Risk analysis method: FMEA/FMECA in the organizations.

Lefayet Sultan Lipol & Jahirul Haq (University of Borås)

Abstract:
This is a report on the *FMEA/FMECA* risk analysis method in industries. We have visited at Parker Hannifin, Borås to know their techniques to implement it and found that the company is familiar with Design and Process *FMEA* only and organization's *FMEA* software is based on MS Excel sheet to put all of the data's of *FMEA* team's risk analysis investigation. The company follows a limit of RPN's 200 and any value beyond this limit and equal to this is marked red. The software presents a graph of RPN's of before action taken and after action taken. The industry is not so familiar with *FMECA* but using qualitative part of criticality analysis (criticality matrix of severity on Y-axis and occurrence on X-axis). The report explains about differences of *FMEA* and *FMECA*. The company is making risk analysis if they are asked to do so by the top management. It is helping the company to avoid accident, re-design and making a reliable design or process.

Keywords: *FMEA, FMECA, RPN, APQP, Criticality Matrix,* C_{pk}, P_{pk}

[FMEA= Failure Mode and Effects Analysis.
FMECA= Failure Mode Effect and Criticality analysis.
RPN= Risk Priority Numbers.
ASAP= As early as possible.
APQP= Advanced Product Quality Planning and Control Planning].

1. Background:

Customers are placing increased demands on companies for high quality, reliable products. The rising capabilities and functionality of many products are creating it additional complex for producer to keep up the quality and reliability. Conventionally, reliability has been accomplished through widespread testing and applies of method such as probabilistic reliability modeling. These are techniques done in the delayed phase of improvement. The challenge is to devise in quality and reliability early in the expansion phase.
Failure Modes and Effects Analysis *(FMEA)* is tactic for evaluate possible reliability troubles in the early hours at the progress cycle where it is simpler to acquire actions to overcome these matters, thereby improving consistency through design. *FMEA* can be apply to recognize probable failure modes, conclude their effect on the process of the product, and categorize actions to diminish the failures. A vital step is anticipating what might go incorrect with a product.
Whereas anticipating each failure mode is not possible, the improvement squad ought to invent as extensive a record of likely failure modes as probable.
Near the beginning and steady use of *FMEAs* in the design process let to the engineer to drawing out failures and manufacture dependable, protected, and customer satisfying goods. *FMEAs* also carry chronological information for use in upcoming product development. [2]

2. FMEA/FMECA Theoretical:

The theory was collected from different books, journals and company sources to get required knowledge about FMEA/FMECA that will help to understand the company research work.

2.1. Definitions of FMEA & FMECA:

Failure Modes and Effects Analysis (FMEA) and Failure Modes, Effects and Criticality Analysis (FMECA) are methodologies designed to identify potential failure modes for a product or process before the problems occur, to assess the risk. Ideally, FMEA's are conducted in the product design or process development stages, although conducting an FMEA on existing products or processes may also yield benefits.
The FMEA team determines, by failure mode analysis, the effect of each failure and identifies single failure points that are crucial. It may also rank each failure according to the criticality of a failure effect and its probability of occurring.
The FMECA is the result of two steps:
– Failure Mode and Effect Analysis (FMEA)
– Criticality Analysis (CA). [1]

2.1.1. Descriptions of FMEA Method:

For calculating the risk in *FMEA* method, risk has three components which are multiplied to produce a risk priority number (*RPN*):

1) Severity (*S*): Severity is described on a 10-point scale where 10 is highest.
2) Occurrence (*O*): Occurrence is described on a 10-point scale where 10 is highest.
3) Detection (*D*): Detection is described on a 10-point scale where 10 is highest.

RPN= S*O*D.
RPN_{min}= *1 while* RPN_{max}= *1000*. [1]
Here we shall try to explain the techniques to take decision of prioritizing a process based on RPN.
Table 1: Example of a risk calculation by FMEA. [1]

	Severity (S)	Occurrence (O)	Detection (D)	RPN=S*O*D
Potential failure 1	*2*	*10*	*5*	*100*
Potential failure 2	*10*	*2*	*5*	*100*
Potential failure 3	*2*	*5*	*10*	*100*
Potential failure 4	*10*	*5*	*2*	*100*

Our first priority will be the potential failure 2 and 4 as we have highest severity ranking there. The potential failures 1 and 3 have same severity ranking 2. But 1 has occurrence 10 higher than 3. So it should be prioritized next. So the results are.

First priority…….. Potential failure 4
Second priority…….. Potential failure 2
Third priority…….. Potential failure 1
Fourth priority…….. Potential failure 3. [1]

There is no threshold value for RPNs. In other words, there is no value above which it is mandatory to take a recommended action or below which the team is automatically excused from an action.

Important notes: Zero (0) rankings for severity, occurrence or detection are not allowed. [27]
There is several type of FMEA such as,

- System FMEA
- Design FMEA
- Process FMEA
- Service delivery FMEA.

But at Parker Hannifin we have learned only about Design and Process *FMEA.* So we should focus on them.
Design FMEA: This is used to analyze products before they are released to manufacturing. A design focuses on failure modes caused by design deficiencies.

Process FMEA: It can be used to analyze manufacturing and assembly processes. A process *FMEA* focuses on failure modes caused by process or assembly deficiencies. [3]

Description of few important parts of FMEA sheet:

Potential failure mode is defined as the manner in which the process could potentially fail to meet the process requirements and/or design intent. Potential failure modes should be described in physical or technical terms, not as a symptom noticeable by the customer. Typical failure modes could be: Bent, Cracked, surface too rough, deformed, hole too deep, hole off location etc. [3, 27]

Potential effects of failure are defined as the effects of failure mode on customers. For the end user, the effects should always be started in terms of product or system performance, such as: Inoperative, leaks unstable etc. And for the next operation, the effect should be started in terms of process performance, such as: cannot fasten. [3, 27]

Potential cause of failure is defined as how the failure could occur, described in terms of something that can be corrected or can be controlled. Typical failure causes could be: Improper gauging, part missing or mislocated, worn tool, improper machine set-up, improper programming. [3, 27]

Current process controls can be process controls such as error/mistake proofing, statistical process control.
There are two types of process controllers to consider:
Prevention: Prevent the cause/mechanism of failure or failure mode from occurring, or reduce their rate of occurrence.
Detection: Detect the cause/mechanism of failure, and lead to corrective actions.
The preferred approach is to first use prevention. [3, 27]

2.1.2. Descriptions of Criticality Analysis (FMECA):

The MIL-STD-1629A document describes two types of criticality analysis: quantitative and qualitative. To use the quantitative criticality analysis method, the analysis team must:
Define the reliability/unreliability for each item, at a given operating time; identify the portion of the items unreliability that can be attributed to each potential failure mode, rate the probability of loss (or severity) that will result from each failure mode that may occur.
Calculate the criticality for each potential failure mode by obtaining the product of the three factors:
Mode Criticality = Item Unreliability x Mode Ratio of Unreliability x Probability of Loss
Calculate the criticality for each item by obtaining the sum of the criticalities for each failure mode that has been identified for the item.
Item Criticality = SUM of Mode Criticalities
To use the qualitative criticality analysis method to evaluate risk and prioritize corrective actions, the analysis team must:
Rate the severity of the potential effects of failure; rate the likelihood of occurrence for each potential failure mode.
Compare failure modes via a Criticality Matrix, which identifies occurrence on the horizontal axis and severity on the vertical axis.
Some advantages to make criticality analysis-

- Help to analysis of the manufacturing or assembly process.
- Documents the rationale for changes. [4]

2.2. Applications of FMEA/FMECA:

FMEA/FMECA methods are used all over industry for a sort of applications and this flexible method can be executed at diverse steps in the product life cycle. *FMEA/FMECA* method can be used to carry design, development, manufacturing, service and other activities to get better reliability and enlarge efficiency. As an example, there is extensive use of both design and process *FMEAs* inside the automotive industry and documentation of this investigation is a general requisite for automotive suppliers. This technique is also generally used in the aerospace, medical, nuclear and other manufacturing industries. [7, 11]

2.3. Benefits of FMEA/FMECA:

Failure Mode and Effects Analysis (FMEA) is a methodology designed to:

- Identify potential failure modes for a product or process.
- Assess the risk associated with those failure modes and prioritize issues for corrective action.
- Identify and carry out corrective actions to address the most serious concerns.

Some benefits of performing *FMEA/FMECA* analysis include:

1. Contributes to improved designs for products and processes.

a) Upper reliability.
b) Better quality.
c) Enlarged safety.

2. Improved consumer satisfaction.

a) Contributes to cost savings.
b) Decreases development time and re-design costs.
c) Decreases warranty costs.
d) Decreases waste, non-value added operations (Lean Management).

3. Contributes to the development of control plans, testing requirements, optimum maintenance plans, reliability growth analysis and related activities.

Cost benefits connected with *FMEA* are generally probable to come from the ability to recognize failure modes in advance at the process, when they are less costly to address. Financial benefits are also resultant from the design progress that *FMEA* is probable to facilitate, as well as minimized warranty costs, enlarged sales through better customer satisfaction, etc. [8, 9]

2.4. Disadvantages of FMEA/FMECA:

If it is used as a top-down tool, *FMEA* may only identify major failure modes in a system. Fault tree analysis (*FTA*) is better suited for "top-down" analysis. When used as a "bottom-up" tool *FMEA* can complement *FTA* and identify many more causes and failure modes resulting in top-level symptoms. It is not able to discover complex failure modes involving multiple failures within a subsystem, or to report expected failure intervals of particular failure modes up to the upper level subsystem or system.

Additionally, the multiplication of the severity, occurrence and detection rankings may result in rank reversals, where a less serious failure mode receives a higher RPN than a more serious failure mode. The reason for this is that the rankings are ordinal scale numbers, and multiplication is not a valid operation on them. The ordinal rankings only say that one ranking is better or worse than another, but not by how much. For instance, a ranking of "2" may not be twice as bad as a ranking of "1," or an "8" may not be twice as bad as a "4," but multiplication treats them as though they are.

The ***FMEA*** requires a thorough knowledge of the issue to be studied. In general, a brainstorming session with several people involved from conception to delivery is required. This means that a team can reach an agreement on the failure modes studied. This method is, therefore, cumbersome to implement. [7]

2.5. Similarities and differences between FMEA & FMECA:

Failure mode and effects analysis (*FMEA*) and failure modes, effects and criticality analysis (*FMECA*) are methods used to identify ways a product or process can fail. The basic methodology is the same in both cases, but there are important differences between the processes**.**

Qualitative versus Quantitative: *FMEA* provides only qualitative information, whereas *FMECA* also provides limited quantitative information or information capable of being measured. *FMEA* is widely used in industry as a "what if" process. It is used by NASA as part of its flight assurance program for spacecraft. *FMECA* attaches a level of criticality to failure modes; it is used by the U.S. Army to assess mission critical equipment and systems.

Extension: *FMECA* is effectively an extension of *FMEA*. In order to perform *FMECA*, analysts must perform *FMEA* followed by critical analysis (*CA*). *FMEA* identifies failure modes of a product or process and their effects, while CA ranks those failure modes in order of importance, according to failure rate and severity of failure.

Critical Analysis: *CA* does not add information to *FMEA*. What it does, in fact, is limit the scope of *FMECA* to the failure modes identified by *FMEA* as requiring reliability centered maintenance (RCM). [10]

3. Company description (Parker Hannifin, Borås):

With annual sales exceeding $12 billion in fiscal year 2011, Parker Hannifin is the world's leading diversified manufacturer of motion and control technologies and systems, providing precision-engineered solutions for a wide variety of mobile, industrial and aerospace markets. The company employs approximately 58,000 people in 47 countries around the world. Parker has increased its annual dividends paid to shareholders for 55 consecutive fiscal years, among the top five longest-running dividend-increase records in the S&P 500 index. Parker has been operating for almost 40 years in Sweden, providing quality services and products to its Swedish OEM (Original Equipment Manufacturer) customers and to other companies through its strong, professional distribution network and Technology Centers. To meet its customers' needs in motion and control, Parker provides the broadest range of products available from any single supplier. This is supported by expertise in nine major technologies: hydraulics, pneumatics, electromechanical, filtration, process control, fluid and gas handling, sealing and shielding, climate control and aerospace. Not only has a product supplier, Parker also offered Value Added Services to help its customers save time and money. [27]

3.1. The figure of a product at Parker Hannifin:

The example of a product is produced at Parker Hannifin. To design this product, the company uses Design FMEA. To produce this product, the industry uses process FMEA.

Figure 1: Front view of a Pressure Valve.

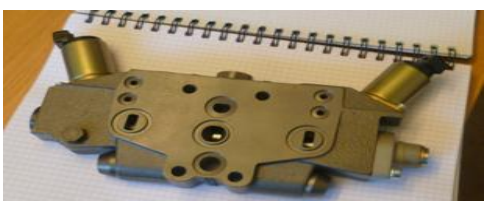

Figure 2: Back view of a Pressure Valve.

The pressure valve is used to pressurize water. [7]

3.2. FMEA example from Parker Hannifin:

ITEM: Potential Failure Mode and Effect Analysis
(Process FMEA)

Model Year/Vehicle: FMEA Number:
Page 1 of 1
Core Team: Lipol, Jahir.

Prepared by: Lipol
FMEA date: 2011-06-14

Position, Funktion/ *Item Function*	Tänkbara feltyper/ *Failure mode*	Tänkbar feleffekt/ *Potential effect(s) of failure*	Allvarlighet / *Severity*	Class	Tänkbara felorsaker/ *Potential causes of failure*	Felintensitet / *Occurrence*	Nuvarande förebyggande konstruktions-styrning/ *Current design controls prevention*	Nuvarande upptäckbarhet/ *Current design controls detection*	Upptäckbarhet / *Detection*	Risk- tal / *RPN*	Rekomenderad åtgärd/ *Recomended Action*	Ansvarig/ *Respons*	Åtgärds resultat / *Action results*				
													Införd åtgärd *Action taken*	Allvarlighet / *Severity*	Felintensitet / *Occurrence*	Upptäckbarhet / *Detection*	Risk- tal/ *RPN*
-cross functional team and develop FMEA.	-FMEA not adequately performed.	-Product liability. -Customer dissatisfaction. -Reduced performance of system or component. -Potential risk of injury. -Reduce level of analysis of process. -High return rate.	10	cc	-Inadequate FMEA development -Cross functional team not assembled. -Facilitation not used. -FMEA expertise is limited. -Lack of adequate FMEA training.	5	-Mistake proofing. -Automatic visual systems. -Proximity switch.	-APQP checklist. -FMEA review process. -Management review process. -Control plan entries.	5	250	-Call an FMEA facilitatior to reduce time required and improve quality of the FMEA process.	-Process engineer team leader or project manager, ASAP.	-FMEA performed under the supervision and leadership of an certified FMEA facilitator.	10	1	2	20

Figure 3: FMEA example from Parker Hannifin.
Important notes: Here it is shown that the ranking of occurrence, detection has been improved after the action was taken but severity remained stationary. Severity will likely stay the same unless failure mode is eliminated. To find the potential causes of failure requires "brainstorming".

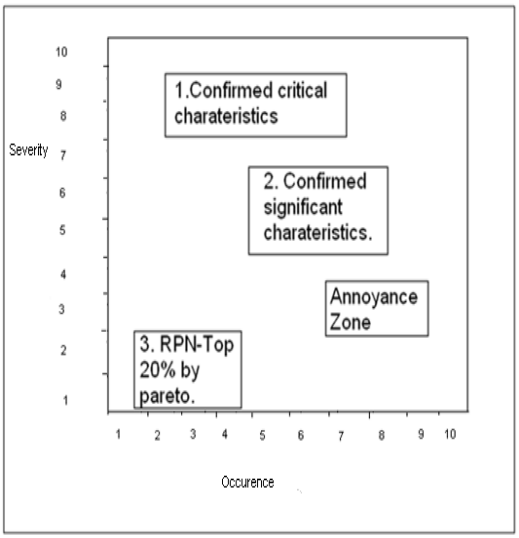

Figure-4**:** Critical and Significant characteristics Action Guidelines.

The occurrence ranking values of a failure mode are plotted on X-axis while the severity ranking values (1-10) are plotted on Y-axis. The figure-4 shows four different zones depending on the occurrence-severity ranking values of a failure mode for a design or process.

Actions are required by priority (figure-4):

1. Confirmed CC is a critical characteristic to be addressed on control plan. Here occurrence-severity values are very high for a failure mode than other zones so it demands more concern than all.
2. An SC is a confirmed significant characteristic to be addressed on control plan. Here severity values are less than confirmed CC zones so it is little less bad than previous zone.
3. Annoyance Zone: In this zone occurrence values are so high but severity values are under control. So it suggests more concern on occurrence of the failure modes.
4. for the top 20% failure modes/causes (Pareto by RPN). Here severity-occurrence values for a failure mode have least values than others. So the area is very good so the under mentioned figure has been drawn to find out the worst failure modes of the process or design as it does not require to investigate all.

[According to table 1, the zones should be considered respectively: confirmed critical characteristics zone (Severity is too high), confirmed significant characteristics (severity is little less than previous), annoyance region (occurrence is very high) and RPN-Top 20% by Pareto]

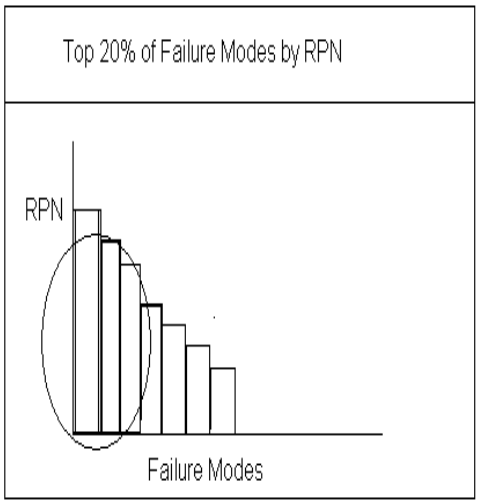

Figure 5: Top 20% Failure Modes by RPN.

In the figure 5, the RPN top 20% by Pareto zone has minimum value of severity & occurrence (see figure-4) than other zones. As a result, the top management is considering the most problematic 20% of them (circled). The different failure modes may be: Bent, Cracked, surface too rough, deformed, hole too deep, hole off location etc.

3.3. Case Study at Parker Hannifin:

In the FMEA sheet, if severity ranks 10, 9 then it marks red. The company maintains a limit of RPNs 200. So if the S.O.D value exceeds that limit, it shows red. Red mark is used as an alarm. In the Parker Hannifin MS Excel sheet, it is not possible to put the values of S, O & D on the first row (first part of figure-6). [27]

Allvarlighet / Severity	Class	Tänkbara felorsaker/ Potential causes of failure	Felintensitet / Occurrence	Nuvarande förebyggande konstruktions-styrning/ Current design controls prevention	Nuvarande upptäckbarhet/ Current design controls detection	Upptäckbarhet / Detection	Risk- tal / RPN	Rekomenderad åtgärd/ Recomended Action	Ansvarig/ Respons	Åtgärds resultat / Action results				
										Införd åtgärd Action taken	Allvarlighet / Severity	Felintensitet / Occurrence	Upptäckbarhet / Detection	Risk- tal/ RPN
9			6			4	216				8	4	1	32
8			5			5	200				6	3	3	54
7			5			6	210				5	2	4	40
6			4			7	168				6	3	3	54

In the first part of figure-6, the values of severity, occurrence and detection has been written after the first row as it is the rule of software. The values of S, O and D which are 9 or 10 marked red including if RPN values equal or greater than 200, it is colored red.

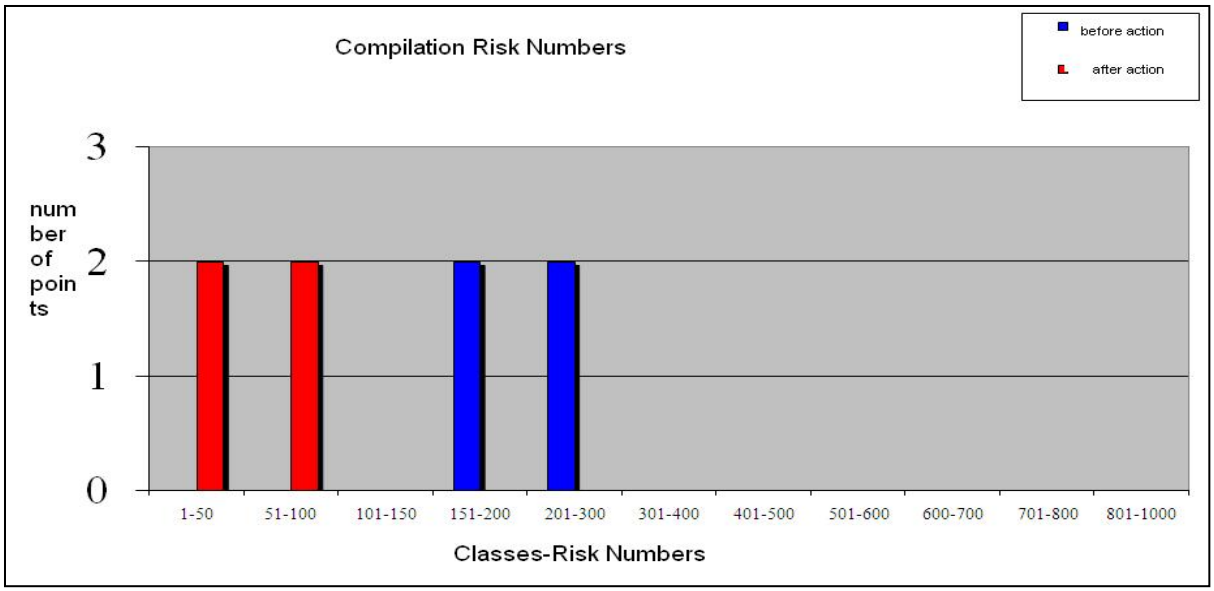

Figure 6: RPN compilation with FMEA software. [27]

[The second portion of the figure-6 comes (immediately) after the first part of the program is completed automatically to show the performance of plotted values in first part of program (of severity; occurrence and detection ranking, 1-10) with different colored bar chart.] In the last part of figure-6, RPN values (in a range, for instance, 201-300, 51-100) are in X-axis and numbers of points to be considered are in Y-axis that was gained from the first part of figure-6. The red bar is for after action while blue bar is for before action. In a summary, it can be observed from the figure that before action the RPN value was 150-260 approximately. But when the action was taken, it decreased exponentially from 150-260 to around 30-100. So the risk was handled superbly. [27]

4. The difference between FMEA and FMECA:

We tried to find some difference between FMEA and FMECA depending on our visit at Parker Hannifin including some literature search.

FMEA	FMECA
1. *FMEA* is the primary step to generating the *FMECA*. [Ref: 3]	1. *FMECA* is more usually used and is more suitable for hazard control.
2. It is used for process. Provides chronological information useful in analyzing potential product failures during the manufacturing process and provide latest ideas for improvements in related designs or processes.[Ref: 3]	2. It is used for system. *FMECAs* need considerable information of system operation necessitating broad planning with software/hardware Design Engineering & System Engineering.
3.Calculation: RPN (Risk Priority Numbers) = S*O*D. Where, S=Severity, O=Occurrence, D=Detection. [Ref: 2& 25]	Calculation: -Quantitive: Mode Criticality = Item Unreliability x Mode Ratio of Unreliability x Probability of Loss - Item Criticality = SUM of Mode Criticalities. - Qualitative: Compare failure modes via a Criticality Matrix, which identifies severity on the horizontal axis and occurrence on the vertical axis.
4. Emphasizes problem prevention. [Ref: 26]	4. Detection and control measures for each failure mode and provide management info.
5. Multiple analysis levels (*Sub-FMEAs*) can be possible. [Ref: 26]	5. *FMECA* does not account for multiple-failure interactions, meaning that each failure is considered individually and the effect of several failures is not accounted for.
6. Examination of human error is limited and output depends on operation mode.[Ref: 23]	6. Human factors are not considered.
7. Criticality analysis absence. [Ref: 26]	7. Severity and probability rankings will help the designer(s) to identify the criticality of the potential failure and the areas of the design that need the most attention. Classifying the severity of the effects of each failure mode, it is possible to know the range from negligible to catastrophic.
8. Improve product/process reliability and quality. [Ref: 23]	8. Production Planning, Repair Level Analysis, Logistics Support Analysis ,Test Planning ,System Safety Analysis, Maintenance Planning Analysis are belongs to the *FMECA*.
9. Increase customer satisfaction and Decreased warranty costs and waste. [Ref: 26]	9. Not only customer satisfaction, also achieve internal customer satisfaction.
10. Reduce non-value added operations and cost. [Ref: 26]	10. Same.
11. Concern with product design and process. Provide new ideas for improvements in similar designs or processes and quality. [Ref: 26]	11. Identifies system and its operator safety concerns. Provide new ideas for system and machinery improvements.
12. Not cost(time) effective. [Ref: 26]	12. More time consuming.
13. Don't use any criticality matrix. [Ref: 2& 25]	13. The criticality matrix provides a means of identifying and comparing each failure mode to all other failure modes with respect to severity.
14. Engineers can compare failure costs to solution cost to reduce life cycle costs. [Ref: 23]	14. same (Reliability vs. serviceability vs. better diagnostics)
15. Gather a cross-functional team of member with various knowledge about the process, product, service &customer requirements. [Ref: 7]	15. May be needs knowledge from cross functional different team but must need system and machinery info.
16. It is an integral part of any ISO 9000 compliant quality systems. [Ref: 2 & 25]	16. Various industries have their own Failure Mode and Effects Analysis Standards. Such as Aerospace and defense companies generally use either the MIL-STD-1629A standard or the SAE ARP5580 standard.

Table 2: The difference between FMEA and FMECA

5. Why Parker Hannifin is performing FMEA:

Parker Hannifin, Borås is not so interested to do risk analysis for design or process but for some important designs or processes, the top management of the company mainly from U.S.A and U.K enforces them to make the *FMEA* risk analysis but it does not hamper the quality of the analysis. It helps the company to avoid accident, re-design and get reliability on design or process. To design the product (figure-1 & 2), the company uses Design *FMEA* while to produce this product, the industry uses process *FMEA.* According to company's information, it is better to use *FMEA/FMECA* risk analysis method for this kind of product but if it does not work so well, *FTA* can be referred. [27]

6. Discussion:

FMEA is a very effective risk analysis method for a company but it is not obligatory to use but if any organization uses it must get several benefits as it is mentioned in this report. In Parker Hannifin, they use only Design and Process *FMEA* and some qualitative part of criticality analysis.

To complete an *FMEA* analysis, it is necessary to make a cross functional group from different departments of the company. The team will be composed of experienced and devoted person will search for failure mode, cause, effect, severity, occurrence, detection etc. together. Brainstorming is very necessary for this *FMEA* worksheet. It is also required to find the proper way to lessen the failure mode. Severity ranking remains almost same if the failure mode is not eliminated.

In *FMEA* worksheet, if severity ranks 10 or 9, it shows red mark (Red marks suggest for quick preventive work). There will be an acceptable RPN limit for any company. It may differ for different companies. Parker Hannifin has a grand limit of 200 RPN. The *FMEA* team needs to see after the action was taken for the design or process whether the RPN value is less than 200 or not (first part of figure-6). In Parker Hannifin software, one will get a graph of RPN of before (red marked) and after action (blue marked). [Second part of figure-6, this part comes automatically after the first part of figure-6 is finished]. Here it is possible to compare the performance development by *FMEA* process. In the second part of figure-6, it is seen that before the action was taken the RPN value was 150-260 but when the corrective action was taken the RPN values plunged exponentially from 150-260 to 30-100. If it is not less than 200, the *FMEA* team is instructed to take necessary corrective action and will have to compare the RPN value of before the action was taken and after the action was taken.

In criticality analysis, the occurrence data's are plotted in X-axis and severity data's are plotted in Y-axis. As a result there are four zones for considered according to the position of failure modes named: confirmed critical characteristics [have maximum severity points], confirmed significant characteristics, RPN- Top 20% by Pareto and annoyance region [severity points are low but occurrence ranking is high] (figure-4). From these zones the *FMEA* team can decide that which failure modes should be prioritized more. According to table 1, the zones should be considered respectively, confirmed critical characteristics zone, confirmed significant characteristics, annoyance region and RPN-Top 20% by Pareto. As first priority is for severity then occurrence, detection consecutively. RPN-Top 20% by Pareto means which 20% failure mode should be prioritized of 100% (figure-5). Top 20% failure modes should be considered as the most part of the zone is very acceptable.

The report consists some differences between *FMEA* and *FMECA*. Importantly, FMEA is used for system and *FMECA* is used for process. *FMEA* is the primary steps to generate FMECA. FMECA is just *FMEA* with criticality analysis. In *FMEA* multiple analysis levels (*Sub-FMEAs*) can be possible. On the other hand, *FMECA* does not account for multiple-failure interactions, meaning that each failure is considered individually and the effect of several failures is not accounted for. *FMECA* is time consuming than *FMEA* (Table: 2). So companies are not very sincere to perform *FMECA* after performing *FMEA*.

Parker Hannifin, Borås is performing FMEA analysis if the organization is asked from the top management of company but it is not hampering of their quality of analysis.

As a result, the main difference between the company findings and the theoretical finding of this report is: Parker Hannifin is using a grand limit for RPN value and it is 200. If severity ranks 10 or 9, it marks red for alarming the design or process. In criticality analysis, the company is only performing the qualitative part (avoiding quantitative part).

7. Conclusion:

There is a working principle of Parker Hannifin to perform *FMEA* and an example of *FMEA* method that was received from Parker Hannifin in this report too. Moreover, the company gave us opportunity to use *FMEA* software and made an *FMEA* analysis with us. The software compiles the comparison of RPN values between before the action was taken (Red) and after the action was taken (Blue).

The report includes a discussion about qualitative part of criticality analysis where occurrence is plotted in X-axis and severity is plotted in Y-axis. Depending on values of severity and occurrence, the failure modes are transferred to different zones named- confirmed critical characteristics, confirmed significant characteristics and RPN- Top 20% by Pareto and annoyance region. The zones should be prioritized depending on severity; occurrence value respectively. The company is not using quantitative part of the criticality analysis as it is troublesome to them.

The article includes little discussion about the theoretical findings and practical observations. There is a comparison between *FMEA* and *FMECA* in this research work. *FMECA* is just *FMEA* with criticality analysis.

As Parker Hannifin, Borås are not interested to make *FMEA/FMECA* analysis if they are not asked from top management; we shall suggest them to make at least *FTA* (Fault Tree Analysis) instead of *FMEA/FMECA* for a design or process at the condition of no obligations. We are hopeful to implement this knowledge in our future life.

8. References:

Books:

1. Donald W. Benbow, Roger W. Berger, Ahmad K. Elshennawy, H. Fred Walker, 2002, *the Certified Quality Engineer Handbook* by ASQ.
2. Bo Bergman & Bengt Klefsjö, 2010, ISBN 978-91-44–05942-6, 3, [rev.] Ed., *Quality: from customer needs to customer satisfaction,* Lund: Student literature.
3. Daimler Chrysler Corporation, Ford Motor Company, General Motors Corporation, Third Edition, April, 2001, *Potential Failure Mode and Effects Analysis (FMEA) Reference Manual* by Adare Carwin Limited.

Scientific Articles and Published Papers:

4. Hot Wire, Issue 46, December 2004, *the eMagazine for the Reliability Professional* by ReliaSoft Corporation available at www.weibull.com/hotwire/issue46/relbasics46.htm
5. Massimo Bertolini, Maurizio Bevilacqua, Roberto Massini, 27 September 2004, *FMECA approach to product traceability in the food industry* by Science Direct.
6. Maria Laura Chiozza, Clemente Ponzetti, 17 March 2009; *FMEA: A model for reducing medical errors* by Science Direct.
7. Fiorenzo Franceschini and Marizio Galetto, 2001, VOL. 39, NO. 13, 2991-3002; *A new approach for evaluation of risk priorities of failure modes in FMEA* by International Journal of Production Research.
8. ICH, Guidance for industry, June 2006, *Q9 quality Risk Management* available at http://www.fda.gov/downloads/Drugs/GuidanceComplianceRegulatoryInformation/Guidances/UCM073511.pdf.
9. David C.Dunkle, ITT Industries- Systems Division, NASA Risk Management Conference 2005; *Prioritizing Human Interface Design Issues for Range Safety Systems using Human Factors Process Fmea* by NASA.
10. Dr. Deborah L. Smith; 2011-05-07, *FMEA: Preventing a Failure before Any Harm Is Done* available at (http://www.isixsigma.com/index.php?option=com_k2&view=item&id=8:fmea-preventing-a-failure-before-any-harm-is-done&Itemid=203
11. Luca Bencini and Steve Pautz; 2011-05-17, *FMEA Can Add Value in Various Project Stages. Available at* http://www.isixsigma.com/index.php?option=com_k2&view=item&id=106minimizing-risks-how-to-apply-fmea-in-services&Itemid=203
12. Tim Williams; 2011-05-22, *Minimizing Risks: How to Apply FMEA in Services* available at http://www.isixsigma.com/index.php?option=com_k2&view=item&id=106minimizing-risks-how-to-apply-fmea-in-services&Itemid=203

Web Pages:

13. http://www.reliasoft.com/newsletter/3q2002/fmea.htm, Date: 2011-05-23.
14. http://www.reliasoft.com/newsletter/v6i1/fmea_process.htm, Date: 2011-05-23.
15. www.quality-one.com, 2011-05-23.
16. www.scribd.com/doc/19251291/Benefits-of-FMEA, 2011-05-20.
17. http://rsdo.gsfc.nasa.gov/documents/Rapid-III-Documents/MAR-Reference/GSFC-FAP-322-208-FMEA-Draft.pdf, Date: 2011-05-08.
18. http://www.fmeainfocentre.com/, Date: 2011-05-26.
19. http://www.volvogroup.com/suppliers/global/engb/supplierapplication/standardsaccess/Pages/fmea.aspx, Date: 2011-05-15.
20. www.asqsection1206.org/uploads/1/5/0/2/.../fma-asq-presentation4-06.ppt, Date: 2011-05-07.
21. http://www.reliasoft.com/xfmea/benefits.htm, 2011-05-01.
22. http://flightservices.org/FMECA.htm, Date: 2011-05-05.
23. http://www.scribd.com/doc/3666204/Failure-Mode-and-Effects-Analysis-FMEA, Date: 2011-05-23.
24. http://www.slideshare.net/Jacobe2008/risk-management-283397, 2011-05-25.
25. http://sce.uhcl.edu/goodwin/Ceng5334/downLoads/FMEA%20Basics.pdf, Date: 2011-05-26.
26. http://www.fmea-fmeca.com, Date: 2011-05-29.

Telephonic and e-mail interview:

27. Joakim Bengtsson, Quality Manager, Mobile Valves Borås, Parker Hannifin AB, Hydraulics Group, Mobile Controls Division Europe, Almenasvagen 22, and SE-501 78 Boras, Sweden.
28. Jan Rohlén, Lecturer, School of Engineering, University of Borås, Sweden, Allégatan 1, SE- 501 90 Borås, Sweden.
29. Sara Lorén, Lecturer, School Of Engineering, University of Borås, Allégatan 1, SE- 501 90, Borås, Sweden.