# Time- and cost-oriented failure mode and effects analysis based on Monte-Carlo simulation

*Balázs Kocsi (kocsi.balazs@inf.unideb.hu)*
*University of Debrecen*

*László Pusztai*
*University of Debrecen*

*Edit Szűcs PhD*
*University of Debrecen*

*István Budai PhD*
*University of Debrecen*

## Abstract
The goal of the Failure Mode and Effects Analysis is to prevent the product from becoming failures and to support management in a more effective allocation of resources.

Making decisions with the application of traditional Failure Mode and Effects Analysis is not always appropriate if the company's financial goals are taken into account.

The goal is to create an approach that considers the duration time and the cost factors of ongoing process activities in prioritizing failures, which helps to make a financially viable decision in process improvement.

The paper finishes with conclusion, and suggestions for future research are made.

**Keywords:** FMEA, risk analysis, failures

### Introduction
The Failure Mode and Effects Analysis (FMEA) is used by process improvement within a company to identify failures and avoid customers from getting defected product. Companies can apply FMEA in the planning phase and during the production to avoid customer dissatisfaction (Nadia, 2013).

There are many industrial areas where FMEA is used to prioritize root causes of failures. It is a really simple and useful technique that is why companies apply it in many different projects. From economic point of view, in the case of process improvement companies must take into account the cost of improvement. The traditional FMEA does not take into account the cost of failures (von Ashen, 2008).

This paper attempts to provide an approach that can surmount the limitations in case of decision-making. For this purpose the paper presents the traditional FMEA in the first part. In the next section this paper attempts to exploring drawbacks of FMEA

techniques which are found in relevant scientific literature. This section discusses the limitations of these approaches in decision-making.

The remaining parts of this paper are organized as follows. In the next section Time- and cost-oriented FMEA is presented. This new approach takes into consideration the cost of failures and the time connected to failures. Finally, a conclusion is drawn and suggestions for future research are made.

## Theoretical background

### *Traditional FMEA*

FMEA is a method for evaluating risks in a way that makes failures comparable. A manufacturing company which uses risk management tool is able to prevent the dissatisfaction of costumer by evaluating potential problems (Nadia, 2013).

The failures are prioritized in terms of Risk Priority Number (RPN). It consists of three types of parameters which are the following. Occurrence shows the frequency of failures, severity shows the impact of the failure, and last but not least detectability presents whether it is easy or not to detect failures (Nadia, 2013).

The aim of the FMEA is to eliminate the root causes or at least decrease the severity or the occurrence, and increase the detectability of failures. In order to sort out which defect has higher effect on the production, experts calculate with the following formula.

equation (1)

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

Where,
RPN: Risk priority number
S: Severity of fault
O: Occurrence of fault
D: Detectability of fault

The parameters can get a value from 1 to 10, where 1 stands for the best result and 10 means the worst result in every case.

The use of FMEA can improve business processes by helping to:

- Improve the performance of a product
- Reduce warranty and product failure costs
- Provide a frame for the history of potential failures
- Identify failures of the process
- Reduce costs of product development

FMEA was invented by the military of the United States of America. FMEA was used by Ford Motor Company as a tool for quality improvement in the automotive industry by the early 70s. Nowadays FMEA is used by many standards such as the ISO-9001 series, ISO/TS 16949 and QS-9000 (Nadia 2013). Bullet points below list the development of FMEA:

- FMEA was proposed such as a standard operational procedure MILSTD-1629 in 1974
- Ford Motor Company started to apply FMEA in 1977
- The IEC (International Electro technical Commission) published SOP of FMEA: IEC 812 in 1985
- General Motors created the 1st edition of FMEA reference Book in 1993
- The 2nd version of FMEA reference book was developed by AIAG in 1995
- The 3rd version of FMEA reference book was developed by AIAG in 2001

- The 4th version of FMEA reference book was developed by AIAG in 2008
- Nowadays, FMEA has been widely used in risk management and quality management as an analytic method by ISO-9001, ISO/TS 16949, CE and QS-9000

*Drawbacks of FMEA*

In most cases when a company uses this approach in risk management Managers just fill in a FMEA form without deep evaluation. The FMEA can be boring and repetitive. The gained benefit depends on the experience of the analyst (Chin, 2009). FMEA was developed for mechanical and electrical equipment, and cannot be applied easily when the proportion of Human factor is high in the process (Baudin, 2007). The scale is not general to determine the factors of risk priority number (von Ashen, 2008). FMEA is difficult to use in case of complex failures, because of does not take into account the connection between the root causes of failures (Kocsi, 2017). Another drawback of the method is that all failures are evaluated and documented including those which do not have any significant effects which can be time consuming (Nadia, 2013).

This section of the paper presents that there are many disadvantages of FMEA despite being very commonly used in the field of quality and project management. The motivation behind the research is to improve the FMEA and decrease its limitations. Furthermore, the new ISO standard includes proposals to take the cost of failure into account in the calculation of risks.

FMEA research is a common field of work nowadays, which is clearly demonstrates in H.-C. Liu et al. 2013 article. This article is a review of the existing academic journal articles between 1992 and 2012. The research categorizes the approaches based on 75 journal articles. These categories are the following: MCDM, Mathematical programming, Artificial Intelligence, Integrated approaches, Other approaches. The other approaches include the cost based models such as (Gilchrist, 1993), (Ben-Daya and Raouf, 1996), (von Ahsen, 2008), (Kmenta and Ishii 2004), (Dong, 2007), (Rhee and Ishii, 2003).

*Shortcomings of cost-based FMEA models*

In the field of quality management cost-oriented modification is an important task, so that the features of the developed product could meet customer needs (von Ashen, 2008).

The first article on cost based model was published by Gilchrist (1993). This approach consists of two cost-based situations. The first is when the customer detects the fault after delivery and returns them under warranty. This is called cost of warranty (cost W). The second is an extreme case when the customer sues the company because of the failure. This is called cost of accident (cost A). In addition the formula also calculates with the factor of probability. The formula is given below.

equation (2)

$$C = p_s W + P_m A$$

Where:

$P_s$ = probability that the costumer detects the fault on delivery
W= cost of warranty
$P_m$= probability that the customer does not detect the fault
A= cost of accident

Gilchrist's model does not consider the situation when failure is detected by workers within the company and is fixed before delivery. For instance, repairing faulty products, repackaging products or cost and time of transportation inside the company are also omitted from the calculation. Another disadvantage of this calculation is that model does not consider whether or not a failure has several root causes. The calculation with this formula gives a cost value which is the cost of the fault.

The second cost based model was developed by von Ashen (2008) which is also presented in this paper. This approach considers the failures which occur in production and are detected by workers, in addition it also take into account the failures which occur during delivery. Cost of failures can emerge because of the two causes that is the cost of internal detected failures and cost of external detected failures. The formula can be seen below.

equation (3)

$$RPN_C = P(O) \times \left\{P(\bar{D}|O) \times E[C^e] + P(D|O) \times E\left[C^i\right]\right\} + P(\bar{O}) \times (D|\bar{O}) \times E[C^c]$$

Where:

$RPN_C$= cost based risk priority number
$P(O) =$ probability of occurrence
$P(\bar{D}|O) =$ conditional probability of not detecting a fault before delivery
$P(D|O) =$ conditional probability of detecting a fault before delivery
$P(D|\bar{O}) =$ conditional probability of indicating a fault before it has occurred
$[C^e] =$ cost of externally detected failures
$\left[C^i\right] =$ cost of internally detected failures
$[C^c] =$ cost of false positive inspection results

The disadvantage of this method is that it does not take into account the case when a failure emerges and therefore the total lead time of the process is increased, so the product will be produced later than planned. Such cases might emerge during of unique production, such as a unique and unrepeatable project. Due to this disadvantage, this method is not suitable for completing a risk analysis in unique production.

**Problem and aim of the research**

First of all, the calculation of RPN number with traditional FMEA is subjective and there is not a universal scale to determine RPN factors. Secondly, as this paper presents above there are some limitations of cost based FMEA models. The formulas of models calculate with different types of parameters, but some cases cannot be used in unique production.

Recent FMEA research has been focused on improving traditional and cost based FMEA limitations by using different parameters which based on measurement. The goal is to create an approach that takes into account the total lead time and the cost factors of the ongoing process activities in prioritizing failures, helping to make financially viable decision in process improvement and project management.

**Time- and cost-oriented FMEA**

The risk calculation of failures in time- and cost oriented FMEA is determined based on measurement. In this way the subjectivity of the traditional method is reduced. The formula of time- and cost-oriented FMEA includes the probability factor of the situation when the total lead time given by Monte-Carlo simulation in case of failures occurs in the production exceeds the planned total lead time.

The given parameters are: cost of fixing process, which is essential to eliminate the fault if the fault becomes real. The failure's probability of occurrence, the planned total lead time compare with the total lead time when the failure occur. The time- and cost-oriented FMEA examines and compares different types of failures by this formula. The method of the calculation can be seen below.
equation (4)

$$t - cRPN = (P_i \times C_{ai} + P_e \times C_{ae}) + C_f)) \times F \times T_p$$

Where:

$P_i$= Probability of detecting a fault before delivery
$P_e$= Probability of not detecting a fault before delivery
$C_{ai}$= Cost of corrective activities within the company
$C_{ai}$= Cost of corrective activities whit out the company
$C_f$= Cost of failure
F= Frequency of failure
$T_p$= Deviation between the planned total lead time and total lead time whit failure

The modified FMEA determines the deviation between the planned total lead time and total lead time when the failures occurs by Monte-Carlo simulation. The simulation input data are the following:

- Logical relationship between the activities
- Maximal and minimal cycle time of activity
- Maximal and minimal cycle time of failures
- Probability distribution of activity and failure times

The minimum and maximum cycle time values of the activities and failures are determined based on measurement. Minimum cycle time value is when the activity runs in the minimum time, maximum cycle time value is when activity runs in the longest time.

If the failures occur and the total lead time similar than the planned total lead time the $T_p$ is got 1 value. If the simulated total lead time higher with 10% than the planned total time, the $T_p$ is got 1.1 value.

**Conclusion**

The traditional FMEA is widely-used and it is accepted as an appropriate tool of quality management. The traditional FMEA has some limitation in case of decision making. A new FMEA approach was presented in this paper which is paid attention to economic aspects. The calculation of developed time- and cost-based FMEA consists of the cost of corrective activities, cost of failure, frequency of failures and deviation between the simulated total lead time and planned lead time. These parameters are based on measurement with the use of which the approach makes failures prioritizing more accurate. With the help of revealed and ranked risk factors, managers could get a comprehensive picture of the potential risks in the operation of a manufacturing process.

In order to implement time- and cost-oriented FMEA, data on the cost of failures and cost of corrective activities must be comprehensive and accurate. In case of a complex production, collection and measurement of these data are time consuming.

Future research should focus on the time factors in risk management. Time factors can be determined easier than cost of failures.

By the new FMEA approach in the planning and operation phase of a manufacturing process, managers can avoid making decisions that can result in costly investments for

the company. Companies can optimize their production in planning and operation phase. This FMEA approach complies with the requirements of new ISO standards.

## References


Anette von Ashen (2008): "Cost-oriented failure mode and effect analysis", International Journal of Quality & Reliability Management Vol. 25 No. 5 pp.466-476

Baudin M. (2007), *Working with Machines*, Productivity Press, New York.

Ben-Daya, M., & Raouf, A. (1996). "A revised failure mode and effects analysis model" International Journal of Quality & Reliability Management, 13, pp 43–47.

Dong, C. (2007). "Failure mode and effects analysis based on fuzzy utility cost estimation", International Journal of Quality & Reliability Management, 24, pp. 958–971

Chin, et al., (2009), "Failure mode and effects analysis by data envelopment analysis", *Decision Support System*, 48, pp 246-256

Gilchrist, W. (1993). "Modelling failure modes and effects analysis", International, Journal of Quality & Reliability Management, 10, pp 16–23

Hu-Chen Liu, Long Liu, Nan Liu (2013): "Risk evaluation approaches in failure mode and effects analysis", A literature review, Expert Systems with Applications, Vol. 40, No. 2, pp. 828–838.

Kmenta, S., & Ishii, K. (2004). "Scenario-based failure modes and effects analysis using expected cost", Journal of Mechanical Design, 126, 1027

Kocsi, B., Pusztai, L., Budai, I., Szűcs, E. (2017): "How to build our houses in order to consume the minimum energy". In: 12th Conference on Advanced Building Skins, Advanced Building Skins GmbH, Conference Proceeding Bern, Switzerland pp. 399-405

Nadia B., Nanci L., Abdel-Rahim A. (2013). "Implementation of Failure Mode, Effects and Criticality Analysis in the Production of Automotive Parts", Quality access to success, Vol 14, No. 135, pp. 67-71

Rhee, S. J., & Ishii, K. (2003). "Using cost based FMEA to enhance reliability and serviceability" Advanced Engineering Informatics, 17, pp. 179–188

Seung J. Rhee, Kosuke Ishii (2003):"Using cost based FMEA to enhance reliability and serviceability", Advanced Engineering Informatics, Vol 17, pp. 179-188