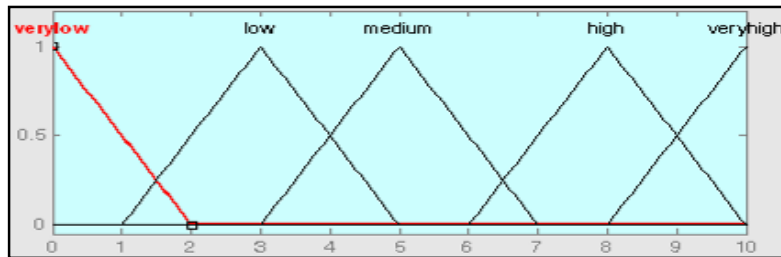


Figure 3 : membership function for innuts index

Assessment of probability of failure	Mean time between failures(MTBF)	Score	Likelihood of non-detection(%)
Very-low	>1 year	1	<0.01
Low	6-12 months	2-3	0.01-0.1
medium	1-6 months	4-6	0.1-0.5
High	1-4 weeks	7-8	0.5-0.99
Very high	<1 week	9-10	>0.99

Table 3 : Scale to measure probability of non-detection

Non-detection	Score	Likelihood of non-detection(%)
Very-low	1	0-5
Low	2	6-15
	3	16-25
medium	4	26-35
	5	36-45
	6	46-55
High	7	56-65
	8	66-75
	9	76-85
Very high	10	86-100

Table 4: Scale used for severity assessment

Severity effect	Score	Meaning
Very-low	1	Less MTTR >1 hour
Low	2-3	MTTR > 1day
medium	4-6	MTTR 1-4days

High	7-8	External intervention for recovery
Very high	9-10	Service shut down, law, security

For output variable, the triangular membership functions are used. Multiple experts with different degree of competences are used to construct the membership function. The descriptive terms describing the output membership function are not important, minor, low, moderate, important and very important.

(2) Fuzzy rule base

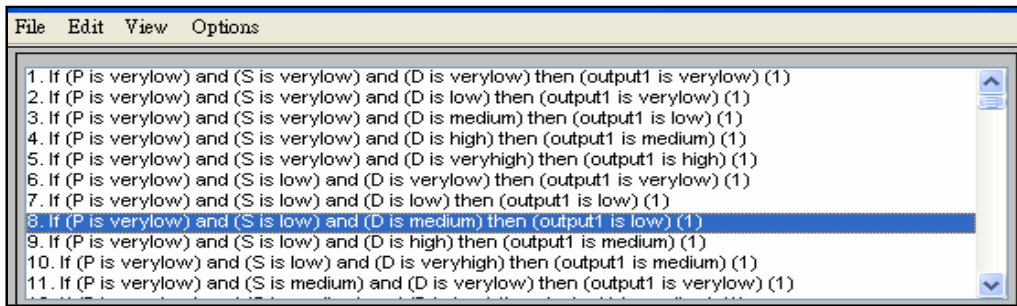
Fuzzy rule base is a collection of expertise’s knowledge. To express this knowledge fuzzy rules provide a natural platform for abstracting information based on expert’s judgment and knowledge. Expert’s knowledge and expertise about the interaction between various failure modes and their effects is represented in form of “If-Then” rules. “If” refers to an antecedent that is compared to the inputs, and “Then” refers to a consequent, which is the result/output. All the rules that have any truth in their antecedent will fire and contributes towards the fuzzy conclusion set. In our case studies, the fuzzy rule base have 125 rules (5(severity)×5(occurrence)×5(detect)). The format of rules framed in this study is shown in figure 4.

For instance:

$$R_i : \text{If } X \text{ is } M_i \text{ then } y \text{ is } N_i \quad i = 1,2,3,\dots,K \tag{2}$$

Where:

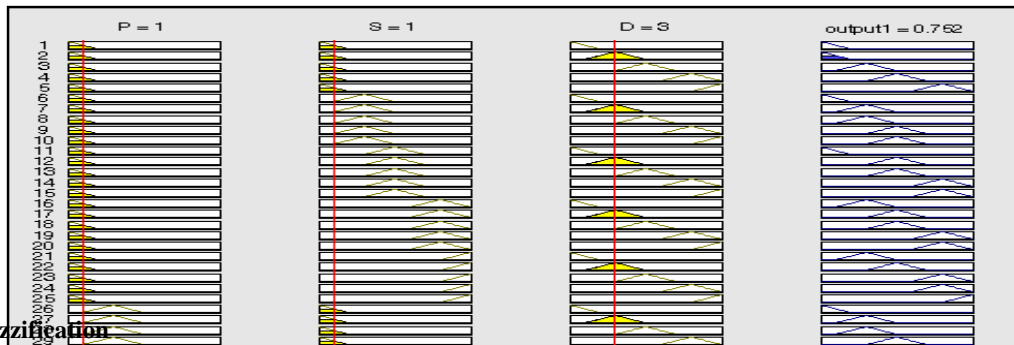
- X is the input(antecedent) linguistic variable.
- M_i are the antecedent linguistic constants
- y is the output(consequent) linguistic variable.
- N_i are the consequent linguistic constants.



(3) Fuzzy inference

Figure 4 : format of fuzzy rules

Fuzzy inference mechanism is based on the compositional rule of inference proposed by Zadeh. By using the inference mechanism an output fuzzy set is obtained from the rules and the input variables. The fuzzy inference uses the method of min-max implication-aggregation inference. The fuzzy reasoning mechanism is represented in figure 5.



(4) Defuzzification

Figure 5: Fuzzy reasoning mechanism

The final step is defuzzification. Defuzzification is to obtain crisp ranking from the fuzzy conclusion set, which is used to express the riskiness level of the failure. There are many defuzzification methods available in literatures but most commonly used are center of gravity , mean of maximum, center of area method. In this study, the center of area method is used for defuzzification which is given by equation 3

$$\text{Defuzzified value} = \frac{\int_{u_B}^y u_B(y) \cdot y \cdot dy}{\int_{u_B}^y u_B(y) \cdot dy} \tag{3}$$

Where B' is the output fuzzy set and u_B is the membership function

4. CASE STUDY

The distribution center is increasing in importance in logistics and supply chain management. Despite the name or role, the operation processes have a fundamental set of activities typically. For a systematic analysis of service failure, the service process of a distribution center decomposed into six steps: receiving, putaway, Storage, Order picking, sortation/accumulation and shipping. These steps are indicated on a flow line in figure 6. We describe each activity in the following:

Step 1: Receiving

Receiving is the collection of activities involved in (1) the orderly receipt all products coming into the warehouse, (2) providing the assurance of the quantity and quality that such products are as ordered.

Step 2: Putaway

Putaway is the act of placing merchandise in storage. It includes material handling, location verification, and product placement. It includes material handling, location verification and product placement.

Step 3: Storage

It is the physical containment of merchandise while awaiting a demand. The storage consists of environment, facility, item size and quantity activities.

Step 4: Order picking

Order picking is the process of removing items from storage to meet a specific demand. It is fundamental activity a warehouse provides for customers.

Step 5: Sortation/ accumulation:

When an order has more than one item, the sortation and accumulation activities must be done to enhance the order picking performance. The sortation of batch picks into individual orders and accumulation of distributed picks into orders.

Step 6: Shipping

The shipping sub-system may include checking orders for completeness, arrange shipping documents, weighting and determine charges, packing merchandise and scheduling the outbound orders.

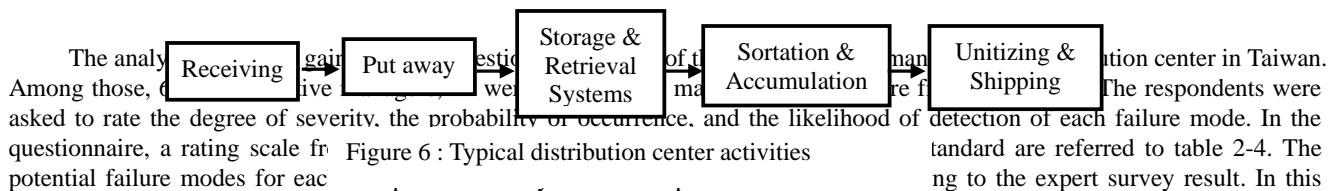


Figure 6 : Typical distribution center activities

The higher the RPN the more preventive action is needed. In order to identify the more critical failure modes, these RPN values are ordered, from lowest to highest value. In this study, list the top 6 failure modes. Those are ‘wrong item/quantity’, ‘unreliable supply of goods’, ‘no goods on designated shelf’, ‘product damage’, ‘inconsistency between actual and book inventories’, and ‘delay of delivery’. Therefore, these six failure modes represent the most critical failure modes in the distribution center. Thus, the preventive actions for these failure modes should be the top focus in the service engineering of the distribution center. In the meantime, the service recovery strategy and actions regarding these failure modes should also gain the most attention and should be planned in advance in order to restore the operation immediately if they do occur.

Table 5: failure mode and effect analysis in distribution center

Sub-system	Sub-process/ activity	Potential failure mode	Severity rating (1-10)	Occurrence rating (1-10)	Detection rating (1-10)	RPN
Receiving	Scheduling the receiving orderly	Tardiness of incoming goods	4.85	3.45	2.15	2.2354
	Provide assurance of order quantity and quality	Unreliable supply of goods	8.65	5.56	4.24	6.8564
Put away	Product handling	Unable to handling product	8.20	3.25	1.58	3.5478
	Location verification	Inefficient product process	6.45	3.78	2.65	3.8795
	Product placement	Inappropriate streamline arrangement of products	5.15	3.54	4.06	4.0145
Storage	environment	Lead to bad goods, fire and security	8.87	2.56	4.85	5.7782
		Insufficient storage space	4.58	6.68	3.68	2.2457

Storage	facility	Air-conditioning malfunction	5.35	2.68	2.47	3.2448
		Material handling device malfunction	8.35	3.55	1.87	3.6457
	warehousing	Wrong location of warehousing goods	6.82	3.45	5.22	4.0257
		No goods on designated shelf	7.42	5.24	3.54	6.5782
inventory	Inconsistency between actual and book inventories	4.54	5.68	5.48	6.1548	
Order picking	Extracting items	Wrong item/quantity	6.57	4.89	5.68	7.5243
	Product traveling among racks	product damage	7.85	2.45	2.14	3.0254
	Documenting picking transactions	Inconsistency between actual and account inventories	3.27	5.64	4.09	5.0324
Sortation/accumulation	Sorting items into orders	Wrong item	7.87	3.54	4.52	4.9687
	Accumulating items into orders	Inefficient order process	6.75	4.12	3.85	4.6875
shipping	Checking orders for completeness	Inconsistency between actual and book orders	7.98	5.68	3.58	4.9687
	shipping documents	Wrong order information	8.28	3.65	4.62	5.0655
	Weighting and determine charges	Wrong charge	8.17	2.57	4.25	4.5678
	Packing merchandise	goods damage	6.54	4.85	3.98	5.0215
	Scheduling the outbound orders	Tardiness of outbound goods	6.42	3.54	3.78	4.1689
	transportation	Product damage	7.88	3.89	5.64	6.3457
Delay of delivery		7.68	4.54	4.69	6.0857	

5. CONCLUSION & SUGGESTIONS

How to reduce service failure is always an important issue for business. It is very important for the service designer to identify the potential service failures and take the necessary action in advance to prevent the failure from occurring. Contrary to the traditional management method, this study adopts engineering perspective to prevent failure occurrence in advance. Because of the limited resources, the manager should prioritize the potential service failure modes in order to take action before the service is delivered. This study integrated the fuzzy inference and FMEA to ensure that the service system can prevent critical failures and thus reduce the risk of service failure.

An example of a distribution center was used to demonstrate the integrated approach. The results show that the greatest potential failure modes in the selected example are: 'wrong item/quantity', 'unreliable supply of goods', 'no goods on designated shelf', 'product damage', 'inconsistency between actual and book inventories', and 'delay of delivery'. From above results, it is clearly that the critical activities in distribution center existing in order picking, receiving and shipping activities.

This research provides an approach that assists the service designer in understanding the potential service failure modes as well as knowing how and where to take preventive action in its service system. The results can not only assist the distribution center to ensure the quality of its service system, it could also provide other service industries with an approach to arriving at an ideal service system design.

The integrated fuzzy inference and FMEA model have many advantages to prioritize the service failure risk. However, there are some concerns should be considered in application. Firstly, the RPN is a relative value. In other words, that RPN have different meaning in vary sub-systems. The company should rank the improvement order under limit resource. And when the operation or service system have great changed that it is need to assess again. For academic, the rating index for severity, occurrence and detection could be considered more quantity than quality. To provide more precise assessment in identify the failure service risk.

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