

## Service reliability assessment using failure mode and effect analysis (FMEA): survey and opportunity roadmap

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### Abstract

Despite Failure Mode and Effect Analysis (FMEA) being a strategic technique for creation of error free service operation, detailed survey study and development of opportunity roadmap for FMEA application in service operation is limited in literature. We presented a preliminary literature survey between 1994 and 2010 that covers 20 journals from 8 different literature databases. The result of our preliminary survey indicated that majority of previous service FMEA studies focused on profit and supply chain-oriented service business practices. New service FMEA research opportunities relating to enhancement in Risk Priority Number (RPN), reprioritization, versatility of its application in service supply chain framework and non-profit service sector as well as combination with other quality control tools are proposed for further investigations.

**Keywords:** FMEA application in service operation; Risk Priority Number (RPN) reprioritization; Service supply chain; Non-profit service sectors; Quality control tools

DOI: <http://dx.doi.org/10.4314/ijest.v3i7.3S>

### 1. Introduction

As a sector that contribute to more than 50% of Gross Domestic Product (GDP) in global economy, the importance of service sector will grow in future (Gecky *et al.*, 2010). Bullinger *et al.* (2003) stated that in the past decade, the marketing science is more dominating to the development of service as a discipline compare to the contribution by the advancement of techniques from product design and manufacturing discipline. Motivated by above situation, enhancing design tool for error free service operation is necessary. Reliable service as manifested by error free service operation is important subject to dig, since unreliable service operation is becoming the source of customers' dissatisfaction (Yang *et al.* 2003; Fowdar, 2008; Hong *et al.* 2010) and driver of unexpected service operation cost. In addition, due to the uniqueness of service characteristics - its intangibility, heterogeneity, inseparability between service provider and consumer, and interrelated relationship among man, machine, and systems makes accessing service reliability has its own challenges (Hashim, 1984). Previous studies that aimed to propose new ideas for future service as a discipline (Menor *et al.* 2002; Chase and Apte, 2007; Torney *et al.* 2009 and Ostrom *et al.* 2010) emphasised the importance of modifying or enhancing reliability assessment tool in product design in service operation. In addition, previous literature that discusses on the progress of reliability assessment issues with FMEA is still focusing in product design and manufacturing (Bouti and Kadi, 1994, Yadav *et al.* 2008 and Bhamare *et al.* 2007). Motivated by the gap, we presented a preliminary survey to the state of the art of FMEA studies in literature during the specified time span and propose new research opportunities with focus to service sectors. The term "service FMEA" in this paper is related to the application of FMEA in service operation.

The remainder of the paper is organized as follows: In section 2, we presented the survey methodology used in this research paper. In section 3, we mapped the classifications of previous FMEA studies based on specific criteria. In Section 4, detailed the observable gaps in previous service FMEA studies and new research challenges are presented. Section 5 is related to conclusions and suggestions to extend our initial survey.

**2. Research Methodology**

Naturally, the service FMEA literature is dispersed to various forms and application settings in the form of periodicals, books, conference proceedings, booklets and so on. To deal with our objective, we used systematic search through literature databases. The FMEA related literature databases spanning from 1994-2010 are chosen. The periodical is preferable among other types of literature since it is perceived as the highest source of research level up-to-date and contains specific issue of interest (Nord and Nord, 1995 in Ngai *et al.* 2009). The publications such as Emerald, Springer, Ebscohost, Inderscience, Informaworld, Hindawi, Sage, IEEExplore, Ingenta, Sciencedirect, and Directory of Open Access Journal (DOAJ) are chosen as the literature databases. Meanwhile, the choice of periodicals to match with the objective of this study is based on factors such as the journals maturity (the length of publication), the impact factor, and scope of the journal. Then, we classify the literature found during the search based on the specific criteria that limited to: FMEA automation, enhancement of FMEA methodology in modelling failure phenomenon, combination of FMEA with other quality tools, FMEA modification, and its versatility in various application settings. We excluded the articles that are written with language other than English. The keywords used in the search are “FMEA”, and “FMECA”. The finding of the literature search is then reported in a tabular format as shown in Table 1.

**3. Results of Preliminary FMEA Literature Survey**

Referring to the specific criteria as determined earlier, the classification of FMEA literature found in our study is shown as above. Based on the result from our initial survey, many studies have promoted to apply FMEA in various service sectors. Nevertheless, in our point of view; there are still some unobserved spots that warrant for further studies as below:

1. Majority of previous service FMEA studies are still dedicated for profit-oriented service. Although possessing significant amount of financial value and improved quality of societal life, the application of FMEA to other non-profit service sectors such as humanitarian (voluntary) service and governmental (public) service are escaped from previous researchers’ attention. Refer to Johnston (2005) and Redman *et al.* (1995) for details of justification to researches in non-profit service sectors.
2. The basis to estimate the RPN is based on a 1-10 scale in previous FMEA literature is less scientific that makes the RPN resulted from such estimation prone to lower accuracy and vary among FMEA practitioners in various industries.
3. Previous service FMEA studies are based on assumption that service customers are behaving in good manners during service delivery; although in daily service delivery and customers can also abuse or do sabotage to service provider(s) and or to other customer(s).
4. Although competing through supply chain is becoming the paradigm for nowadays business, previous service FMEA studies are still dedicated to single company practice and overlook on implementing FMEA in supply chain framework.

In addition, considering bi-directionality of customer in service, the change of business paradigm from single company into collaborative business orientation in supply chain framework, the growing concern to sustainability issues, and transition from pure manufacturing business into product-service business scope; there are surely some opportunities in future service FMEA researches. Refer Sampson (2000), Foster (2008), Xu and Wang (2009), and Kim *et al.* (2010) as basis to get deep insight on service FMEA researches. However, due to the vast scope of service FMEA as subject for further study, we only presented new research opportunities that limited to some areas such as: improvement in estimating the RPN, modification of FMEA method in service operation, and expansion of FMEA study in various service areas.

**Table 1. Classification of FMEA References**

FMEA Scope	Tool/ Content/Topic	References
<b>Combination with Other Quality Tools</b>	FMEA-Quality Function Deployment (QFD)	Bosch and Golzalves (2005), Tan (2003), Annamalai <i>et al.</i> ,(2006), Gin <i>et al.</i> , (1998), Pujawan and Geraldin (2009), Braglia and Frosolini (2007), Al-Mashari <i>et al.</i> , (2005) Bosch and Enriquez (2005), Chen and Ko (2009), Tanik (2010), Hassan <i>et al.</i> , (2010)
	FMEA-Fault Tree Analysis (FTA)	Arcidiacono ( 2004)
	FMEA-QFD-Statistical Process Control-Design Of Experiments	He <i>et al.</i> , (2002)
	FMEA-Statistical Process Control	Teng and Ho (1996)
	FMEA-Hazard Analysis Critical Control Point (HACCP)	Scipioni (2002), Bertolini <i>et al.</i> , (2006), Varzakas <i>et al.</i> , (2007), Arvanitoyannis <i>et al.</i> , (2009)

**Table 1 (cont'd). Classification of FMEA References**

FMEA Scope	Tool/ Content/Topic	References
<b>Combination with Other Quality Tools</b>	FMEA-Kano Method	Shahin (2004)
	FMEA-Project Management	Santos and Cabral (2008)
	FMEA-TRIZ Method	Bariani <i>et al.</i> , (2004)
	FMEA-HAZOP (Hazard and Operability Study)	Ilangkumar and Thamizmani (2010)
	FMEA-Service Blue Printing	Chuang (2007)
	FMEA-Petri Nets	Bertolini <i>et al.</i> , (2006)
<b>Reprioritization of the Risk Priority Number (RPN)</b>		
	Fuzzy Logic	Pelaez and Bowles(1995), Dong (2009), Puente <i>et al.</i> , (2002), Xu <i>et al.</i> , (2002), Sharma <i>et al.</i> , (2005), Sharma and Sharma (2010), Braglia <i>et al.</i> , (2003), Kumar and Chaturvedhy (2011), Aidin and Ozkan (2008), Tan and Mey (2005), Sharma <i>et al.</i> , (2008), Zafiroopoulos and Dyalinas (2000)
	Cost basis	Ben Daya and Raouf (1996), Ahsen(2008), Carmignani (2009), Rhee and Ishii (2003), Jeegadeshnan <i>et al.</i> , (2007), Dong (2007), Kmenta and Ishii (2004)
	Analytical Hierarchy Priority (AHP)	Braglia (2000), Ouedraogo <i>et al.</i> , (2010)
	Multi- Expert Multi Criteria Decision Making	Franceschini and Galletto (2001)
	Graph Theory	Gandhi and Agrawal (2002)
	DEMATEL (Decision-Making Trial and Evaluation Laboratory)	Hosseini <i>et al.</i> , (2006), Chang and Cheng (2011)
	Poisson Distribution	Senol (2007)
	Taguchi Loss Function	Karuppuswamy <i>et al.</i> , (2006)
	Grey Theory	Chang <i>et al.</i> , (1999), Sharma <i>et al.</i> , (2007), Pilay and Wang (2003)
	Error Commonality Index	Chao and Ishii (2003)
	TOPSIS (Technique for Order Preference by Similarity to Ideal Solution)	Sachdeva <i>et al.</i> , (2009), Braglia <i>et al.</i> , (2003)
	Group Oriented Decision Making	Jenap and Dhillon (2005)
	Izonote Concept	Gwiazda (2007)
	Anova (Analysis of Variance)	Karupussami and Narayanagounder (2009)
	Data Envelopment Analysis (DEA)	Chang and Kuo (2009),Garcia <i>et al.</i> , (2005), Chin <i>et al.</i> , (2009)

**Table 1 (cont'd). Classification of FMEA References**

FMEA Scope	Tool/ Content/Topic	References
<b>Application of FMEA in Various Industrial Settings</b>		
	Mechanical Product Design	Miguel <i>et al.</i> , (2005), Bahmed <i>et al.</i> , (2006), Korayem and Iravani (2008)
	Food Manufacturing	Scipioni <i>et al.</i> , (2002), Bertolini <i>et al.</i> , (2006)
	Software Development	Rebelo and Goyal (2010), Dilibabu and Krisnaiah (2006)
	Building Industry	Layzell and Ledbetter (1998)
	Aviation Safety Management	Lee ( 2005)
	Automotive and Shipbuilding Industry	Albuquerque <i>et al.</i> , (2009), Buksa <i>et al.</i> , (2010), Estorilo and Posso (2010)
	Wastage Treatment	Yeh and Hsieh (2007)
	Drug Research & Development	Inoue and Yamada (2010)
	Spare Part Management	Tsakatitas <i>et al.</i> , (2007), Braglia <i>et al.</i> ,(2005)
	Civil Construction Project	Wong <i>et al.</i> , (2006)
<b>Application of FMEA in Various Industrial Settings</b>		
	Outer Space Program	Satish <i>et al.</i> , (2009)
	ERP (Enterprise Resource Planning) Implementation	Yang <i>et al.</i> , (2006)
	Working Safety Assessment	Fera and Macchiaroli (2009), Suhendra and Compart (2007), Thivel <i>et al.</i> ,(2008)
	Goods Quarantine	Dai <i>et al.</i> ,(2008)
	Semiconductor and Metal Manufacturing	Byrne and Sheahan (2007), Deng <i>et al.</i> , (2007), Mili <i>et al.</i> , (2009)
	Entertainment Security	Berkeley (1998),
	Healthcare	Jeong <i>et al.</i> (2007), Ookalkar <i>et al.</i> , (2009), Chiozza and Pozenti (2009), Mummolo <i>et al.</i> , (2010), Chang <i>et. al</i> (2010), Geum <i>et al.</i> , (2010), Aksezer (2010), De Giorgi <i>et al.</i> , (2010), Attike <i>et al.</i> , (2010)
	Maintenance	Bertolini <i>et al.</i> , (2006), Pujadas and Chen (1996), Elharam and Horner (2002), Al-Mishari and Sulaiman (2008)
	Education	Shintavalai and Mamengkol (2008),
	Travel	Shahin (2004)
	Electronic Commerce	Linton (2003)

**Table 1 (cont'd). Classification of FMEA References**

<b>FMEA Scope</b>	<b>Tool/ Content/Topic</b>	<b>References</b>
<b>Application of FMEA in Various Industrial Settings</b>	Residential Service Provision	Browman <i>et al.</i> , (2010)
	Transportation Service	Jeegadeshnan <i>et al.</i> , (2007)
	Consumer Good Trading	Chuang (2007), Chuang (2010)
	Sales Service	Qiang (2009)
	Culinary	Ozilgen (2010)
	<b>Application of FMEA in Supply Chain Framework</b>	Pharmaceutical Logistics
Aerospace Product Manufacturing		Sinha <i>et al.</i> , (2004)
Automotive product design and Manufacturing		Leung <i>et al.</i> , (2005), Teng <i>et al.</i> ,(2006)
<b>Modification Of FMEA</b>		Holistically - oriented FMEA
	Reliability assessment of product re-manufacture	Lam <i>et al.</i> , (2001), Parkinson and Thompson (2004),
	Reliability assessment of lean manufacturing system	Shaweney <i>et al.</i> , (2010)
	Evaluating qualitative attribute of business process	Zakarian <i>et al.</i> , (2006)
	<b>FMEA Automation</b>	
<b>Enhancement of Failure Assessments</b>		
	Behaviour Modelling	Eubanks <i>et al.</i> ,(1996), Kmenta <i>et al.</i> , (1997), Kmenta and Ishii (1998)
	Petri Net	Adamyam and He (2004)
	Framing Interactive Failure evaluation	Nepal <i>et al.</i> , (2008)

**4. New Research Challenges**

**4.1 Enhancing the Risk Priority Number estimation Methodology**

Correct evaluation of RPN is important in FMEA stages since it is the basis for resource allocation to curb the cause of service reliability problem. To overcome the shortcomings of the RPN estimation method based on Military Standard 1629A, many techniques have been proposed as shown in Table 1. However, the basis to build various RPN estimation techniques is still based

on 1- 10 scale of RPN ratings that seemed to have less scientific basis. Furthermore, as failure event occurrences are time dependent phenomena, the role of time as dimension to estimate the RPN should also be considered in future research. Fulfilling the gap on counting the RPN metric into more scientific basis, Sutrisno and Kwon (2010) presented risk reprioritisation approach using conditional probability. Extending their study, new opportunities in this research direction are as below:

- How to determine the RPN reprioritisation method by considering the occurrences of failure events along finite time span with uncertainty in their number and time occurrences?
- Previous RPN estimation methods are neglecting the reality that service customers in some situations are still tolerating against failure occurrences. In this case, the question for next study is on “how to incorporate the aspect of customers’ tolerability in counting the risk of service failure”?
- Although the use of cost as basis to prioritize the risk seemed to be useful for practical situation, some works are still waiting ahead to develop it by incorporating input from other disciplines such as physiology and sociology. For example, “how we can quantify the cost based- risk of patient worry (fear) due to medical malpractice”?
- All service FMEA studies above are only viewing risk of failure as a treat to firm. Meanwhile, the occurrence of failure event is also creating opportunities to firm. From this perspective, embodiment of the concept on competing threat and opportunity into FMEA, and how to determine the ratings scale of opportunity priority number as proposed by Koo *et al.* (2008) into more scientific basis is still becoming big question to answer?
- The basic principle of previous FMEA methodology is that the attention of FMEA decision makers to curb the of service quality problems should be prioritised to the failure modes with the highest RPN. However, in daily situation; the FMEA team has to deal with multi conflicting service attributes that are often opposing one another.
- Referring to the cost oriented RPN reprioritisation methods and the use of Taguchi Loss Function to quantify deviation from customers’ specification, “how can we make balance corrective improvements since spending too many resources to rectify quality problems is a gain to customer but a loss to service provider”?

#### 4.2 Modification of FMEA to Create Resilient Service Systems against Jay Customers

*Jay customers* are kind of customers who abuse services to service providers or to customers. They should also be considered in design resilience service since their economic, social, and physiological impact cannot be neglected. Although efforts have been dedicated to modify FMEA to deal with holistic failure assessment from every company functions (Devadasan *et al.* 2003) and embodiment of robust design into FMEA (Mekki, 2006), it looked that previous modification overlook on the existence of *jay customers*. Many challenges are still remaining left on modelling the interaction between impact of internal service failure and external service failure due to customers’ abuse and counting the RPN of service failure occurrences in such situation.

#### 4.3 Combination of FMEA and other Quality Control Tools

In order to improve capability of FMEA, previous researchers have devoted in combining it with other quality tools. Linking attribute of customer dissatisfactions into Quality Function Deployment (QFD) can be a starting point toward better service provision. Initial research that modifies QFD to deal with customer service problems is proposed by Stauss (1993). Labridus and Schibowsky (1994) presented integration on Aggregate Analysis and QFD to analyse customer dissatisfactions. Shahin (2004) combined Kano and FMEA to customer *centered* service dissatisfaction assessment. As reliable service design needed to be constructed into more systematically business process, embodiment of *Axiomatic Design* into integration among Kano Method, FMEA, and QFD toward customer dissatisfaction-based service design seemed promising as new research direction. Furthermore, as corrective actions should also consider the competitive situation, linking the result of Kano Method, FMEA, QFD, *Porter Competitive Model* and *Game Theory* also seemed to be promising area for deeper study. Since service operations are mostly practiced in multistage operation in industry, combining cause selecting control chart with FMEA is challenging study. At last, testing the robustness of proposed corrective actions with design of experiments (DoE) upon integration among Kano Method, QFD and FMEA is also important and absent in contemporary literature.

#### 4.4 Application of FMEA in Service Supply Chain Framework

As business paradigm has moved from individual enterprise centric into supply chain centric oriented, endeavours to develop FMEA within supply chain framework are growing. Sinha *et al.* (2004) used FMEA to access criticality of risk factors within aeroplane manufacturing supply chain. Teng and Ho (2006) discussed problems of FMEA application in collaborative manufacturing environment. Kumar *et al.* (2009) presented FMEA study to access risk of each steps in reverse logistics activities within pharmaceutical industry.

Referring to Seth *et al.* (2006a) and Seth *et al.* (2006b), variation in external factors among tiers will naturally cause service quality variations. As every tier involved in such business relationship has different priorities in viewing risk will make endeavour to solve collaborative risk become challenge. In addition to Vanany *et al.* (2009); many works are still remaining left for future studies.

For example,

- What metrics shall be used to model the risk caused by qualitative measures such as difference in customs, language, and regulations and so on among tiers?
- How to allocate appropriate resources to curb faulty service provision occurred at certain tier?
- How to model the propagated reverse –and forward risk of service quality deficiencies?
- How to isolate the source of service quality problems in complex tiers relationship?
- What and how to share information among tiers by considering confidentiality?
- What kind of decisions support tools should be designed to facilitate tiers to choose among various risk handling techniques?

Finally, extending the study of Shahin (2010), what and how should we determine the service producer(s) and customer(s) within service supply chain framework is critical for future research.

#### **4.5 Application of Service FMEA to Support Transition to Product-Service System (PSS).**

Driven by the degrading revenue from pure product selling business, companies are now changing their business paradigm into incorporate product service model in their sales process (Kim *et al.* 2010). To improve transition from such situation, identification of critical success factors by mitigating obstacles from changing business process from pure manufacturing to PSS oriented as revealed by Uchihara *et al.* (2006) using FMEA is still unknown. Next, continuing the research of Lee *et al.* (2010b), what and how should service FMEA be used as tool to measure and manage the risk of transforming from pure manufacturing to product-service oriented companies.

#### **4.6 Expanding the Application of FMEA in Non Profit Service Sectors**

##### **4.6.1 Humanitarian and Governmental Service Sector.**

Humanitarian logistics service is a growing field (Mc Lachin *et al.* 2009). Schultz *et al.* (2009) presented the indicators to measure logistics-oriented service operation. Olorunfoba and Gray (2009) revealed that the structure, service quality attribution and entity model of tiers and players in humanitarian service operation are different from profit oriented service supply chain. Based on their propositions, some research questions to answer in this domain are:

- What and how to rank the interrelated critical risk factors in humanitarian service supply operations?
- What is the most critical service quality attributes that leads to customer's dissatisfactions?
- How to expand the concept of reliable and lean philosophy to humanitarian service operations?

Extending the lack of attention on improving reliability, innovativeness, and productivity of public service delivery, empirical researches in using FMEA to uncover the cause of lower productivity and innovation of governmental service and comparing it among countries seem to be interesting research avenue.

#### **4.7 Development and Application of Service FMEA in Green Service Profit Chain**

Dealing with immaturity in the structure of service supply chain and sustainability issues, researchers have proposed application of sustainability-FMEA related studies. Lindahl (2002) presented environmental FMEA (E-FMEA) model based on product design perspective. Hsu and Hu (2008) revealed key dimensions and approaches in adopting green supply chain. Hu *et al.* (2009) proposed the risk estimation techniques based on FMEA and AHP of electronics product manufacturing. Baltcioglu *et al.* (2010) proposed a framework for service supply chain. Kassinis and Soteriou (2003) showed that the environmental practices of service firms are positively affecting the customer satisfaction. The gap in previous research is performing empirical study on service reliability assessment in a green-oriented service supply chain of any business practice.

#### **4.8 Utilization of customer complaint data for continuous learning process**

Using report from customer complaint is invaluable toward improved service operation. Uusitalo *et al.* (2008) introduced a process-oriented framework in handling complaints. Lee *et al.* (2010a) presented computerised reliability problems with Failure Reporting, Analysis, and Corrective Actions (FRACAS) systems. By assuming the methods on mining and dealing vagueness of customers complaint are available; the next challenge to use information from such data mining result are on how to share the data, and use it for continuous improvement. Finally, referring to Hensley and Sulek (2011), how and to what extent should we incorporate customer feedbacks and their involvements in improving service reliability upon FMEA is accomplished.

#### 4.9 Application of FMEA for Accessing Sustainability of Service Business

Sustainability is contemporary issue that is driven by imbalance between growing trend of global consumption and the trend of depleted natural resources. For the survival, service firms shall identify and design service operations by referring to four dimension of sustainability namely social, economical, technical, and environmental sustainability. Initial study to deploy sustainability metrics can be found in Edgeman and Hensler (2005).

In this part, some unanswered research questions are:

- What metrics that represent above such dimensions?
- How to quantify the four sustainability metrics since customer(s) of sustainability aspect is our descendant that possibly will have different expectations from nowadays?

Using FMEA to identify the risk factors related to those sustainability metrics and integrating them into QFD to formulate the best sustainability strategy of service operation is still absent in literature.

#### 5. Conclusion

Among service quality attributes, service reliability is one of the sources of customer dissatisfaction and should be managed proactively for business sustainability. The result from our initial literature survey indicated that service FMEA researches are still dominated by profit and single company orientation, and overlook on the utilisation of service FMEA in supply chain operation. Although many endeavours have been dedicated to utilise FMEA in various service sectors, driven by the challenges in modern business and the escalation of global disastrous events, many gaps are still left for future study. Certainly, this paper is not free from limitations. As this study is merely based on limited literature, we encourage future researches to extend our initial survey by using more databases and incorporate other type of references such as book chapters, dissertations, and literature that are written using languages other than English. Moreover, we also suggest that other researchers to widen discussion on the role of FMEA in enhancing six sigma-oriented service systems, focus to human error issues, application of service FMEA in virtual setting, and its role in creating value within collaborative business framework.

#### Acknowledgements

The first author would thanks to Dr. Elizabeth Cudney and anonymous referees for their comments which improve the presentation of this study. Also, the first author's thanks to Prof. Hyuck Moo Kwon for support during the manuscripts preparation and Prof. Jean Couillard suggestions during manuscript preparation. Financial Support from Ministry of Education, Republic of Indonesia and Pukyong National University to accomplish this study is gratefully acknowledged.

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Received January 2011

Accepted May 2011

Final acceptance in revised form May 2011