DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

AN APPLICATION OF PROCESS FAILURE MODES AND EFFECTS ANALYSIS IN THE AVIATION INDUSTRY

by
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AN APPLICATION OF PROCESS FAILURE MODES AND EFFECTS ANALYSIS IN THE AVIATION INDUSTRY

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M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled **"AN APPLICATION OF PROCESS FAILURE MODES AND EFFECTS ANALYSIS IN THE AVIATION INDUSTRY"** completed by **MUKADDER NUR TANYERİ** under supervision of **PROF DR. HASAN SELİM** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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Mukadder Nur TANYERİ

APPLICATION OF PROCESS FAILURE MODE AND EFFECTS ANALYSIS IN A MANUFACTURING COMPANY OPERATING IN AVIATION INDUSTRY

ABSTRACT

Increasing the value added activities in an enterprise by effective production management, and continuous improvement of production processes will bring high quality products and consequently will provide competitive advantage due to increased customer satisfaction. One of the commonly used techniques for improving processes in manufacturing and service systems is Process Failure Mode and Effect Analysis (PFMEA). This technique is a quality technique that detects the potential defects which may occur in the production processes and provides non defective production by taking preventive actions using the Risk Priority Numbers (RPN).

In this research, PFMEA is applied within the scope of Advanced Product Quality Planning of a new product that will be produced in a company which manufactures aircraft equipment. This application aims to produce the final product which is compatible with the production specifications and the design data without any defect. In the application, first of all, process flow charts are constructed in accordance with the operation steps, and parts are grouped accordingly. Then, PFMEA is started. By using brainstorming method and experience-based knowledge, potential failure modes are determined for each work step, and RPNs are calculated based on the Severity (SEV), Occurrence (OCC) and Detection (DET) values. Finally, it is obtained that eight of the potential failures require preventive actions primarily, and these actions are carried out within the specified time period.

This study reveals that true understanding of the technical drawings and procedures by the production operators, and using supplementary tools in production processes have the highest importance. By taking the preventive actions, values of the RPNs are reduced from the critical level, potential failures that may occur in the production process are eliminated, and repair, scrap and labor costs are decreased substantially. The failure reports on the manufacturing processes in a specific time period confirms the viability of the proposed PFMEA.

Keywords: Process failure mode and effects analysis, aviation industry, quality management

HAVACILIK SEKTÖRÜNDE FAALİYET GÖSTEREN BİR İMALAT FİRMASINDA SÜREÇ HATA TÜRÜ VE ETKİLERİ ANALİZİ UYGULAMASI

ÖZ

Bir işletmede etkin bir üretim yönetimi ile katma değer yaratan faaliyetlerin arttırılması ve üretim süreçlerinin sürekli iyileştirilmesi kaliteli ürünlerin üretimini, kaliteli ürünler ise müşteri memnuniyeti ve sonuçta rekabet üstünlüğü sağlamaktadır. İmalat ve hizmet sistemlerindeki süreçlerin iyileştirilmesinde yaygın olarak kullanılan tekniklerden biri süreç hata türü ve etkileri analizidir. Bu teknik, süreçlerde meydana gelebilecek hataların belirlenerek, bu hatalara ilişkin risk öncelik değerlerine göre önleyici aksiyonlar alınması sonucu hataların önlenmesini amaçlayan bir kalite tekniğidir.

Bu çalışmada, havacılık sektöründe faaliyet gösteren bir imalat firmasında üretilecek yeni bir ürüne ilişkin ileri ürün kalite planlaması kapsamında, süreç hata türü ve etkileri analizi tekniği kullanılmıştır. Uygulama ile üretim adımlarının hatasızlaştırılarak nihai ürünün üretim talimatlarında yer alan gerekliliklere ve tasarım verisine tam olarak uyum sağlaması hedeflenmiştir. Uygulama gerçekleştirilirken ilk olarak, operasyon adımlarına göre süreç akış şemaları oluşturulmuş, parçalar bu akış şemaları doğrultusunda gruplandırılmıştır. Ardından, Süreç Hata Türü ve Etkileri Analizi çalışmasına geçiş yapılmıştır. Beyin fırtınası yöntemi ve tecrübeye dayalı bilgi birikimi ile her bir iş adımı için olası hata türleri belirlenmiş ve hataların şiddeti, ortaya çıkma olasılığı ve tespit edilebilme derecesi kullanılarak Risk Öncelik Sayıları (RÖS) hesaplanmıştır. Toplamda sekiz adet hata türü öncelikli olarak önleyici aksiyon almayı gerektirmiştir ve belirlenen zaman zarfında ilgili önleyici aksiyonlar gerçekleştirilmiştir.

Çalışma sonucunda, teknik resimlerin ve ilgili talimatların üretim operatörleri tarafından doğru bir şekilde anlaşılmasının ve parçaların işlenmesi sürecinde üretime yardımcı araçların kullanımının en büyük öneme sahip faktörler olduğu ortaya konmuştur. Önleyici aksiyonların uygulanması sonucunda RÖS değerleri kritik

seviyenin altına düşürülmüş, üretim sürecinde meydana gelebilecek hatalar önlenmiş, tamir, hurda ve işçilik maliyetlerinde büyük oranda iyileşme sağlanmıştır.

Anahtar Kelimeler: Süreç hata türü ve etkileri analizi, havacılık sektörü, kalite yönetimi

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CHAPTER ONE
INTRODUCTION

Over the past half-century, quality has become one of the most important point in terms of competitive advantage. Nowadays, companies can maintain their operations as how much importance they give to quality. Quality can be defined as meeting customer expectations at highest level and maintaining this ability. The pioneers of quality concentrate on different topics about quality definition. It is defined as suitability to the target by Deming, usability by Juran, compliance with clearly defined requirements by Crosby, and focusing on suitability to the target by Ishikawa (Rajagobal & Scheuing, 1996).

Total Quality Management (TQM) approach is firstly applied in U.S.A and then adopted by Japanese companies successfully. This approach put customer at first place within all activities. Statistical tools are used to improve quality and processes as part of TQM approach. The most common tools are flow charts, Ishikawa diagram, check sheets, scatter diagram, Pareto analysis, histograms and control charts. Besides them, some new quality approaches are started to be used to enhance customer expectations. FMEA is one of relatively new TQM methods aiming to identify and evaluate potential risks that can happen during processes and take preventive actions against them in a systematical way.

PFMEA is used to analyze processes and focuses on the types of defects that result from process failures. PFMEA is also known as a process development approach because of the improvements applied on the processes (Stamatis, 2003).

In this research, PFMEA technic is used to prevent from potential risks of a new product within the scope of Advanced Product Quality Planning process in an aircraft equipment supplier company. The critical potential failure modes are determined by using RPN values based on severity, occurrence and detection assessment, and the identification of potential failure modes are based on experiences and past data. Expected occurrence, severity and detection values are defined to verify the effectiveness of the preventive actions. For the failure modes with high RPNs, related preventive actions are taken and then revised RPNs are calculated accordingly.

This study reveals that true understanding of the technical drawings and procedures by the production operators, and using supplementary tools in production processes have the highest importance. As a result of the PFMEA application, potential failures in the production process are eliminated, and repair, scrap and labor costs are substantially decreased. Accordingly, the customer satisfaction would be increased. As a result of the PFMEA application, potential failures in the production process are eliminated, and repair, scrap and labor costs are substantially decreased. Accordingly, the customer satisfaction would be increased.

CHAPTER TWO
FAILURE MODE AND EFFECTS ANALYSIS

Increasing the value added activities in an enterprise by effective production management and continuous improvement of production processes will provide competitive advantage by maintaining high quality products and customer satisfaction.

FMEA is one of the quality technics that increase quality. It is a standardized methodology that enables to assess and prevent risks linked to a product or a process by

- Identifying and evaluating the potential failures and effects,
- Defining and implementing actions with a continuous effort.

It is a standardized analytical technique to assess

- The effect of potential failure on the customers,
- The appearance probability of a failure leading to its effect,
- The ability to detect or prevent from the potential failures within the product life cycle.

The terms failure, mode, effect and analysis can be defined as follows.

- Failure: unsatisfactory performance
- Mode: the way failure occurs
- Effect: the result of failure
- Analysis: the way of investigating the failure and its effects on processes.

In order to apply FMEA, there should be some pre-conditions to have such as customer should be defined, the aim should be known transparently, the problems should be prioritized and the method should be applied as planned.

The main aims of FMEA can be stated as follows.

- To decide the types of failures, their effects and severity,
- To define the most critical failures,
- To provide perfect, non-defective product by making the improvements which, eliminate failures, malfunctions and critical cases (Stamatis, 2003).

2.1 The Benefits of FMEA

With the help of FMEA, potential failures can be prevented for similar products or processes. It provides FMEA team extract those failures from system with the minimum effort and cost, therefore the overall process improves.

The main benefits of FMEA can be stated as follows.

- Reduction in the cost of non-quality,
- Reduction in the waste of time, potential risks,
- Prioritizing the risks of product or process imperfections that are linked with preventive solutions,
- Improvement in the product reliability and maturity,
- Providing easy understanding about how system works.

2.2 Types of FMEA

System FMEA: It focuses on failure modes which occur because of system deficiencies by analyzing overall system and sub-systems. It aims to increase quality, reliability and preservability of the systems. The benefits of system FMEA are as follows.

- The problems which may affect system performance unfavorably are reduced,
- Enables conducting procedures within system,

- Detects surpluses of system,
- Determine the optimum system design.

Design FMEA: It is used before producing the products to eliminate the effects of bad product design. It aims to increase quality, reliability and preservability of design. The benefits of design FMEA are as follows.

- Determining the design development process priorities,
- Detecting the potential failures when designing,
- Specifying the critical characteristics.

Service FMEA: It helps to analyze defects in an organization. By prioritizing the organization processes, work-flow, system and process analyses can be done efficiently, and control plans are made in a better way after specifying the critical characteristics of the organization.

PFMEA: It is a methodical approach used for identifying risks on process deviations. It aims to analyze potential risks in a production / assembly process in order to prevent or reduce the potential risks in that process.

2.3 Process Failure Mode and Effects Analysis

It helps to identify potential risks/failures which may occur in production processes and enables to take appropriate actions according to prioritization as a result of RPN numbers. It is a quality technique that detects the potential defects which can occur in the production process, and provides non defective production by taking preventive actions.

PFMEA analyses the potential risks of a process in order to prevent or appease potential failures on this process. In other words, it is the preventive way contributing to set a secured and robust process. It enables to eliminate deficiencies caused by production and/or assembly process. By using PFMEA, critical and essential characteristics of the processes can be specified and listed. According to this list, potential failure mode and their effects are determined. In PFMEA, all processes are specified, specifications for each process are given, potential failure mode and potential effects of failure are determined, the severity of the effect is assessed, potential causes are listed and occurrence and detection of the failure mode are assessed.

The improvements made upon processes shows that FMEA can also be defined as a process development approach. PFMEA gives the possibility to evaluate production processes in terms of detecting weaknesses by analyzing the machines, tools and labor used in those processes to produce perfect products (Yılmaz, 1997).

The general triggers to conduct PFMEA are listed in the following.

- New design, new process
- Change in the existing process
- To increase product reliability hence recognition in sector
- To reduce time and cost in the product development stage
- Transfer of work
- Continuous improvement activity (Kaizen)
- To test product reliability
- To define the potential affects when a change/regulation is applied to product
- Leads a way to eliminate high potential risks in processes
- Customer request, etc.

CHAPTER THREE
LITERATURE REVIEW

FMEA was applied first time at USA army named as “Procedures for Performing a Failure Mode, Effects and Criticality Analysis (FMECA)”, with MIL-P-1629 code, as a reliability evaluation technique to determine the effects of system and equipment failures. FMEA is a reliable technique for determining the effects of system and hardware failures. The failures are classified according to the mission success and effects on the personnel/hardware safety (Deb et al., 1998).

In 1969, FMEA was applied by the NASA Apollo project, which will bring people to the Moon. Since this product was unique and costly, it was desirable not to make any parts or system fail. It had been decided to implement FMEA in order not to endure the high cost of the entire system backup. Between 1970 and 1975, the first industrial application of the FMEA in the US aircraft industry, the SMC 800-31 procedure, was made and then spread throughout the world (Arabian-Hoseynabadi et al., 2010).

Safety is critical in aerospace industry, and FMEA provides a precautionary methodology to this industry. Therefore, it is used to evaluate safety of Concord and Airbus aircraft in the United States and France, respectively. Ford Motor company used FMEA technic at first time in Research and Development stage of an automobile in 1977. In the following years, it published a handbook titled “Potential Failure Mode and Effects Analysis” to generalize the method. After the Ford Motor’s PFMEA applications in its business, automobile manufacturers in America also introduced the FMEA into the management of suppliers, and took it as a key figure (Rakesh et al., 2013).

FMEA, which has been a complementary part of engineering designs for many years, has become an essential tool especially for aviation and automotive industries. Also, governmental bodies use this technic to prove dependability of their systems (Chen et al., 2008).

ISO 9000 series are published by International Standard Organization in 1988. These series force organizations to focus the quality management systems' structure in terms of customer expectations and requirements. In automotive industry, QS 9000 was adopted instead of ISO 9000 as it includes TQM methods like FMEA. FMEA takes place in that standard under the "quality planning" title. It is also one of the key elements of QS 9000. These elements are listed in the following.

- APQP: Advanced Product Quality Planning
- SPC: Statistical Process Control
- MSA: Measurement System Analysis
- PPAP: Production Parts Approval Process
- FMEA: Failure Mode and Effects Analysis

Automotive Industry Activity Group and American Standards Organization procured copyrights of FMEA standard in 1993 (Mekki, 2006).

Pantazopoulos and Tsinopoulos (2005) claimed that FMEA is the one of the potential tools that can be used for robustness analysis in electrical and electronic components production as well as in complicated assemblies. The purpose of their study is to find out system weaknesses and therefore minimize the risk of potential failures. They used FMEA in the design stage of a product in metal forming industry.

Konguraja and Gobi (2015) implemented PFMEA in a small and medium scale pump industry, and the rate of rework is decreased and consequently the delivery performance is improved by the application. In addition, they indicated that an effective control plan is important to ensure that the key process inputs would be properly documented.

Le Saux (2006) applied the PFMEA in a GaAs semiconductor manufacturing environment by considering the relationship between process control plan and FMEA. In the study, the process control plans are updated after analyzing and ranking the risks and dynamic FMEA is deployed and maintained.

Çevik and Aran (2009) applied PFMEA to improve the quality process in a leverage manufacturing process within a factory. The failures in the leverage manufacturing process were analyzed within FMEA application. As a result of the analysis, the occurrence of top failures and customer complaints are decreased. Besides, it is suggested that the actions decided in FMEA application should be monitored and supported by statistical process control methods.

Yıldız (2016) proposed an innovative approach which integrates FMEA with the grey relational analysis which is commonly used for solving problems under missing or incomplete information. The researcher indicates that the FMEA and the assumption that risk factors have equal weight may give incorrect results in the priority ranking due to some limitations. However, in situations where risk factors have different weights gave more meaningful results.

Çelikdemir (2012) applied FMEA to specific machines at first in order to minimize the effects of machine-based failures. Then, PFMEA was implemented on the basis of products produced in those machines. As a result, it was seen that using both machine-based FMEA and PFMEA provides to find different causes of a potential failure. Quality cost, level of failed parts per million and the rate of customer complaints have significantly improved.

Sönmez (2017) applied FMEA to sub processes of the production processes of a company (goods in, incoming inspection, packaging etc.) which operates in the automotive sector and performs metal works. FMEA team benefited from case study method during application. As a result, potential failure modes and preventive actions were defined. After implementing the actions, the processes of raw material and auxiliary material acceptance, input quality control, stocking and intermediate deliveries were improved by 52.6% and packaging by 54.3%. AHP, fuzzy logic and gray theory were used while analyzing the failure modes.

Parsana and Patel (2014) presented a case study which conducts an FMEA on manufacturing process of cylinder head which is closed, and often detachable.

First of all, manufacturing operations were listed and potential failures were determined. The criteria for ranking of severity, occurrence and detection are determined considering the past failure data. After calculating all RPNs, FMEA chart was completed. RPN of the potential failure of Nozzle Bore Depth Plus has been determined the highest RPN. It was concluded that FMEA helped in improving the efficiency of the manufacturing process and quality of product, thus decreasing the number of defective products and saving of rework cost and time.

Kalraiya and Kalraiya (2017) presented an effective tool for improving the quality of manufactured products. FMEA was chosen as a tool and applied on the welding process. While analyzing the joint welding, variety of weakness such as cracking, undercut, stress relieving, improper pre heat are determined as potential failures. Those failures are evaluated to take preventive, corrective actions in order to enhance the quality of the products.

Banduka, Veža and Bilić (2016) proposed a new approach which integrates lean manufacturing with PFMEA since both of them aims to identify, prevent and correct the failures happen during the production process. An application is made in an automotive company which produces electronic circuit boards and cables. Typical PFMEA of a specific product was ready, then it was aimed to compare it with the new approach in terms of effectiveness. In the study, the proposed PFMEA has proven to be very beneficial and practical for identifying and fixing problems and failures. The greatest benefit of the application is the improvement in product and process quality.

Şenyiğit and Ekinci (2016) applied FMEA in supplier selection process by analyzing the suppliers' risks. They used revised FMEA which combines classical FMEA and Analytical Hierarchical Process (AHP). The suppliers were compared in terms of quality, delivery, price and performance as the main criteria. AHP and FMEA were conducted correspondingly including other 18 sub criteria. According to the pairwise comparison matrix, one of the suppliers was selected as the most suitable option. The selected supplier had the lowest RPN value which ensures it has fewer risks than the other suppliers.

Aksay, Orhan and Kurutkan (2013) applied FMEA in a public hospital for eliminating the risks occur in the hospital laboratory activities since medical errors may result in death. It was concluded that the regulations which increase personnel motivation and decrease stress factors, decrease RPN value to the tolerable limit. Moreover, it was stated that FMEA can be applied to the hospital processes as a risk control mechanism.

Yaylalı (2008) applied PFMEA in agricultural sector for the four production steps of dropper which are flat dropper production, round dropper production, flat drip irrigation pipe production and round drip irrigation pipe production. In total, 49 potential failure modes were determined, and preventive actions were taken for six of them. The highest RPN was calculated as 333 which belongs to the potential failure of deformed dropper in flat dropper production. When determining the potential causes, cause-and-effect diagram was used. By means of PFMEA application, the six risky potential failures were eliminated.

A literature review study about FMEA including the academic journal articles published between 2002 and 2012 is given in Nuchpho, Nansaarng and Pongpullponsak, A. (2014).

Nuchpho, Nansaarng and Pongpullponsak (2014) presented a literature review about FMEA. Academic journal articles published between 2002 and 2012 were considered in the study. The researchers show that FMEA is a very important reliability analysis tool which has been widely used in many organizations and areas.

Along the production sector, FMEA is frequently used in other industries for different purposes. The reader may refer to Alkaya (2007), Kuvvetli (2008) and Kahraman (2009) for the applications of FMEA in different industries.

CHAPTER FOUR
APPLICATION

4.1 Introduction

This research presents a PFMEA application within the scope of advanced product quality planning of a new product that will be produced by existing methods in a company which manufactures aircraft equipment. With this application, it is aimed to produce the final product which is compatible with the customer specifications and design data.

The remaining of this section is organized as follows. In Section 4.2, the company is introduced briefly. In Section 4.3, the production environment is presented. The PFMEA application is presented in Section 4.4.

4.2 Introduction of the Company

The company is one of the suppliers of leading civil aviation companies, who was established at the beginning of twenties in İzmir. The factory's headquarters is in Germany. It produces plane parts for as aircraft equipment. Many different kinds of products are produced in company. Production volume of the company is getting higher parallel to the improvements of civil aviation sector.

4.3 The Production Environment

The product AF is an aero structure that hosts complex systems and equipment. Since it has a highly complex structure, its functionality, location and accessibility from the fuselage entail a design challenge in itself.

The production area of the AF product is made of four groups which are sub-part group, quick assembly group, sub assembly group and main assembly group. Therefore, the production area is designed as process layout in which production tools and equipment are placed accordingly.

In sub-assemblies group, drilling operations are carried out, in the sequel riveting, painting and marking operations are done in assembly group. Finished parts are montaged and finalized in main jig. Parts are produced by using production helping tools and equipment. Each of the equipment has a unique identification number and periodically controlled by company tooling team.

AF parts are processed according to a work order which include operation steps and the list of materials. Besides, technical drawings of the parts are kept up-to-date in production area for production operators.

The parts of AF product are categorized as follows.

- Sub Parts: These parts are delivered to customer as supplied from vendor.
- Quick Assembly: Only nut plates are montaged onto loose assemble parts.
- Sub Assembly: Parts are assembled separately to fit with other units.
- Main Assembly: Finished AF product

4.4 The PFMEA Application

First of all, a team is made up for conducting PFMEA within the company which consist of PFMEA moderator, PFMEA facilitator and specialists from different departments associated with the process. FMEA team members are appointed by the FMEA moderator. The scope of PFMEA is defined by a process flow diagram by the moderator. Since the scope is too large and complicated, the process is divided into sub-processes. Therefore, the order and interactions of the sub-processes are taken into account so as not to miss any potential defects during the analysis.

When determining the potential failures, it is important to benefit from experiences, past statistical data, the methodology and customer feedback. In addition, PFMEA moderator has prepared an internal procedure to explain how to implement a successful PFMEA within the company. This procedure can be defined as a guideline for PFMEA team including the scope, content and the method of the application.

Manufacturing flow-charts of the AF parts are prepared according to the operation steps in order to see the work flow. PFMEA groups are created accordingly. A sample work flow is presented in Figure 4.1.

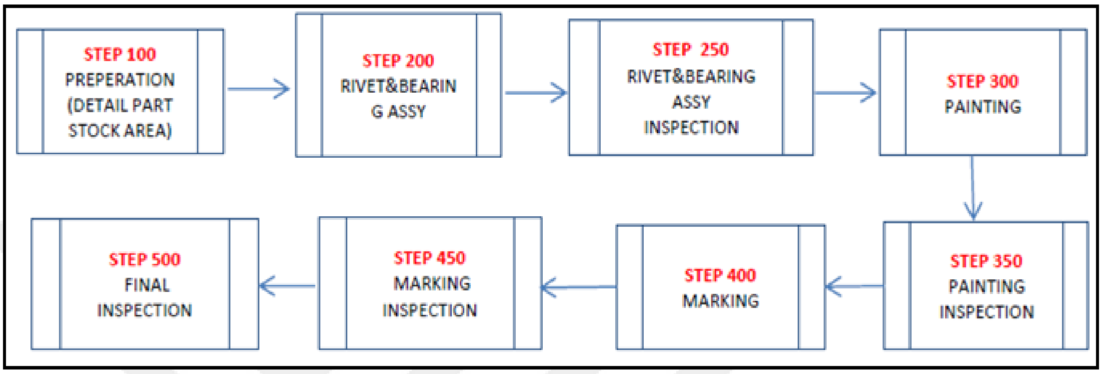

Figure 4.1 Sample work flow

Parts are processed as required in customer specifications and technical drawings. Therefore, potential failure modes are determined for the parts that are processed opposite to requirements.

The descriptions used within the scope the PFMEA application is defined as follows.

- <u>Process Steps:</u> Process steps which have to be identified during the preparation phase correspond to the scope of the analysis. In this study, process steps are introduced with manufacturing flow charts to see the operations in detail.

- <u>Sub Processes:</u> Sub-processes should be listed to detail the process step.

- <u>Specification:</u> Provide the requirement to be fulfilled at the corresponding process step.

- <u>Potential Failure Mode</u>: It is the nonfulfillment of the process specifications and/or technical design data which affects the intended process steps in a negative way.

Example:

Process step: Screw end on body

Specification: Torque 2Nm ± 0.5

Acceptable failure modes:

- Torque below 1.5 Nm
- Torque above 2.5 Nm
- Don't screw on body

- <u>Potential Failure Effects</u>: It corresponds to the impact of the failure, i.e. how the potential failure will be perceived by the customer (internal/external).

- <u>Severity</u>: Estimated consequence of the failure on further processes or final product in 1 to 10 scale. The severity assessment used in the PFMEA application is presented in Table 4.1.

Table 4.1 Severity assessment

Criteria	Assessment	Type
Not any effect on further processing or product functionality	1	-
Low effect on further processing or product functionality	2-3	Low severity
The failure negatively affects product functionality but not at the sacrifice of human life, injuries or the loss of workshops	4-5-6	Moderate severity
The failure has an intensive negative effect on product functionality which may result in a failure of the end product but not a risk for human life	7-8	High severity
End product is effected negatively, and injuries or the loss of workshops can happen in the further processing	9	Very High Severity
The failure results in sacrifice of human life and permanent detrimental effects	10	Critical

- <u>Current Prevention:</u> It is process weakness which drives to the failure as a consequence.

- Occurrence: Estimated probability of the cause represented by a 1 to 10 scale which leads to the identified effect. The occurrence ranking used in the application is reported in Table 4.2.

Table 4.2 Occurrence ranking

Criteria	Assessment	Type	Frequency per product produced
Not happened before	1	-	-
Failure rarely happen	2-3	Low probability	1 in 20
Occasional failure	4-5-6	Moderate probability	1 in 10
Failure happens too often	7-8	High probability	1 in 2
Failure rate almost 100 %	9-10	Very high probability	1 in 1

- Detection: What are the current controls to detect the potential failure mode?

- DET: Assessment of the ability of the manufacturing verification to identify potential manufacturing weakness before released to customer. The detection ranking used in this study is presented in Table 4.3.

Table 4.3 Detection ranking

Criteria	Assessment	Type
Failure is obvious and can be immediately detected	1	Very high probability
Failure can be easily detected	2-3	High probability
Failure is hard to detect	4-5-6	Moderate probability
To detect the failure, special test methods or equipment is required	7-8	Low probability
It is not possible to detect the failure	9-10	Improbable detection

- RPN is used to rank and compare the seriousness of failure mode in 1 to 1000 scale.

- Description of preferred action: The purpose of the action is to eliminate/mitigate the risk by reducing the OCC and/or the DET. RPN classification and the preventive actions are presented in Table 4.4.

Table 4.4 RPN Classification and the preventive actions

RPN	SEV	Preventive Actions
≤ 10	≥ 9	Risk is tolerable, action not required
≤ 40	< 9	Risk is tolerable, action not required
≤ 40	≥ 9	Risk is not tolerable, action required
40 < RPN < 100	< 7	Risk is tolerable, action not required
40 < RPN < 100	≥ 7	Risk is not tolerable, action required
RPN ≥ 100	≥ 1	Risk is not tolerable, action required

- OCC ranking should be reducing thanks to action mitigation on the potential causes identified.

An increase in process verification should reduce the DET ranking. Reduction of the SEV ranking is highly limited.

- Expected OCC: Estimated probability of the cause in 1 to 10 scale in case of the preventive actions are implemented.

- Expected DET: Assessment of the ability of the manufacturing verification to identify potential manufacturing weakness before released to customer in 1 to 10 scale in case of the preventive actions are implemented.

- Expected RPN: Expected RPN are used to estimate the efficiency of the preventive actions identified to mitigate the risk.

- Revised OCC: Estimated probability of the cause in 1 to 10 scale after the implementation of preventive actions in a dedicated workshop.

- Revised DET: Assessment of the ability of the manufacturing verification to identify potential manufacturing weakness before released to customer in 1 to 10 scale after the implementation of preventive actions in a dedicated workshop.

- Revised RPN: It represents the efficiency level of the preventive actions. In our application, severity value remains the same since it is only related with the product's design. Thus, revised occurrence and detection values are considered.

During weekly PFMEA meetings, potential failure modes are detected by brainstorming according to past data, experiences, customer feedback and reports. Each process specification is evaluated separately in a detailed way in conjunction with technical drawings of related parts. Table 4.5 reports the number of failure mode detected for each process and the total number of failure mode.

Table 4.5 The number of failure modes

Processes	Nº of failure modes
DRILLING	16
RIVET ASSY	17
CLEANING	1
INSTALLATION OF ANCHOR NUTS	5
APPLICATION OF SEALING MATERIALS	5
BEARING ASSY	5
INSTALLATION OF BUSHES	6
ELECTRICAL CONNECTION	3
TIGHTENING OF SCREWS AND NUTS	4
PAINTING	5
MARKING	1
INSTALLATION OF FASTENERS AND NUTS	2
PRESSING AND INSERTION OF BUSHES AND BEARINGS	2
Total Nº of failure modes	**72**

4.4.1 Failure Modes

SEV, OCC and DET values are determined as defined previously, and RPNs are calculated accordingly. The PFMEA team only focuses on failure modes which require preventive actions. According to the RPNs, the potential failure modes that require preventive actions are determined and reported in Table 4.6.

The severity value is determined as 7 for scrap and 3 for rework operations by agreeing with the customer. All failure modes stated in Table 4.5 are assessed and

RPNs are calculated. However, only the ones that requires preventive actions are presented in Table 4.6. The completed PFMEA sheet is given in Appendix 1. After calculating the RPNs, the preferred preventive actions are described and assigned to the related specialist as action owner within the time limit of action target date. Expected occurrence and detection values are determined accordingly while severity values should remain the same since it is only related with the product design.

Table 4.6 RPN ranking

No	Process	Potential Failure Mode	Potential Failure Effects	SEV	OCC	DET	RPN
1	Drilling	Hole diameter is above tolerances	scrap	7	3	3	63
2	Drilling	Hole diameter is out of roundness	scrap	7	3	3	63
3	Riveting	Incorrect rivet usage	rework	3	7	7	147
4	Riveting	Incorrect installation onto part	rework	3	7	7	147
5	Marking	Missing marking	rework	3	7	5	105
6	Fastener assy	Not tightened screws	rework	3	7	5	105
7	Painting	Part thickness below tolerances	rework	3	7	7	147
8	Bearing assy	Non-moving bearing	scrap	7	3	3	63

Table 4.6 reveals that failure modes 3,4 and 7 have the highest RPNs, and need preventive action primarily. Failure modes 5 and 6 have the second highest RPNs. Failure modes 1, 2 and 8 come next. The actions are determined according to RPN value order.

4.4.2 Preventive Actions

If the hole diameter is above the nominal value, the part is treated as scrap since fastener assembly becomes impossible into this hole.

For failure mode 1;

- Potential Cause Mechanisms of Failure: incorrect drill diameter, runout, worn out drill

- Current Prevention: test plate drilling before operation

- Detection: fitting control of fastener during riveting operation

- Action: designing a drilling template for the operators that has the correct hole diameter as required in customer specifications.

In this way, the risk of wrong hole diameter value can be eliminated. For this action, process engineering team is assigned for template design and the expected values are assessed as in the following.

Sev: 7, Expected Occurrence: 1, Expected Detection:3, Expected RPN: 21

Out of roundness of holes are not permitted since it negatively effects fastener assembly.

For failure mode 2;

- Potential Cause Mechanisms of Failure: wrong cutting parameter

- Current Prevention: test plate drilling before operation

- Detection: fitting control of fastener during riveting operation

- Action: color identification of drilling bit

By using color identification of RPM, the risk of hole diameter is out of roundness can be eliminated. For this action, process engineering team of the company is assigned for template design and the expected RPN is calculated as in the following.

Sev: 7, Expected Occurrence: 1, Expected Detection:3, Expected RPN: 21

The rivets are stored in tool boxes in production area according to their types (diameter). Assembling the incorrect rivet type onto parts as shown in the design document causes rework.

For failure mode 3;

- Potential Cause(s) Mechanisms of Failure: lack of distinct material identification labels

- Current Prevention: qualification process of operators for technical drawings

- Detection: final quality inspection

- Action: putting apparent identification labels onto each rivet tool boxes.

Stock department is assigned for this action since raw material supply to production is under their responsibility, and the expected RPN is calculated as in the following.

Sev: 3, Expected Occurrence: 2, Expected Detection:2, Expected RPN: 12

Rivet positions onto parts shall be assembled as shown in technical drawings. Otherwise, part shall be reworked.

For failure mode 4;

- Potential Cause(s) Mechanisms of Failure: incompetence of operators, lack of attention

- Current Prevention: qualification process of operators for technical drawings

- Detection: final quality inspection

- Action: improving qualification training of operators within the scope of technical drawings.

Technical training department is assigned for this action and the expected RPN is calculated as in the following.

Sev: 3, Expected Occurrence: 2, Expected Detection:2, Expected RPN: 12

Parts are marked for product number identification which provides traceability. Missing marking causes rework operation.

For failure mode 5;

- Potential Cause(s) Mechanisms of Failure: incompetence of operators, lack of attention

- Current Prevention: qualification process of operators for technical drawings

- Detection: marking control according to the inspection plans

- <u>Action:</u> improving qualification training of operators within the scope of technical drawings

Technical training department is assigned for this action and the expected RPN is calculated as in the following.

Sev: 3, Expected Occurrence: 2, Expected Detection:5, Expected RPN: 30

Screws shall be tightened with the defined torque wrench while assembling.

For failure mode 6;

- <u>Potential Cause(s) Mechanisms of Failure:</u> incorrect adjustment of the torque wrench by production operators

- <u>Current Prevention:</u> not applicable

- <u>Detection:</u> visual control

- <u>Action:</u> only qualified calibration personnel is nominated for torque wrench adjustment

Calibration laboratory department is assigned for the action and the expected RPN is calculated as follows.

Sev: 3, Expected Occurrence: 2, Expected Detection:3, Expected RPN: 30

Parts that are completely assembled shall be painted in order to prevent from corrosion. The paint thickness shall be within tolerances, otherwise, part shall be repainted.

For failure mode 7;

- Potential Cause(s) Mechanisms of Failure: work orders do not include paint thickness tolerances, therefore, operators perform the job based on their experiences visually

- Current Prevention: not applicable

- Detection: final quality control

- Action: works order will be updated as including paint thickness tolerances.

Production Planning department is assigned for the action, and the expected RPN is calculated as follows.

Sev: 3, Expected Occurrence: 2, Expected Detection:3, Expected RPN: 30

Bearing assembly is performed by using a press machine. The bearing can move if correct load is applied by the machine.

For failure mode 8;

- Potential Cause(s) Mechanisms of Failure: incorrect load application for installation

- Current Prevention: qualification of personnel for the process

- Detection: inspection of play with hand

- Action: The pressing load (daN) to be applied will be defined in the work order to prevent the calculation manually by the operator.

Production Planning department is assigned for the action and the expected RPN is calculated as follows.

Sev: 7, Expected Occurrence: 1, Expected Detection:3, Expected RPN: 21

The actions are reviewed on weekly meetings by the participation of PFMEA team members. The important point is to fulfill the tasks within the given time frame since it is also monitored directly by the customer. The timeline to accomplish an action differs in relation with its complexity and hardness. However, the objective is to complete the PFMEA before the serial production is started. When an action is accomplished by the action owner, Revised RPNs are calculated by the team for verification.

4.4.3 Revised RPNs

After the implementation of each recommended preventive action, the probability of detection and occurrence are re-assessed. All implemented actions are taken into account in the re-calculation of the revised RPNs associated to the potential failures. Severity values remain the same in the PFMEA application. In order to determine revised RPNs, the production flow is monitored until the desired product volume is reached. Production failure reports, process quality issues and customer complaints are used to evaluate potential failures' revised RPNs.

For action 1, 2 and 8, production failure reports and customer complaints are investigated for a three shift-set period after the required action has been completed. For actions 3,4,5,6 and 7, the process quality issues, customer complaints and failure reports are analyzed and five shift-set periods has been waited to recalculate the RPNs.

Table 4.7 reports the RPNs calculated after all required actions have been taken. It is seen that all revised RPNs correspond to the "no-action required" level according to Table 4.4.

Table 4.7 ReRPN ranking

No	Process	Potential Failure Mode	Potential Failure Effects	SEV	Revised OCC	Revised DET	Revised RPN
1	Drilling	Hole diameter is above tolerances	scrap	7	1	3	21
2	Drilling	Hole diameter is out of roundness	scrap	7	1	3	21
3	Riveting	Incorrect rivet usage	rework	3	2	7	42
4	Riveting	Incorrect installation onto part	rework	3	2	2	12
5	Marking	Missing marking	rework	3	2	5	30
6	Fastener assy	Not tightened screws	rework	3	2	5	30
7	Painting	Part thickness out of tolerances	rework	3	2	5	30
8	Bearing assy	Non-moving bearing	scrap	7	1	3	21

In order to evaluate the effectiveness of the PFMEA application conducted in this study, number of defects and failure reports before and after the PFMEA are compared. The following figures illustrate the data recorded in the first quarter of the year under concern.

Fig. 4.2 illustrates the supplier and production related defects and total defects observed before the PFMEA whereas Fig. 4.3 illustrates the production related failure reports representing the nonconformity.

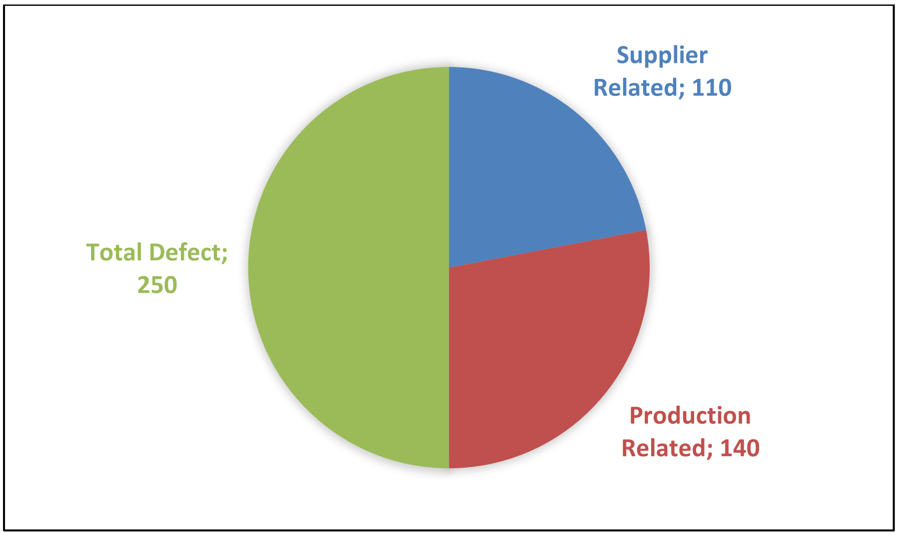

Figure 4.2 The number of defects before the pfmea

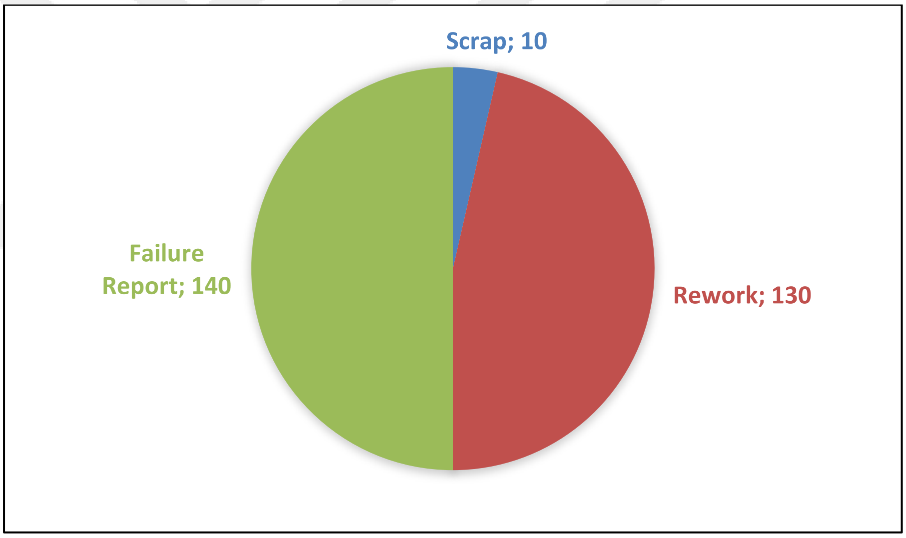

Figure 4.3 The number of failures before the pfmea

The results reveal that most of the failures can be reworked. However, this causes time loss which may result in backlog. Scrap costs are more than the rework costs as unprocessed material prices are higher.

After the PFMEA application, the parameters observed in the second quarter are analyzed and the results are illustrated in Fig 4.4 and 4.5. Currently, 56 % of the failures arise from the production whereas 44 % of them originated by the suppliers.

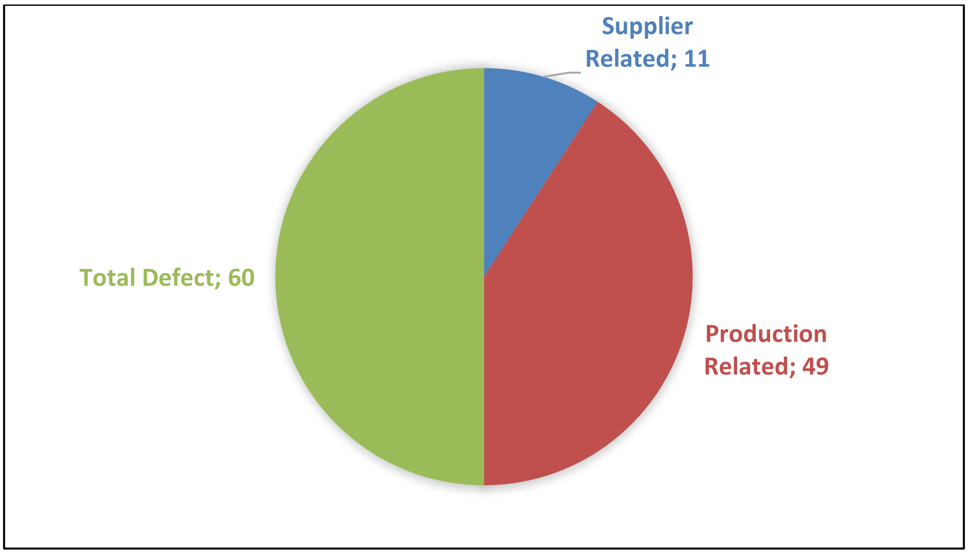

Figure 4.4 The number of defects after the pfmea

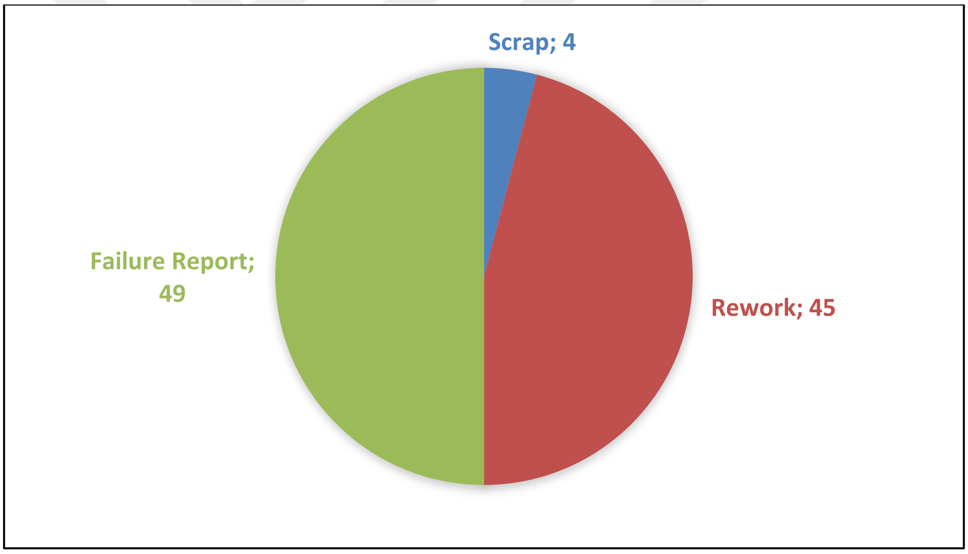

Figure 4.5 The number of failures after the pfmea

The results denote that the production failures are decreased by 65 % by the PFMEA. In addition, supplier related failures are decreased by 90 %. During the PFMEA, suppliers are requested to perform their own FMEA for the parts they supply for the company within the scope of incoming quality complaints.

CHAPTER FIVE
CONCLUSIONS

Quality can be defined as meeting customer satisfactions preeminently. The essential features of creating quality in a manufacturing organization is keeping customer satisfaction at a high level and sustain this at a long term. Therefore, producing non-defective and complete product is not enough to achieve quality, meeting customer expectations comes at first.

PMEA is of the effective technic to create quality in processes. This method systematically decreases the number of defects and increase customer satisfaction accordingly.

In this research, PFMEA is applied in an aviation company production process in order to achieve non-defective manufacturing. Since safety is a must for aviation industry and the products are too costly, they shall produce non-defective products. In order to achieve this, PFMEA can be used to prevent from potential failures that can occur in the production processes.

Amongst the products of the company, AF has a strategic importance because of its position in an aircraft. It is a new project transferred from headquarter to the company, and the scrap cost is too high for this product. Therefore, customer require PFMEA application before serial production is started. Within the application, 72 potential failure modes are detected. After calculating the RPNs of these failures, eight of them have been determined to require preventive actions. The PFMEA team determined firstly the preventive actions and then handle these actions in order according to RPNs. The actions are not intended to prevent from failures temporarily, but to establish a system to avoid from these failures permanently.

This study reveals that true understanding of the technical drawings and procedures by the production operators, and using supplementary tools in production processes have the highest importance. By taking the preventive actions, values of the RPNs are reduced from the critical level, potential failures that may occur in the production process are eliminated, and repair, scrap and labor costs are decreased substantially. The failure reports on the manufacturing processes in a specific time period confirms the viability of the proposed PFMEA.

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APPENDIX

Appendix 1: PFMEA Sheet

No	Process	Requirement	Potential Failure Mode	Potential Failure Effects	SEV	Potential Cause	Current Prevention	OCC	Detection	DET	RPN	Action	Action target duration	SEV	Expected OCC	Expected DET	Expected RPN	Action completion status	SEV	Revised OCC	Revised DET	Revised RPN
1	Drilling	Hole diameter is within tolerances	Hole diameter is above tolerances	scrap	7	missing pilot hole, missing tooling	test plate drilling before operation	3	fitting control of fastener during riveting operation	3	63	Designing a drilling template for the operators that has the correct hole diameter as required in customer specifications	1 month	7	1	3	21	Completed	7	1	3	21
2	Drilling	Hole diameter has roundness	Hole diameter is out of roundness	scrap	7	wrong cutting parameter	test plate drilling before operation	3	fitting control of fastener during riveting operation	3	63	Color identification of all drilling bits	2 months	7	1	3	21	Completed	7	1	3	21
3	Riveting	Correct rivet usage	Incorrect rivet usage	rework	3	lack of significant material identification labels	qualification process of operators for technical drawings	7	final quality inspection	7	147	Putting apparent identification labels onto each rivet tool boxes	2 months	3	2	7	42	Completed	3	2	7	42
4	Riveting	Correct installation onto part	Incorrect installation onto part	rework	3	incompetence of operators, lack of attention	qualification process of operators for technical drawings	7	final quality inspection	7	147	Improving qualification training of operators within the scope of technical drawings	1 month	3	2	2	12	Completed	3	2	2	12
5	Marking	Marking onto part as required in design document	Missing marking	rework	3	incompetence of operators, lack of attention	qualification process of operators for technical drawings	7	marking control according to inspection plans	5	105	Improving qualification training of operators within the scope of technical drawings	1 month	3	2	5	30	Completed	3	2	5	30
6	Fastener assy	Tightened screws	Not tightened screws	rework	3	incorrect adjustment of the torque wrench by production operators	not applicable	7	visual control	5	105	Only qualified calibration personnel is nominated for torque wrench adjustment and torque wrenchs are adjusted	1 week	3	2	5	30	Completed	3	2	5	30
7	Painting	Part thickness within tolerances	Part thickness below tolerances	rework	3	work orders do not include paint thickness tolerances therefore operators perform the job based on their experiences visually (acc. To number of layer)	not applicable	7	final quality inspection	7	147	Works order will be updated as including paint thickness tolerances and operators will measure the thickness for each layer	2 months	3	2	5	30	Completed	3	2	5	30
8	Bearing assy	Moving bearing	Non-moving bearing	scrap	7	incorrect load application for installation	qualification of personnel for the process	3	inspection of play with hand	3	63	The pressing load (daN) to be applied will be defined in the work order to prevent the calculation manually by the operator	2 months	7	1	3	21	Completed	7	1	3	21