Determining Occurrence in FMEA Using Hazard Function

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Abstract—FMEA has been used for several years and proved its efficiency for system's risk analysis due to failures. Risk priority number found in FMEA is used to rank failure modes that may occur in a system. There are some guidelines in the literature to assign the values of FMEA components known as Severity, Occurrence and Detection. This paper propose a method to assign the value for occurrence in more realistic manner representing the state of the system under study rather than depending totally on the experience of the analyst. This method uses the hazard function of a system to determine the value of occurrence depending on the behavior of the hazard being constant, increasing or decreasing.

Keywords—FMEA, Hazard Function, Risk Priority Number.

I. INTRODUCTION

FMEA, Failure Mode Effect Analysis is an efficient tool of system's risk analysis due to failures. FMEA analyzes the system according to three important factors related to failures. This first factor is the Severity (S) of the failure representing the effect or hazard of failure occurrence. The second factor is Occurrence (O) that is representation of how often the failure occurs. The third factor is the Detection (D) which is represented by available methods and techniques that may detect the occurrence of a failure before the effect of this failure appears. Each factor may take a value from 1 to 10, where 1 is for the best state and 10 for the worst state. For example, a severity of 9 means that there is a high effect of failure occurrence, where an occurrence of 2 means that the frequency of occurrence of the failure is very low. Multiplication of the values of the three factors gives the Risk Priority Number (RPN) that ranges from 1 (best case) to 1000 (worst case). RPN is computed for each failure mode of the system. For complex system, there may be large number of failure modes making it tedious analysis. RPN then is used to priorities the failure modes of the system. Attention is to be paid on modes that have highest RPN as improvement of these modes contributes more on improvement of the overall system [1].

The value that is to be assigned for each factor in FMEA can depend on the one that is analyzing the system. There are guidelines to help in assigning these values. For example a severity level of 10 or 9 is associated with a mode that has a failure to meet safety and/or regularity requirements. The effect of a failure is important to determine the level of severity. The effect of a failure is represented by the consequence of a failure. Experience with a product or a process helps in determining this consequence of course this requires knowledge sharing and development of the team members to predict the consequence of a failure especially for failure modes that have not been experienced. The severity is assigned for each effect not for each failure as each failure may have more than one effect hence, later each effect may be avoided in different manner [1].

An occurrence level of 10 is assigned for a failure mode that occurred more than 10% of times. Table I lists the guidelines for determining the occurrence level. Process data could be used for accurate determining of the occurrence level of a failure mode. History of failures of a process or a product could be a good source of data to be used for determining the occurrence level. If there is no history of failures (new product of process), estimation of how often a failure may occur and the potential causes of the failure can help for determining the occurrence level [2].

When there is no mechanism for prevention or detection of a failure (likelihood of detection is almost zero) detection factor takes value of 10. To determine the level of detection, current controls to detect a failure are considered [2].

According to the value assigned for each factor, RPN value may be depend on analyst of the system especially the level of his expertise with the system as well as dealing with FMEA [2].

A method for determining an accurate value of occurrence is presented in this paper. This method uses hazard function of a system or component as it represents the rate of failure which is associated to the frequency of failure per unit of time. This helps in more accurate determination of the RPN values, hence more improvement on the level of the system [1].

TABLE I
GUIDELINES FOR DETERMINING THE LEVEL OF OCCURRENCE

Likelihood of failure	Criteria	Level
Very high	≥ 1 in 10	10
	1 in 20	9
High	1 in 50	8
	1 in 100	7
	1 in 500	6
Moderate	1 in 2000	5
	1 in 10,000	4
	1 in 100,000	3
Low	1 in 1,000,000	2
Very low	Elimination through preventive control	1

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II. METHOD

Hazard function, *h(t)* is the failure rate of the system. It represents the relationship between probability of instantaneous failure *f(t)* and reliability at a system *R(t)*. Hazard function is shown in (1). Hazard measures the conditional probability of a failure when a system is currently working. Hazard is also known as instantaneous failure rate that measures the speed of failure.

$$h(t) = \frac{f(t)}{R(t)} \qquad (1)$$

The shapes that a *h(t)* can take is represented by bathtub curve which shows three different shapes; decreasing, constant and increasing failure rate. The shape of *h(t)* depends on the phenomena of failure of the system, a typical hazard function is shown in Fig. 1.
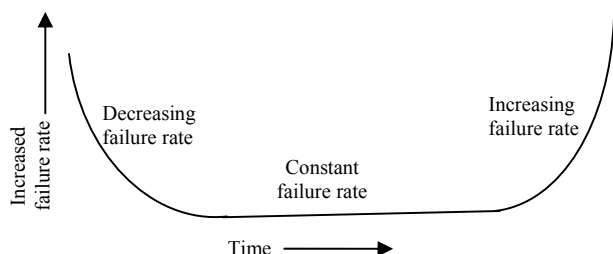

Fig. 1 A typical hazard function

Decreasing failure rate occurs in some systems during burn-in period. In decreasing failure rate systems the number of failures per unit of time is decreasing, thus the system is improving with time in terms of number of failures. This means that theoretically number of failures per unit of time may decrease to reach zero when the time reach infinity. Practically, this is not the case given that reliability cannot increase over time of a system. A system will reach the end of its life before the failure rate reaches zero for a decreasing failure rate system. One popular distribution in reliability engineering that represents decreasing failure rate is Weibull distribution when the shape parameter of the distribution is less than one [3].

Constant failure rate is for systems that follows exponential distribution as for high quality integrated circuits. In constant failure rate as the name states, the failure rate remains constant over time along the life of the system. For such systems, each year it is expected to have the same number of failures on average. In this case, there is no effect of time on the system as there is no aging or wear out. This property is known as memory-less, so a system always is considered as new regardless of the age of the system. Although of this property of constant failure rate system, the reliability starts with one at time zero and reaches zero at time infinity [3].

Increasing failure rate represents most of the systems where wear-out and aging occurs such as mechanical systems. The number of failures increases with time representing the nature aging. The rate at which failure occurs depends of the hazard function which also may be varying with time. Usually the rate of failures starts with a value at the beginning of the system's life and increases as the deterioration occurs on the system. Weibull distribution with a shape parameter that is greater than one represents increasing failure rate. The hazard function of a normal distribution is increasing with time [3].

Determination of occurrence value for constant failure rate is easy and straightforward using hazard function. For example, if a system or component has a constant hazard rate that equals 0.1 failures per year then, the percentage of time at which failure occurs can be calculated from the failure rate over the expected life of the system or component. The expected life for systems with constant failure rate equals to the rispricoal of the failure rate that is for the example 10 years, this gives a failure of 1% of times [4].

When the number of failures per unit of time is decreasing then the true value of occurrence may be less than what is recommended in the guidelines as the system is improving. For example, assigning a value of 8 for occurrence of a decreasing failure rate system may be higher than the true value, hence it will place the associated failure mode in higher rank than the actual, and so improvement on the system may have higher contribution if effort is given to another failure mode that is more important [5].

For a system or a component that has an increasing failure rate, the true value of occurrence cannot be constant over the life of the system. In order to represent that nature of the system that has increasing failure rate, the occurrence value should increase with time. For example, if a system currently has an occurrence value of 7, after certain period of time, this value may be increased to 8 or 9 as the number of failures in the system is increasing, hence this system will eventually reach occurrence level of 10. The rate at which the failure increases determines the time at which the occurrence value increases by one. High rate of increasing requires less time of increasing the occurrence value and vice versa [4], [5].

To determine an initial value of occurrence for increasing failure rate system, it is recommended to use the guidelines but this time according to the hazard of the system. Mean time to failure (MTTF) is the expected time a system works prior a failure. This time can be used to calculate the initial value of occurrence. The hazard at MTTF gives the rate of failure at the time where a failure in a system occurs [3].

For decreasing failure rate system, the hazard of the system is high at the beginning of the system's life, and it decreases with time. Occurrence has low value as the system's hazard is decreasing. If the system is new (no time passed on the system), then the hazard is maximum and occurrence is high though. Occurrence is determined to find RPN to improve a system or prevent some failures, then, no need to use high value of occurrence for decreasing failure rate system. The value of hazard at the MTTF of the system may be used in accordance to the guide to determine the value of occurrence of the system. Once a system passed its expected life, occurrence value could be lowered as the hazard level decreased [3].

The MTTF for constant failure rate equals to the reciprocal

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of the hazard rate, hence, it is not required to calculate an initial value of occurrence level for constant failure rate systems [3].

Next section shows implementation of the proposed method for determining the occurrence value from the hazard function for different systems as case studies showing; increasing, decreasing, and constant failure rate.

III. CASE STUDY

To clearly show how the proposed method can be used to determine the occurrence level, here is the implementation of three different cases:

A. Decreasing Failure Rate System

Weibull distribution represents a decreasing failure rate system for a shape parameter (β) less than one. Suppose a failure mode with $\beta = 0.25$ and $\theta = 100$ hours. Then, according to Weibull distribution, the expected life of the system is 2400 hours. The hazard at the expected life equals 0.00023 failures per hour. According to the guideline in Table I, the occurrence value is around 4. At the first 100 hours of system's life, the hazard is 0.0025 failures per hour and the occurrence value is 6. This implies that there is no need to keep the value of the occurrence constant as the system is operating and the hazard is decreasing. A smaller value of occurrence can be used to keep attention on other failure modes. Fig. 2 shows that for the given example, the occurrence value remains almost constant at a value of 4 at time equals to 1000 hours of the system's life. The occurrence level remains almost constant at 4 for this case study, for other examples, the occurrence may reach lower values, hence become less important with time. The main idea for decreasing failure rate system is that as the hazard of this system is decreasing with time, there is no need to keep the occurrence of higher values than the true value that is represented by the hazard of the system. This helps in focusing more on other failures that are more important in terms of hazard.
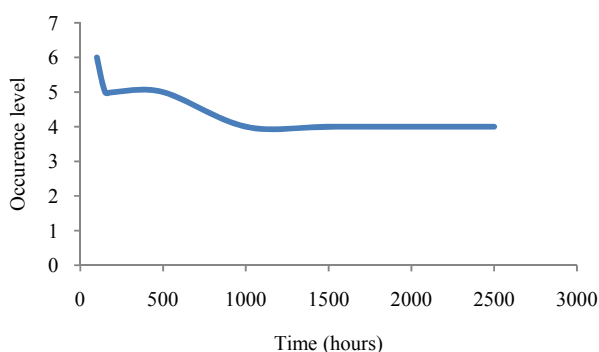

Fig. 2 True occurrence level versus time for Weibull (β=0.25, θ=100)

B. Constant Failure Rate System

Exponential distribution is the only distribution that represents a constant failure rate phenomenon. The hazard is not a function of time; it has a constant value all over the life of a system. Suppose a system that a failure mode has an exponential failure distribution with parameter $\lambda = 0.005$ failures per hour, this means that the expected life of the product is 200 hours and the hazard function has a constant value of 0.005. The occurrence value is set to be about 6 to 7 and this value does not change as the system is operating. For constant failure rate systems, failures occur only by a random cause. This means that a failure will not occur as a result of a problem in the system (as aging). Also, an occurrence of a failure does not depend on an occurrence of other failures (previous failures). Dealing with constant failure rate system is easier than other systems as the analyst of the system has to analyze the system once, set occurrence level and keep dealing with the system as the first time. Understanding that occurrence is constant for constant failure rate system enables focusing on other failure modes or systems.

C. Increasing Failure Rate System

For increasing failure rate system, suppose a failure mode that follows a Normal distribution with parameters $\mu = 250$ hours and $\sigma = 50$. The expected life of the system is 250 hours and the hazard at the expected life equals 0.016 and an occurrence value of 7 or 8. For increasing failure rate, it is not accurate to keep the value of occurrence at about 7 , once the system passes time of 250 operating hours the hazard is more than 0.016 and hence the occurrence will be greater and eventually the occurrence may reach value of 10 in which attention should be paid in such failure mode. When the hazard reaches 0.1, then the associated occurrence is 10, and before 250 hours of operation, the hazard is less than 0.16, so the occurrence is less than 7.

For example, at 50 hours of operation, the hazard equals 0.00000268 and hence the occurrence value is between 2 and 3. At the beginning of the systems operating time, no need to worry about occurrence comparing to progressive times of operation where hazard of the system increase and hence the frequency of failures increases as well.

Fig. 3 shows the occurrence level versus time for the case study of Normal distribution with mean equals 250 and standard deviation equals 50. The curve in the figure shows that the occurrence level increases as the time increases due to the increasing in the hazard. The shape of the curve may be different from what Fig. 3 shows depending on the parameters of a distribution or the distribution itself.

Also, the figure shows that after 500 hour of the system's life for the one in the case study the occurrence level reaches 10 as the hazard becomes very high. The rate at which the occurrence level increases is not linear as shown in Fig. 3 there are more than one segment of the curve.

Regardless of the increasing rate, it is important to pay attention for systems that have increasing failure rate because if you keep dealing with a constant value for occurrence level, the nature of the system becomes different with time; hence, it is required to find a new more accurate value of occurrence level, so the RPN value becomes more accurate.
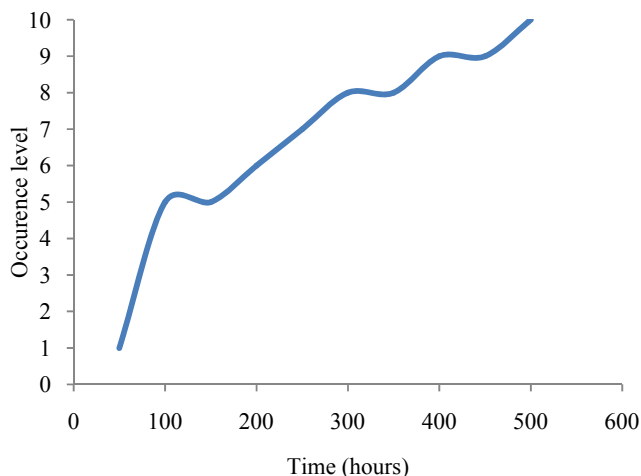
World Academy of Science, Engineering and Technology
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Fig. 3 True occurrence level versus time for Normal (μ=250, σ=50)

IV. CONCLUSION

FMEA is an efficient tool in analyzing systems in terms of failure modes and their effect. FMEA prioritizes failure modes according to the RPN which is a multiplication of severity, occurrence and detection of a failure. Assigning the correct value for each component of RPN requires expertise and is considered as tedious task to perform. Severity level determination is related to the consequence that could occur as a result of failure. Determining the value of severity gets easier when there is a history about the failures of a system. In case there is no historical data, estimation of severity values is important. Detection is related to any mechanism or control that a system uses to prevent the occurrence of a failure or to give an alarm once a failure occurs. Detection is directly related to components or controls available in the system for feedback purposes. The issue here is with assigning the value of occurrence. In FMEA, occurrence is related to the frequency at which failure occurs, which is at the end related to the hazard of a system. Simply, high hazard systems are expected to fail more than low hazard system. Where hazard here is one measurement of system's sustainability that is related to time, it is not hazard in terms of safety. Hazard in terms of safety is related to the severity level in FMEA.

A method for assigning a value for occurrence was presented here. The method proposes assigning the value of occurrence in accordance with the hazard of the failure mode. As a hazard can be increasing, constant, or decreasing failure rate it is more accurate to assign the value of occurrence taking into consideration the type of the hazard of the failure mode, especially when there is no historical data about the frequency of the failure of a system for a particular failure mode. It is required to know the reliability or failure distribution of a mode of a failure for a system which represents the nature of the system in terms of failure times. Although, some of these distribution requires having historical data of failure, but determining the value of occurrence level using this method will be more accurate and representing the system as the hazard of a system may change with time. Decreasing failure rates starts with high value of occurrence

level and can be lowered with time as the failure rate is decreasing. The rate of decreasing in the occurrence level depends on the rate of decreasing of hazard using guidance for determining the occurrence level based on the frequency of failures for a particular failure mode of a system. In the other hand, the occurrence for systems that has increasing failure rate should be kept increasing with time to represent the nature of the system of aging. The rate of increasing in the occurrence level is related to the rate of increasing in the hazard rate. This implies that if the occurrence level is kept constant the analysis on the system will not be accurate especially at times close to the expected life of the system. Dealing with low value of occurrence level while in reality the value should be higher will lead to focusing on other elements in FMEA rather than occurrence, but this does not match the nature of the system or how the system is changing with time. Constant failure rate system has a constant value of occurrence that does not change with time as the hazard stays at the same level during the life time of the product. For constant failure rate systems, once the hazard or failure rate is found, then no need for further review of the value, and hence system analyst will deal with one constant value of occurrence level through the life time of the product unless improvement takes place and affects the hazard rate of the system, then the new value should be considered and so.

The analysis of occurrence using hazard function represents the nature of the systems in more accurate scenario. That is, occurrence for decreasing failure rate systems is important to watch at the beginning of the operating life of the system as after this time the hazard will decrease and so the occurrence level should decrease. But the opposite for increasing failure rate in which occurrence level should be keep increasing as time passes on the system, because the hazard is increasing with time. Applying this method gives more accurate prioritizing list of failure modes.

As FMEA recommends that after analyzing a system and prioritizing the failure modes, applying the 80/ 20 rule to improve the current failure modes, this will lead to change in the resulting RPN that is the RPN after improvement. The occurrence may change in this case, but it still can be analyzed and determined using the new hazard function as it may change.

This paper proposes a method for determining occurrence level using hazard function. The examples of case study showed how to apply the proposed method referring to the guidance for determination of occurrence level.

Further work may consider other components of FMEA that are severity and detection for more accurate determination of the levels for better estimation of RPN and less relaying on the experience of the system analyst.

REFERENCES

[1] R. McDermott, R. Mikulak, and M. Beauregard, *The Basics of FMEA*. New York: Taylor and Francis Group, 2009.
[2] L. Lipol, and J. Haq, "Risk analysis method: FMEA/FMECA in the organizations," *International Journal of Basic and Applied Sciences*, vol. 11, iss. 5, 2011.

[3] C. Ebling. *An Introduction to Reliability and Maintainability Engineering*. New York: Waveland Press, 2005.
[4] R. Sharma, D. Kumar, and P. Kumar, "Systematic failure mode effect analysis (FMEA) using fuzzy linguistic modelling," *International Journal of Quality & Reliability Management*, vol. 22, iss. 9, 2005.
[5] N. Xiao, H. Huang, Y. Li, L. He, and T. Jin, "Multiple failure modes analysis and weighted risk priority number evaluation in FMEA," Engineering Failure Analysis, vol. 18, iss. 4, 2011.