Service-Oriented FMEA and Grey Relational Analysis Based Approach to Service Reliability Assessment

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Abstract

Failure mode and effect analysis (FMEA) is a systematic approach for identifying potential failures before they occur, with the intent to minimize the risk associated with them. It has been widely used in the various manufacturing industries as a solution to reliability problems. As the importance of the service sector is increasing, however, it has been recently extended to some applications in services. Despite these attempts, FMEA cannot be directly applied to the reliability problems in a service industry. Due to the heterogeneity and customer participation in service process, we cannot perfectly prevent service failures. For this reason, we suggest a new risk priority number with three input parameters that consist of severity, probability of occurrence, and recoverability. In this paper, we propose an approach for assessing service risk and service reliability using the service-oriented risk priority number (S-RPN). An example regarding a hypermarket service process is used to demonstrate the proposed approach.

Keywords: Service Failure, Service Reliability, Service-Oriented RPN, Fuzzy FMEA, Grey Relational Analysis

1. Introduction

To survive in today’s competitive market environment, most of companies are increasingly focusing on utilizing services to satisfy customers’ needs and offer differentiated products [1]. The value of services depends on service reliability that is identified by satisfaction derived from the relationship between customer needs and service providers. The reliability corresponds directly to the service outcome and is mentioned as the most important dimension of assessing service quality [2]. The service reliability can be measured by its processes’ reliabilities, since a service consists of many processes. The service reliability is described as two delivery levels according to the promised performance dependably and accurately [3, 4]. And, the reliability of a service process can be defined as the capability of satisfying the specified performance requirements in a given period of time. Products and systems usually have continuous distribution functions in terms of reliability and failure. While service processes have discrete distribution functions and are independent from time. Therefore, failure types or the numbers of failures can be considered as more important events than their occurrence time or period [5]. Due to the characteristics of the services that are different from products, methods or methodologies for analyzing the reliability of product are hard to apply in service reliability analysis [5].

The objective of this paper is to propose an approach for assessing service risk and service reliability using the service-oriented risk priority number based on fuzzy failure mode effects analysis (FMEA) and grey relational analysis. The service reliability can be considered as mode and effects that can be occurred at each step of the service process. Because the failure modes of services are distinct from the failure modes of tangible systems, we need to develop a novel notion of a failure in a service delivery process. We use an event-based process model to facilitate service design and represent the relationships between functions and failures in a service. We define the failure mode of service as interaction ways that can be failed in a service delivery process. The basic unit of a service is a transaction which is a specific single instance of delivery of the service. In this paper, the fuzzy set theory is used to define the frequency of failures in service processes and characterize service
reliability based on linguistic terms during FMEA. Grey theory is employed to determine the degree of relation and ranking among risk factors that are represented as potential failure causes.

The remainder of this paper is organized as follows. Section 2 reviews the relevant researches of service reliability. Section 3 describes the proposed approach to assess service reliability. Section 4 gives a case study a hypermarket service process. Closing remarks and future work are presented in Section 5.

2. Literature Review

In general, reliability is defined as the persistence of ability to perform and maintain its functions or quality over time under stated conditions. The role of the passage of time is the essential characteristic in the definition of reliability [6]. The major concern of failure analysis in manufacturing industries is to emphasize the prevention of problems linked to the proactive treatment of the system rather than finding a solution after the failure happens [7].

Even though there are many definitions for a service, a service can be defined as a transaction or process that delivers service contents from service providers to customers. From the definitions on a service and reliability, service reliability can be described in terms of the success or failure of transactions that is occurred at various times [6]. A service failure occurs when customer’s expectations are not meet [8, 9] or service performance falls below a customer’s expectation [10, 11]. Customer perception is a major factor that determines whether a service failure occurred even if the company has the best strategic plans and the tightest quality control procedures [8, 12].

FMEA is widely used to handle the failures of manufacturing industries and its goal is to identify potential failures before they occur, with the intention to minimize the risk associated with them [13, 14]. Though FMEA has been extended to some applications in service sector in recent years [8, 15], these researches used the traditional risk priority number (RPN) of FMEA for evaluating the risk priority of each failure mode. Risk prioritization is particularly important in service industries where the characteristics of services should be considered. Many researchers have been conducted to provide methodologies considering the multilateral perspective of a service such as fuzzy logic, grey theory [16, 17], and so on. These methods are, however, still limited to the manufacturing sector. In the next session, we propose a new systematic approach for risk prioritization of service failures that considers recovery strategies and actions.

3. Service-Oriented FMEA

3.1 Risk and the Risk Priority Number of FMEA

In the traditional FMEA, the risk priority number (RPN) is calculated by the multiplication of three risk factors, severity, occurrence and detection, and each factor can be described as the following [18]:

1) Severity (S): Result generated from failure
2) Occurrence (O): Opportunity or probability of a failure
3) Detection (D): Opportunity for an unidentified failure because of the difficulty in detection

The traditional risk prioritization ignores that three factors may have different weights in system, and especially occurrence is a key factor in non-repairable system. Patrick et al. [18] emphasize that the severity and the occurrence are two key items which should be used in FMEA priority analysis rather than the item of the detection.

A service failure in service industries is a problematic outcome causing significant damage to customer satisfaction [19, 20, 21]. The RPN of FMEA is used to identify potential failures before they occur to minimize the risk associated with them. However, some researchers have been raised different views on the appropriateness of the RPN [17].

The notion of risk has both uncertainty and some kind of loss or damage that might be received. The risk is understood to someone as a subjective thing, because a risk depends on who are looking [22]. In analyzing risk, we are attempting to envision how the future will turn out if we undertake a certain course of action. Fundamentally, a risk analysis consists of an answer to the following three questions:
1) What can happen? (i.e., what can go wrong?)
2) How likely will it happen?
3) If it does happen, what are the consequences?

The first question is related with a failure mode, and the second and third question can be interpreted as the occurrence and severity of the RPN.

If it is possible to reduce the risk at small cost, then the risk is unacceptable. Conversely, a much larger risk may be perfectly acceptable if it brings with it the substantially reduced cost or increased benefit [22]. Thus one of the factors related with the questions cannot talk about the risk in isolation and the risk can be evaluated by product of severity, occurrence and detection.

3.2 Service-Oriented Risk Priority Number (S-RPN)

The detection of the traditional FMEA is important for maintainability control in a repairable system. The failures which can be detected by the maintenance crew or by some diagnostic process may involve dormant failure modes or latent failure like a metal growing crack. However, the ultimate outcome of a service failure in services is revealed as customers’ behaviors; stay or leave [23].

In the service sector, customers are one of the most importance sources in service failures [15]. A customer may stay after service failure if the customer is satisfied with a service recovery process. However, the customer may leave if the recovery efforts are poor, causing the customer to be even more dissatisfied [23]. And so, a service failure will be finally decided if the customer is not satisfied with the recovery efforts. Due to the heterogeneity and the customer participation in a service delivery process, we cannot perfectly prevent service failures in advance. For the reason, recovery efforts and processes are more important than a detection process.

Service failure may vary considerably across the dimensions of timing, severity, and occurrence [24]. We propose a new RPN with three input parameters that consist of severity (S), probability of occurrence (O), and recoverability (R). The new RPN named as service-oriented risk priority number (S-RPN) is determined by the multiplication of three indexes as equation (1).

\[
S-RPN = \text{Severity} \times \text{Occurrence} \times \text{Recoverability} \tag{1}
\]

The term ‘recoverability’ means that the committed transactions have not read data written by the aborted transactions in software engineering. However, we define the recoverability in S-RPN as the definition of NASA report [25]: “Recoverability is the ability to restore correct service delivery after experiencing a failure”. The recoverability also falls into the context of maintainability, which includes physical replacement and repair of system components. For our research, the recoverability is the complement of reliability and is measured as the probability that the service is recovered within a specified time interval after the occurrence of a failure.

Figure 1 shows the proposed approach for assessing service reliability based on failure modes and service processes. The proposed method consists of four phases: (1) identify failure modes, (2) define FMEA parameters using S-RPN, (3) defuzzify the defined FMEA parameters, and (4) determine the degree of grey relation and ranking. In the initial phase, service processes are modeled and analyzed to identify the failure modes of services using service blueprint. For any service, a blueprint can trace processing steps and information flows between a customer and a provider. We can identify service processes and isolate fail points in the service through designing a blueprint. The second phase is to determine three input parameters, i.e., severity (S), probability of occurrence (O), and recoverability (R), which are used in the proposed service-oriented FMEA. Each parameter will be described as five linguistic terms. Then, these parameters are fuzzified using a membership function to determine degree of membership in each parameter. The expertise of many experts is used to construct the membership function. The interpretations of these linguistic terms used in this paper are given in Table 1 and the triangular membership functions are as shown in Figure 2. After determining the degree of grey relation and ranking using grey theory, service reliability is evaluated based on the generated service processes.
Figure 1. The proposed method for service reliability evaluation

<table>
<thead>
<tr>
<th>Linguistic term</th>
<th>Severity</th>
<th>Probability of occurrence</th>
<th>Recoverability</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Remote</td>
<td>A failure has no effect on customer satisfaction</td>
<td>Failure is unlikely</td>
<td>The chance that a failure can be successfully recovered is very high</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>A failure that would lead slight dissatisfaction to customer</td>
<td>Few failures</td>
<td>The chance that a failure can be successfully recovered is high</td>
<td>2, 3</td>
</tr>
<tr>
<td>Moderate</td>
<td>A failure that would lead noticeable dissatisfaction to customer</td>
<td>Occasional failures</td>
<td>The chance that a failure can be successfully recovered is moderate</td>
<td>4, 5, 6, 7</td>
</tr>
<tr>
<td>High</td>
<td>A failure that would lead significant dissatisfaction to customer</td>
<td>Repeated failures</td>
<td>The chance that a failure can be successfully recovered is low</td>
<td>8, 9</td>
</tr>
<tr>
<td>Very high</td>
<td>A failure that would lead serious dissatisfaction to customer</td>
<td>Failure is almost inevitable</td>
<td>The chance that a failure can be successfully recovered is remote</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 2. Membership function for the linguistic terms
3.3 Defuzzification

Usually, an assessment of the three indices is subjective and qualitatively described as natural language. The disadvantage of the traditional FMEA is that various sets of the indices may produce an identical value of RPN. Therefore, the risk implication may be totally different [26, 27]. The other disadvantage of the RPN ranking method is that it neglects the relative importance between the indices. Some researchers have applied fuzzy set theory to deal with these problems [16, 28, 29]. Xu et al. [28] presented a fuzzy logic based method and an assessment expert system for the FMEA of a diesel engine turbo charger system. Pillay and Wang [16] used a fuzzy rules base and grey relation theory to determine RPN by multiplying the factor scores of S, O, and D. The defuzzified values of each of the linguistic terms are used to generate the defuzzification of the membership functions. Defuzzification is used to obtain the crisp number of a fuzzy set and can be calculated by Equation (2) which is proposed by Chen et al. [29].

\[
K(x) = \frac{\sum_{i=1}^{n} (b_i - c_i)}{\sum_{i=1}^{n} (b_i - c_i) - \sum_{i=1}^{n} (a_i - d_i)}
\]  

(2)

Where \( K(x) \) is the defuzzified crisp number.

3.4 Grey Relational Analysis

Grey theory is used to define relationships between discrete quantitative and qualitative series and solve a decision-making problem which is characterized by incomplete and partially known information. Grey theory has been widely applied to various fields, such as optimization, engineering, economy, history, geography, traffic, and management [16]. Chang et al. [17] applied grey theory to develop a FMEA framework for determining a risk priority number by assigning relative weighting coefficient. The procedures of determining the degree of relation and ranking are as follows [30]:

(i) Establish comparative series: comparative (information) series, \( \{x_1, x_2, \cdots, x_n\} \), are failure modes and represented as various linguistic terms.

\[
X = \begin{bmatrix}
    x_1 \\
    \vdots \\
    x_n
\end{bmatrix} = \begin{bmatrix}
    x_1(1)x_1(2) \cdots x_1(k) \\
    x_2(1)x_2(2) \cdots x_2(k) \\
    \vdots \\
    x_n(1)x_n(2) \cdots x_n(k)
\end{bmatrix}
\]

(3)

The linguistic terms describe each decision factors of the failure mode.

(ii) Establish standard series: The standard series, \( x_0 = [x_0(1), x_0(2), \cdots, x_0(k)] \), is an objective series that reflects the ideal of desired level of all the decision factors.

(iii) Obtain the difference between the comparative and standard series: The difference between the two series, \( D_0 \), is calculated to determine the degree of grey relationship as following:

\[
D_0 = \begin{bmatrix}
    \Delta_{01}(1)\Delta_{01}(2) \cdots \Delta_{01}(k) \\
    \Delta_{02}(1)\Delta_{02}(2) \cdots \Delta_{02}(k) \\
    \vdots \\
    \Delta_{0n}(1)\Delta_{0n}(2) \cdots \Delta_{0n}(k)
\end{bmatrix}
\]

(4)

Where, \( \Delta_{0j}(k) = \|x_0(k) - x_j(k)\| \).

(iv) Compute a grey relational coefficient: A grey relational coefficient is determined to compare the decision factors with standard series as following.

\[
\gamma(x_0(k), x_j(k)) = \frac{\Delta_{m-K} + \xi \Delta_{m-DX}}{\Delta_{0j}(k) + \xi \Delta_{m-DX}}
\]

(5)
\[
\Delta_{o_j}(k) = \left|x_{o}(k) - x_j(k)\right|,
\]
\[
\Delta_{m} = \sum_{j} m \sum_{k} \left[x_{o}(k) - x_j(k)\right],
\]
\[
\Delta_{m} = \sum_{j} m \sum_{k} \left[x_{o}(k) - x_j(k)\right],
\]

Where \( x_{o}(k) \) is a minimum or maximum value in the standard series, and \( x_j(k) \) is a minimum or maximum value in the comparative series, and \( \xi \) an identifier, \( \xi \in (0, 1) \) only affecting the relative value of risk without changing the priority.

(v) Determine the degree of relation: The degree of relation \( \Gamma(x_i, x_j) \) denotes the relationship between the potential cause and the optimal value of decision factors and is represented by:

\[
\Gamma(x_i, x_j) = \sum_{k=1}^{n} \beta_{k} \gamma\{x_i(k), x_j(k)\}
\]

Where \( \beta_{k} \) is the weighting coefficient of the decision factors and \( \sum_{k=1}^{n} \beta_{k} = 1 \).

(vi) Determine the ranking of the relational series: The relational series represent the relationship between potential causes and optimal value of the decision factors in FMEA. As increasing the value of the degree of relation, the effect of the cause is decreased. We can determine the ranking of the relational series based on the degree of relation by identifying the risk priority of potential failure causes.

In the next section, the proposed method is applied to evaluate service reliability using a case study of a typical automotive service operation.

4. Case Study

To demonstrate the usefulness of the proposed approach, we performed a case study with an example regarding a hypermarket service process. The service blueprint in Figure 3 shows a simplified version of the standard service, starting when the customer arrives at parking space and finishing when the customer leaves the market [8].

The results of Service-Oriented FMEA at each stage and the linguistic terms generated by the experts are summarized in Table 2. In Table 2, three indices (S, O, R) are described linguistically as Remote, Low, Moderate, High, and Very high. For the service process in a hypermarket, we adopt the guidelines as described in Table 1 and the membership function for the linguistic terms as shown in Figure 2. These linguistic terms are defuzzified using equation (2) to produce a crisp number and the results are listed in Table 3. The comparative series is represented in a matrix based on the linguistic terms that are assigned to each failure, and then converted to numerical values by defuzzification as shown in Table 3.

In Service-Oriented FMEA, the standard series should consist of the lowest level of linguistic term, Remote, in the case study, since the small value of RPN represents the less risk. The defuzzified value of Remote is 0.136, which represents the average value. To compute the grey relation coefficient using equation (5), the difference of the standard and comparative series is calculated using equation (4). In this paper, we assume that \( \xi = 0.5 \). The weighting coefficient for the linguistic terms, assigned in equation (6) for calculating the degree of relation, will have a large influence on the final ranking of failure modes. The objective of this research is to apply FMEA to service process for identifying the failure modes which seriously impact customers’ satisfaction. The coefficient should be decided depending on the objective of the analysis and the reliability of the data available. To evaluate how the results of FMEA are different according to the weighting coefficient, we assume that the values of \( \beta_{S} \), \( \beta_{O} \), and \( \beta_{R} \) are (0.4, 0.2, 0.4) and (0.4, 0.4, 0.2) for the case 1 and 2 respectively. The grey relational coefficients for the first failure (f1) in case 1, \( \gamma_{S} \), \( \gamma_{O} \), and \( \gamma_{R} \) are calculated as following:

\[
\gamma_{S} = \frac{0 + [(0.5)(0.793)]}{0.068 + [(0.5)(0.793)]} = 0.372
\]
\[
\gamma_{O} = \frac{0 + [(0.5)(0.793)]}{0.147 + [(0.5)(0.793)]} = 0.730
\]
\[
\gamma_{R} = \frac{0.793 + [(0.5)(0.793)]}{0.793 + [(0.5)(0.793)]} = 0.333
\]
And, then the degree of relation for the first failure was calculated by Equation (6) as following:

\[ \Gamma(x_1, x_2) = \{(0.4)(0.372) + (0.2)(0.730) + (0.4)(0.333)\} = 0.43 \]

![Figure 3. Service blueprint for a hypermarket (Adapted from [8])](image)

**Table 2.** Comparative series and defuzzified crisp value for a hypermarket

<table>
<thead>
<tr>
<th>Participant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure modes</td>
</tr>
<tr>
<td><strong>Linguistic terms assigned to each failure and defuzzified value</strong></td>
</tr>
<tr>
<td>Severity</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td><strong>Resources</strong></td>
</tr>
<tr>
<td>f1</td>
</tr>
<tr>
<td>f2</td>
</tr>
<tr>
<td>f3</td>
</tr>
<tr>
<td>f4</td>
</tr>
<tr>
<td>f5</td>
</tr>
<tr>
<td>f6</td>
</tr>
<tr>
<td><strong>Front-line servers</strong></td>
</tr>
<tr>
<td>f7</td>
</tr>
<tr>
<td>f8</td>
</tr>
<tr>
<td>f9</td>
</tr>
<tr>
<td>f10</td>
</tr>
<tr>
<td>f11</td>
</tr>
<tr>
<td>f12</td>
</tr>
<tr>
<td>f13</td>
</tr>
<tr>
<td>f14</td>
</tr>
<tr>
<td>f15</td>
</tr>
<tr>
<td><strong>Sub-system</strong></td>
</tr>
<tr>
<td>f16</td>
</tr>
<tr>
<td>f17</td>
</tr>
<tr>
<td>f18</td>
</tr>
<tr>
<td>f19</td>
</tr>
<tr>
<td>f20</td>
</tr>
<tr>
<td>f21</td>
</tr>
</tbody>
</table>
Table 4 shows the results of the proposed approach for the case study. The rankings of the failure modes can be affected to service reliability based on the risk priority of potential failure causes. In particular, the results from the two cases showed different rankings for f1, f4 (unable to find front-line server), and f11 according to the weighting coefficient values of the occurrence and recoverability. The failure modes of f4 and f11 were considered as the more critical failure modes under the situation which the occurrence is more critical rather than the recoverability, because f4 and f11 were affected from failure occurrences rather than their recoverability. The failure mode of f1 can be considered as a critical failure, if its recoverability is more urgent situations. Therefore, a critical failure such as insufficient parking space should have priority for increasing customer satisfaction and service reliability.

Through the case study, we demonstrated that the proposed approach can be applied to identify critical failures that are hard to define their detectability and the probability of occurrence using the existing FMEA. And the proposed approach is more suitable to design service processes including failures that cannot be prevented inherently.

**Table 4. Results of the proposed approach for the case study**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Failure modes</th>
<th>Defuzzified value and grey relational value for S,O, and R</th>
<th>Degree of relation &amp; Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S</td>
<td>Y_S</td>
</tr>
<tr>
<td>Resources</td>
<td>Insufficient parking space</td>
<td>0.804</td>
<td>0.372</td>
</tr>
<tr>
<td></td>
<td>Shopping cart malfunction</td>
<td>0.283</td>
<td>0.730</td>
</tr>
<tr>
<td></td>
<td>Air conditioning malfunction</td>
<td>0.540</td>
<td>0.495</td>
</tr>
<tr>
<td></td>
<td>Escalator malfunction</td>
<td>0.540</td>
<td>0.495</td>
</tr>
<tr>
<td></td>
<td>Sales floor is not clean</td>
<td>0.540</td>
<td>0.495</td>
</tr>
<tr>
<td></td>
<td>Wrong price tag</td>
<td>0.804</td>
<td>0.372</td>
</tr>
<tr>
<td>Front-line servers</td>
<td>Goods quality is not good</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>No goods on sales shelf</td>
<td>0.804</td>
<td>0.372</td>
</tr>
<tr>
<td></td>
<td>Unable to find front-line server</td>
<td>0.804</td>
<td>0.372</td>
</tr>
<tr>
<td></td>
<td>Unkindness of front-line server</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>Slow processing speed of cashier</td>
<td>0.540</td>
<td>0.495</td>
</tr>
<tr>
<td></td>
<td>Unfriendly attitude of cashier</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>Calculation mistake of cashier</td>
<td>0.804</td>
<td>0.372</td>
</tr>
<tr>
<td></td>
<td>Inappropriate complaints adjustment</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>Inappropriate refund/returned policy</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td>Sub-system</td>
<td>Forecasting error of goods</td>
<td>0.804</td>
<td>0.372</td>
</tr>
<tr>
<td></td>
<td>Unstable supply of goods</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>Incoming inspection failure</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>Inconsistency between actual and book inventory</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>Wrong location of warehousing goods</td>
<td>0.929</td>
<td>0.333</td>
</tr>
<tr>
<td></td>
<td>Wrong replenishment of goods in sales shelf</td>
<td>0.804</td>
<td>0.372</td>
</tr>
</tbody>
</table>

5. Conclusion

In this paper, we proposed an approach for assessing service reliability by extending concepts from the failure modes and effects analysis of tangible systems to services. We introduced service-oriented FMEA with service-oriented risk priority number (S-RPN) that consists of severity (S), probability of occurrence (O), and recoverability (R). Service processes were modeled and analyzed to identify the failure modes of services using service blueprint. The fuzzy set theory was used to characterize service
reliability based on linguistic terms during the service-oriented FMEA. Additionally, grey theory was employed to determine the degree of relation and ranking among risk factors that are represented as potential failure causes. Through the case study involving a hypermarket service process, we demonstrated that the proposed approach can help access service reliability by identifying significant service failures. The proposed approach can provide a quantitative method to support service process design by understanding failure modes that are affected to service reliability.

To improve the proposed approach, we need to develop a method to better identify failure modes based on service processes and customers’ satisfaction. Additionally, since service reliability are sensitive to human errors in a service, future research efforts will be focused on evaluating human errors in the service reliability. Also, the proposed approach will be compared to other decision-making methods for accessing service reliability.

6. References