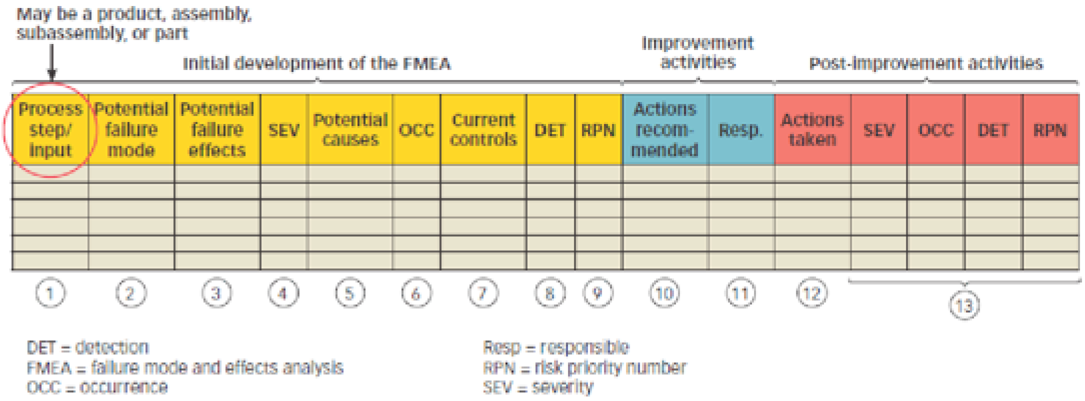
FAILURE MODE & EFFECTS ANALYSIS (FMEA)

Also called: potential failure modes and effects analysis; failure modes, effects and criticality analysis (FMECA).



Failure modes and effects analysis (FMEA) is a step-by-step approach for identifying all possible failures in a design, a manufacturing or assembly process, or a product or service.

- “Failure modes” means the ways, or modes, in which something might fail. Failures are any errors or defects, especially ones that affect the customer, and can be potential or actual.
- “Effects analysis” refers to studying the consequences of those failures.

Failures are prioritized according to how serious their consequences are, how frequently they occur and how easily they can be detected. The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones.

Failure modes and effects analysis also documents current knowledge and actions about the risks of failures, for use in continuous improvement. FMEA is used during design to prevent failures. Later it’s used for control, before and during ongoing operation of the process. Ideally, FMEA begins during the earliest conceptual stages of design and continues throughout the life of the product or service.

Begun in the 1940s by the U.S. military, FMEA was further developed by the aerospace and automotive industries. Several industries maintain formal FMEA standards.

Limitations of traditional Risk Analysis

Challenge 1: Subjectivity

Risk management is based on the so-called "Scoring" method. The risk of an event is calculated by scoring its likelihood (sometimes subjectively) and multiplying it by its severity (usually subjectively). The most frequent defence for this method is that "real data is hard to come by".

Challenge 2: Models are unreliable and cannot be quality-controlled

Every model needs to make some assumptions in order for it to be implementable. This is fine, but the reliability of models falls off dramatically when some of the basic assumptions that go into building them fall apart. For example, the classic Black-Scholes model for option pricing makes the assumption that equity returns are normally (or predictably) distributed. The failure of this model was dramatically demonstrated more than 10 years ago by the collapse of Long Term Capital Management. Furthermore, models are rarely tested to see if they really work.

Challenge 3: Quantitatively sophisticated methods are impractical

Most business problems are by nature complex. Which means that there are numerous interacting agents which influence an outcome that usually has low predictability. When someone claims they do "tactical" complexity management - which basically means treating each problem as unique - this allows them to amplify the effect of the FUD **(F**ear**-U**ncertainty-**D**oubt) factor and gloss over quantitative methods that can be objective.

Pitfalls and Limitations of FMEA

For all its benefits, the FMEA does have a few limitations.

- It is, for example, only as good as the team behind it. Issues beyond team members' knowledge aren't likely to be detected or resolved – constituting unknown unknowns. Moreover, if the team forgets to list failure modes, they'll be ignored. In either case, the upshot is a failure waiting to happen.

- Another limitation is a function of the FMEA's basis for prioritizing failure modes according to their risk. This won't *eliminate* the failure modes and may well require other actions outside of the FMEA and the team carrying it out.

- The FMEA is a big job, and the team walks a fine-line between taking on too large of a scope and taking on one that's too small. If not enough focus is on those details, many failure modes will be missed. On the other hand, too many details may make the analysis seem a daunting task. The solution is to break the process down into manageable segments.

- Finally, a pitfall many organizations encounter is in failing to recognize that the FMEA is not a static model. For successful risk management, the FMEA should be regularly updated as new potential failure modes are identified and corresponding control plans are developed.

FMEA has become integral to any production process, and is widely considered an improvement over traditional risk analysis, which treats each potential failure in isolation. Still, it's not a panacea: It is an assessment tool, not one that is designed to eliminate problems. It will yield the best results when supplemented with other tools to see the control plans through.

How fuzzy sets help to solve these problems

The factors considered in traditional failure mode and effect analysis (FMEA) for risk assessment are frequency of occurrence (*P*), severity (*S*) and detectability (*D*) of an item failure mode. Because of the subjective and qualitative nature of the information and to make the analysis more consistent and logical, Rajiv Kumar Sharma, Dinesh Kumar, Pradeep Kumar, ("Systematic failure mode effect analysis (FMEA) using fuzzy linguistic modelling", International Journal of Quality & Reliability Management) approach using fuzzy logic is proposed. In the proposed approach, these parameters are represented as members of a fuzzy set, fuzzified by using appropriate membership functions and are evaluated in fuzzy inference engine, which makes use of well-defined rule base and fuzzy logic operations to determine the criticality/riskiness level of the failure. The fuzzy conclusion is then defuzzified to get risk priority number. The higher the value of RPN, the greater will be the risk and lower the value of RPN, and the lesser will be the risk.

The study by Rajeev Kumar Sharma et al., 2005 show that using fuzzy sets provide an alternate ranking to that obtained by the traditional method. The study concluded that the fuzzy logic-based approach not only resolves the limitations associated with traditional methodology for RPN evaluation but also permits the experts to combine probability of occurrence (P), severity (*S*) and detectability (*D*) of failure modes in a more flexible and realistic manner by using their judgement, experience and expertise.

How Z numbers can reduce uncertainty

Another paper by Wen Jiang (*Failure Mode and Effects Analysis based on Z-numbers* **–** Wen Jiang, et al., 2017**)** proposed a new method for failure mode and effects analysis (FMEA) based on Z-numbers. In the proposed method, firstly, Z-numbers are used to perform the valuations (Z-valuation) of the risk factors like occurrence (P), severity (S) and detection (D). Secondly, the Z-valuations of the risk factors are integrated by fuzzy weighted mean method. A new risk priority number named as ZRPN is calculated to prioritize failure modes based on a modified method of ranking fuzzy numbers.

Reliability of information is a very important issue in decision-making, management of information and risk valuation and analysis. This study presented a novel method for properly evaluating the level of risk. The main novelty introduced in this paper is taking into account the reliability part of the uncertain valuation with Z-numbers.

Traditional FMEA uses the risk priority number (RPN) to prioritize failure modes. A RPN is obtained by multiplying the ratings of occurrence (O), severity (S) and detection (D) of a failure mode. The three factors O, S and D are all evaluated using ratings (also called rankings or scores) from 1 to 10. The failures with higher RPNs are assumed to be more important and should be given higher priorities. Owing to its visibility and simplicity, the traditional RPN method has been widely used in a number of industries as a solution to various reliability problems. However, some setbacks are still exposed to the traditional FMEA, which have been criticized by many researches (Chinet al., (2009). Failure mode and effects analysis using a group-based evidential reasoning approach. (*Computers & Operations Research, 36*, 1768–Gargama & Chaturvedi, 2011). Criticality assessment models for failure mode effects and criticality analysis using fuzzy logic. (*IEEE Transactions on Reliability,* Pillay, A. & Wang, J., 2003). Modified failure mode and effects analysis using approximate reasoning. (*Reliability Engineering & System Safety,* Sankar, N. & Prabhu, B. S., 2001). Modified approach for prioritization of failures in a system failure mode and effects analysis. *International Journal of Quality & Reliability Management, 18*, 324–Sawant, ett al., 2010). Failure mode and effect analysis-based quality assurance for dynamic MLC tracking systems. Wang, et al. (2009). Risk valuation in failure mode and effects analysis using fuzzy weighted geometric mean.

Evidence theory has been employed to quantify the imprecision and uncertainty in reliability and risk analysis. Here, Z numbers were employed to quantify the uncertainty in reliability when using fuzzy sets.

How Rough numbers are useful

Rough numbers help in increasing the information available to us. The fuzzy numbers are discrete in nature and may not capture all the information present. Since, in the rough set theory, we work with a range and not just a single number, there is a greater accuracy in our FMEA predictions. Rough numbers when applied to ZRPNs therefore provide a more accurate risk analysis as we increase the information available to us to incorporate an entire range of values in between a lower and an upper bound as opposed to simply one number.

Procedure

- Using the concept of rough number, we get an interval for each component in a Z-number. Subtracting the lower limit from the upper of a rough set gives the rough boundary interval.
- Collecting the boundaries together, we get a set of 7 numbers, 4 from part A and another 3 from part B of the Z number for each decision maker's rating for a particular failure mode. This can be considered to be a Z-number in itself where part A is a trapezoidal and part B is a triangular fuzzy set.
- It was observed that the failure analysis data follows the beta distribution instead of a normal distribution as previously assumed, with a time dependence. In order to fit the data with us into a beta distribution, the fuzzy sets in the Z-number needs to be defuzzified and then the part A and part B should be combined to give a complete picture.
- Taking the mean and standard deviation of each fuzzy set and then combining the parts by taking a geometric mean will give the crisp values required.
- Then, using the sample mean(μ) and sample standard deviation (σ) will give the shape parameters, α and β for the beta distribution, according to the following equation.

$$\alpha = -\frac{\mu(\sigma^2 + \mu^2 - \mu)}{\sigma^2}$$

$$\beta = \frac{(\sigma^2 + \mu^2 - \mu)(\mu - 1)}{\sigma^2}.$$

- Finally, a function was defined which takes in parameters α, β and time, x and returns the beta distributed values using which the Failure Modes can be ranked separately based on P, S or D as per requirement.