

SUPPLY CHAIN OPTIMIZATION IN FOSTER GEARS

Submitted in partial fulfillment of the requirements for the award of

Master of Business Administration

by

ANDERSON BLESSWIN. P
39410012



SCHOOL OF BUSINESS ADMINISTRATION

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with Grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
Jeppiaar Nagar, RAJIV GANDHI SALAI, CHENNAI - 600 119

April - 2021



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Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai – 600 119
www.sathyabama.ac.in**

SCHOOL OF BUSINESS ADMINISTRATION

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **ANDERSON BLESSWIN. P (39410012)** who have done the Project work entitled **SUPPLY CHAIN OPTIMIZATION IN FOSTER GEARS** under my supervision from January 2021 to March 2021.

Ms. KAVITHA RAJAYOGAN
Internal Guide

Mr. R. PREMKUMAR DAVID
External Guide

Dr. BHUVANESWARI G.
Dean – School of Business Administration

Submitted for Viva voce Examination held on _____.

Internal Examiner
(Name in Capital letters
With signature)

External Examiner
(Name in Capital letters
With signature)

DECLARATION

I **ANDERSON BLESSWIN.P (39410012)** hereby declare that the Project Report entitled **SUPPLY CHAIN OPTIMISATION IN FOSTER GEARS** done by me under the guidance of **MS. KAVITHA RAJAYOGAN** and **MR. R. PREM KUMAR DAVID** at Foster Gears, SS-14, SIDCO Industrial Estate, Chennai – 600 098 is submitted in partial fulfillment of the requirements for the award of Master of Business Administration degree.

DATE:

PLACE:

SIGNATURE OF THE CANDIDATE

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

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I wish to express my thanks to all Teaching and Non-teaching staff members of the School of Business Administration who were helpful in many ways for the completion of the project.

ANDERSON BLESSWIN. P

Foster Gears

SS-14, Sidco Industrial Estate
Chennai-600 098. ☎ 9176807512

MFRS: All types of gears



CERT. NO: FG20-051128

TO WHOMSOEVER IT MAY CONCERN

This is to certify that Mr. ANDERSON BLESSWIN. P (39410012) of 'SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY' has done his project 'SUPPLY CHAIN OPTIMIZATION IN FOSTER GEARS' at Foster Gears, Ambattur SIDCO from 23.11.2020 to 05.02.2021. His conduct and character during this period is found to be good.

FOSTER GEARS
SS-14, SIDCO INDUSTRIAL ESTATE
CHENNAI - 600 098.

For **FOSTER GEARS**



(R. Premkumar - Manager)

Authorised Signature

LIST OF CONTENTS

S.NO	TITLE	PAGE NO
	Abstract	iv
	List of abbreviations	v
	List of figures	vi
	List of tables	vii
1.	Introduction	
1.1	Company profile	1
1.2	Heritage	1
1.3	Design for Engineering services	2
1.4	Services	3
1.5	Our products	5
1.6	Quality assurance	8
1.7	Case studies	9
1.8	Failure mode and effect analysis	11
1.9	Stages of FMEA	16
1.10	Objectives	18
2	Review of Literature	19
3.	Methodology	
3.1	Elucidation	41
3.2	Problem Description	41
4	Problem Analysis and Interpretation	

4.1	Introduction	43
4.2	Gleason's trident	43
4.3	FMEA Stage Two	46
4.4	Inspection Chart	51
4.5	Interpretation	75
5	Findings, Suggestions & Conclusion	
5.1	Findings	76
5.2	Suggestions	76
5.3	Conclusions	76
	REFERENCES	77
	BIBLIOGRAPHY	81
	APPENDIX	82

ABSTRACT

Machine errors are a significant source of manufacturing defects. Such errors could deviate plans and place innumerable pressures in the supply chain. Therefore, an efficient method is needed to identify and alleviate potential defects in the supply chain. Failure mode and effect analysis is one of the technique used to anticipate, evaluate and resolve potential process and design errors.

Successful supply chains use integrated measurement systems such as these to achieve their organizational objectives. The traditional use of Pareto chart, cause and effect diagram and histogram involves ambiguity with the identification of root causes for the manufacturing errors. Gleason's trident used in the root cause analysis of FMEA reduces this ambiguity by using parameters like machine, material and manpower. Yet the chart process requires the definition of occurrence, severity, detection and risk priority number to complete FMEA. The proposed approach has been used in a company in order to detect the risk factors in production area and eliminate rejections through Failure Mode and effect analysis.

KEYWORDS

Supply Chain, Failure mode and effect analysis (FMEA), Gleason's trident, Severity, Occurrence, Detection and Risk Priority Number (RPN).

LIST OF ABBREVIATIONS

FMEA	Failure Mode and Effect Analysis
PFMEA	Process Failure mode and effect analysis
DFMEA	Design Failure mode and effect analysis
O	Occurrence
S	Severity
D	Detection
RPN	Risk priority number
LGS	Long shafts
HRC	Rockwell hardness value

LIST OF FIGURES

FIGURE NO	DESCRIPTION	PAGE NO
3.1	Process flowchart	40
4.1	Gleason's trident	43
4.2	Digital Rockwell hardness tester	44
4.3	FMEA second stage flowchart	47

LIST OF TABLES

TABLE NO	DESCRIPTION	PAGE NO
1.1	Difference between PFMEA & DFMEA	13
1.2	Tools used in Root cause analysis	16
3.1	Design parameters	41
3.2	Long shaft trials	41
3.3	Rejected trial shafts	42
4.1	Hardness values of ten trial shafts	45
4.2	Results of Gleason's trident	46
4.3	Occurrence table	47
4.4	Severity table	48
4.5	Detection table	49
4.6	FMEA Chart	50
4.7	FMEA Recovery table	50
4.8	Inspection report 1	52
4.9	Inspection report 2	53
4.10	Inspection report 3	54
4.11	Inspection report 4	55
4.12	Inspection report 5	56
4.13	Inspection report 6	57
4.14	Inspection report 7	58
4.15	Inspection report 8	59

4.16	Inspection report 9	60
4.17	Inspection report 10	61
4.18	Inspection report 11	62
4.19	Inspection report 12	63
4.20	Inspection report 13	64
4.21	Inspection report 14	65
4.22	Inspection report 15	66
4.23	Inspection report 16	67
4.24	Inspection report 17	68
4.25	Inspection report 18	69
4.26	Inspection report 19	70
4.27	Inspection report 20	71
4.28	Inspection report 21	72
4.29	Inspection report 22	73
4.30	Inspection report 23	74
4.31	Inspection report 24	75

CHAPTER – 1

INTRODUCTION

The people's quest for manufactured goods has been growing rapidly over the years. Therefore in order to meet up with the high demand and to eliminate errors management have come up with innovative methods to produce goods at a faster rate without any malfunctions. Industries have witnessed numerous changes and evolution with the introduction of many operative tools like lean management, six sigma, kaizen, 5S and failure mode effect analysis etc. From large scale to small scale enterprises, companies are following up these tools in order to achieve a zero PPM. One amidst the medium scale sectors, is Foster Gears.

1.1 COMPANY PROFILE

Foster Gears is a medium scale unit situated in Ambattur Industrial Estate, SIDCO. Founded and built in 1991, the company is engaged in the engineering, design and manufacture of high precision custom solutions. It provides mechanical components, assemblies, gears and motion control solutions to the most recognized names in the medical, aerospace and industrial markets. Foster gears' team members are dedicated to enhancing lives through innovative solutions.

1.2 HERITAGE

Foster Gears brings over 30 years of accumulated experience, expertise, and proven performance to our global network of medical, aerospace and industrial customers and partners. Since we opened up clients in the United States in 1995, we have developed new processes, methods and services to provide the highest precision gears and mechanical components, working directly with our partners to enhance their competitiveness in a global market.

With clients in the U.S., Switzerland, U.K and India, as well as a rich network of worldwide strategic partners, Foster Gears has the global reach and expertise to create custom solutions for the most challenging technological applications. Over multiple generations and across diverse markets, we have focused on maintaining the highest standards of quality and innovation.

Whether it's an airplane landing smoothly, a pacemaker that extends a life, or a hydraulic system that allows a farmer to bring in a crop, our precision technology is

enhancing the lives of people in every corner of the globe. Teamwork is our fuel for exceptional results. It takes hundreds of thinkers, creators, and builders, working seamlessly together to produce the innovative products our clients demand. Our diverse and elite team of degreed engineers, skilled machinists, and exacting support personnel bring a distinctive combination of education, experience, insight, continuous improvement and determination to the Foster Gears team. We are fully invested in our people, and that ongoing investment returns to us in exceptional results.

“The work we do cannot be separated from the people who do it.”

R. Premkumar, Chairman, Foster Gears.

Even small parts can make a big difference. Our work can be found in many of the world’s greatest products. Some help regular people every day, like our micro-machined components found in a range of medical devices. And others help move mankind forward, like our precision gear and actuation systems in space-based telescopes, Mars Explorers and commercial jet applications that allow planes to fly and land safely. These are just a few of the examples of the application of our parts that help inspire our sense of meaning and purpose. That’s what makes us proud to work for Foster Gears.

Enhancing lives through innovative solutions. We crafted a vision for creating possibilities: Thinking. Exploring. Imagining. Solving. Belonging to the Foster Gears team means operating within our specific code of conduct, and owning our set of governing values. Every member of our team pledges to:

- strive for continuous improvement, growth, and development
- cultivate a culture of trust, support, and open communication
- encourage diversity in teamwork, and mutual respect
- exercise our social and environmental responsibility
- engineer, design, and build with creativity and innovation
- Abide by and inspire ethical practices.

1.3 DESIGN ENGINEERING SERVICES

Foster Gears’ engineers are skilled in the design, optimization and validation of your concepts, prototypes and next generation products and systems. We seek new

ways to meet engineering challenges. From initial concept to the final delivered product, our team supports design development throughout the entire process.

From the initial design phase, our long-term customers and partners find it advantageous to include Foster Gears engineers when and where our expertise is critical to the project's success. When our partners consult with us early on in the process, they find they avoid the implications of having to do costly rework down the line.

- Feasibility Studies
- Comprehensive assessment for custom configurations
- Prototypes, validation and optimization
- Tolerance stack-up, backlash, hysteresis, total integrated error
- Life expectancy, speed, torque and duty cycle
- Load values, directions and vibration
- Materials selection, finishes and lubrication
- Surface treatments
- SolidWorks 3D modeling software

1.3.1 Design for Manufacturability

DFM is essential in realizing the transformation of new concepts into mass-produced products and assemblies. Foster Gears focuses on integrated product development, collaborating with and engaging key stakeholders from the project charter stage. We conduct thorough feasibility studies and implement proper quality tools to ensure that product designs are reliable, manufacturable and acceptable to the end user.

1.4 SERVICES

We stand ready to bring expertise and innovation to any part of the world whenever and wherever you need it.

1.4.1 Customer Service

Our manufacturing and customer service sites provide real-time responsiveness to continued customer and market demands; this includes live line requests the same day. Our Customer Service teams are completely integrated with our Engineering and Manufacturing personnel, which allows real-time commercial and technical support.

1.4.2 Program Management

Our Program Management teams are made up of technical staff ready to support and partner with customers from the earliest stages of product development through final project delivery in order to reach optimal solutions. Project Managers use audited, systematic processes and pull from a wealth of diverse production methods in order to meet and exceed your expectations.

1.4.3 Logistics and After Sales

From logistics, transportation and inventory management, our emphasis on quality and precision are evident in our complete after-sales support solutions. Every supply chain, from origination to final delivery, is complex and unique. Foster Gears is able to customize effective solutions that will maximize your investment, generate further sales through additional products or services, secure business relationships in the near and long term, increase customer satisfaction, brand recognition and customer loyalty, differentiate you from your competitors and achieve the best cost-benefit proposition for your organization.

With our global reach, we can move products and ensure their timely delivery anywhere in the world. Our objective is to reduce inventory redundancy, eliminate waste and increase system-wide efficiency to keep your supply chain moving.

1.4.4 Rapid prototyping services

Our dedicated engineers have the comprehensive knowledge of advanced materials and technologies required to take on challenging projects. From micro-engineered complex products to gears and motion control solutions, we work with you to make critical design decisions, size and integrate components from various disciplines, and verify system performance prior to production. With state-of-the-art product development equipment and capabilities, Foster Gears can help you bring your product to market quickly and efficiently. Our prototyping capabilities include:

- Engineering and project management
- Complex functional models
- Prototypes and pre-production parts, using traditional and new additive manufacturing methods
- Small series production

- Miniaturized precision mechanical parts
- Gears and motion control solutions involving motors, actuators, electronics and control software

1.4.5 Instrumentation

Precision gears and components are integral to overall system performance across a variety of industrial applications. Whether it's a gauge to evaluate pressure, laboratory equipment to analyze chemical composition, or down hole and subsea oil exploration instruments, Foster Gears has extensive experience working with numerous industry segments. Precision components include gearboxes, housings and couplings, shafts, needles and miniature pins, gauge clusters, actuator and solenoid components, high security locking pins and customized inserts.

1.4.6 Hydraulics

Foster Gears specializes in high precision hydraulic valves and related componentry including pilot pins, plungers, poppets, cages, spools, pins, armatures, shafts, seats, ports and sensor housings.

1.5 OUR PRODUCTS

1.5.1 Precision gears

From prototype through high volume production, Foster Gears designs and manufactures a full range of high precision custom gears and precision gearboxes for critical medical, aerospace and industrial applications. With design engineering and manufacturing teams working together under one roof, we are sure to provide you with an optimal solution that is designed for manufacturability. Our precision gears typically range in size from 6mm (.24") to 102mm (4"). Foster Gears designs, engineers, validates and optimizes custom solutions to meet the most challenging program requirements. Our high precision gears and custom gearbox solutions meet quality standards up to AGMA Q12 or AGMA 2015/ISO 5 specifications.

Prototyping: Foster Gears maintains a dedicated prototyping center with EDM capability that allows us to support our customers requiring quick turn proofs of concept

Gear Cutting: CNC and manual Gleason Pfauter, Fellows, Mikron & Barber Coleman machines for shaping and hobbing

Gleason Bevel Gear Cutting: Dedicated Gleason bevel gear cutting area

Grinding: Studer CNC and manual, Tschudin OD & ID grinders

Full complementary capability: CNC milling, large and small diameter CNC turning (multi-axis), lathe, mill and drill

1.5.2 Custom made gear boxes

Foster Gears' speed increasing and decreasing planetary systems, right angle and spur gearboxes can be found in critical applications from avionics to surgical robotics. Our design engineers customize configurations for optimal performance over the life of a program for accurate, repeatable results

1.5.2.1 Design engineering support

- Comprehensive assessment and feasibility studies
- Reviews of tolerance stack-up, backlash, hysteresis, total integrated error
- Life expectancy, speed, torque and duty cycle
- Load values, directions and vibration
- Types: Speed increasing and decreasing planetary systems, Right Angle gearboxes, Spur gearboxes

1.5.3 Electro mechanical assemblies

Foster Gears has earned trusted advisor status with the most recognized names in the medical, aerospace and industrial markets when it comes to motion control systems. Our engineers work side by side with OEMs, as an extension of their development teams to engineer custom gear trains and electromechanical assemblies over many generations of a product platform.

1.5.4 Custom made mechanical components

1.5.4.1 Swiss turning

Our custom components are found in critical applications from airbag deployment systems to implantable medical device components. Due to quick production times and consistent production methods, Swiss screw machines can produce a large number of small, tight tolerance precision parts relatively quickly in a cost effective manner. Our precision turned parts typically range in diameter from 0.3mm (.0118") to 32mm (1.25") with tolerances less than 10µm (0.0004").

1.5.4.2 Micro manufacturing

Think big. Engineer small. From miniature connectors to implantable medical device components, Foster Gears' legacy and continued expertise lie in the production of precision miniature parts and micro components with features measured in microns.

1.5.4.3 CNC Milling

Foster Gears provides high precision milled parts for critical applications in the medical, aerospace and industrial markets. We excel at geometrically complex components requiring very tight tolerances. All secondary operations are managed by us so that we may provide parts complete, thereby simplifying your supply chain.

1.5.4.4 Precious metal components

Foster Gears is a leader in the precious metal machining of high precision micro parts for the medical market. Custom components found in class I, II and III medical devices include electrodes, contacts, marker bands and catheter tips. Precious metal components typically range in diameter from .01mm (0.00039") to 16mm (0.63").

1.5.4.5 Technical ceramics

With a specialty in miniaturization, Foster Gears injection molds, presses, machines and shapes a range of ceramic materials for custom applications that are ideally suited to this medium. Whether it's a geometrically challenging component that requires specific mechanical, electrical and thermal properties, or it is a quick turn prototype for proof of concept and design evaluation, we engineer ceramic solutions to meet the most challenging specifications. Parts typically range in size from 0.3mm (.0118") up to larger shapes of 30mm (1.18") with tolerances less than 5 -10µm (0.0002" - 0.0004").

1.5.4.6 Metal Injection Molding

Metal Injection Molding is a practical alternative to traditional production processes such as machining, press sintering and lost-wax casting.

1.5.4.7 Micro 3D Printing

Whether it is for a quick turn prototype or a geometrically complex component that can't be machined, Foster Gears employs various types of proprietary high precision additive manufacturing technologies for sintered metals as well as ceramics.

1.6 QUALITY ASSURANCE

Our strict adherence to the most demanding quality and safety management systems standards ensure effective performance of our processes and systems. We use statistical methods along with numerous quality-related processes and procedures to assure the integrity of the gears, components, assemblies and systems we supply. Our manufacturing facilities have been registered to various industry and environmental standards by independent accrediting firms.

1.6.1 Continuous Improvement

Quality, compliance and continuous improvement are at the heart of Foster Gears' philosophy. Our dedicated, management-led Continuous Improvement Department employs a range of techniques and philosophies to achieve incremental, constant and repeatable improvements. Collectively, they define what quality means to Foster Gears: efficiency, effectiveness and adaptability to our business partners' needs. At Foster Gears, we've worked hard to implement a culture of continuous improvement with the end goal of achieving superior performance and on-time delivery of products and services within budget.

Focused on remaining the best at what we do, our Continuous Improvement teams conduct quarterly Kaizen events and utilize Advanced Product Quality Planning (APQP) for continuous improvement.

Additional quality management techniques include:

- Production Part Approval Process (PPAP)
- Failure Mode and Effect Analysis (FMEA, DFMEA, PFMEA, SFMEA)
- Statistical Process Control (SPC)
- Quarterly Kaizen Events
- 5 S Workplace Organization
- Value Stream (Process) Mapping/Thought Process Map
- Quality Function Deployment (QFD)
- Measure System Analysis (MSA)
- Pareto Analysis
- Spaghetti Diagrams
- Emphasized Demand Flow Technology Through Production and Vendor

- Kan Ban (visual and electronic)
- Point-of-Use (POU) for Tooling and Consumables
- Advanced Validation and Inspection

Foster Gears is equipped with the tools, systems and process controls to respond to rising market pressures and the increasing sophistication and complexity of our customers' products and systems.

From our manufacturing systems and validation processes through to final inspection, customers can count on us for the consistent delivery of the highest quality precision components, gears and assemblies. Foster Gears employs a wide range of tools to improve quality of delivery, from corrective and preventive action plans, to root cause analysis. Further, we are continually investing in new technologies to improve quality, cost and lead time, technologies such as our OGP Vision System for measurement validation, and the PECO CNC gear measurement system.

1.6.2 Quality certifications

Our quality related processes and procedures not only assure the integrity of the components we produce, but have facilitated our designation as a certified supplier to major OEMs.

Our facilities and state of the art machining centers are audited to the strictest compliance standards, including ISO 9001 and ISO 13485, AS9100, ITAR, and C-TPAT.

1.7 CASE STUDIES

1.7.1 Foster gears and Hydraulics

Repeatability and reliability are critical elements in the performance of a hydraulic valve. In a cartridge valve application, Foster Gears worked with a market leader in hydraulic solutions to refine a critical part used to guide a poppet. Because of the complexity and working parameters of the valve, all of the internal parts: poppets, spools, plungers and guides, have to be precise with tolerances well below 0.0005" (10 times less than the size of a human hair). Given our integrated manufacturing capability, we already have a vertical process that internally controls all aspects of production typical of valve parts: machining, heat treating, grinding, honing and surface processing. For this part, we were able to adopt an important honing step to consistently

hold a tolerance less than 0.0001" (.0025 mm). This eliminated any residual valve leakage, and significantly improved the valve's performance.

1.7.3 Industrial

As the number of options for fabricating precision micro parts grows -- from precision turning and multi-axis machining, to ceramic and metal injection molding and precision stamping -- innovation in manufacturing technologies offers the opportunity to re-evaluate traditional manufacturing processes. For example, a Foster Gears customer for industrial printing and coding technologies requested our help with a precision component that consisted of three machined and sub-assembled parts. From the outset, we considered ways of re-designing the three machined parts into one single component using alternative fabrication methods that are more practical and economical, hence saving cost in manufacturing while reducing the number of components and steps in the process chain. For us, like many in the Swiss precision manufacturing community, it's the kind of thinking and approach to problem-solving we apply every day.

1.7.4 Ophthalmology

The challenge of minimally invasive surgical instrumentation is met head on by Foster Gears engineers who specialize in the micro machining of small-scale instruments and components. Our team was able to assist one major medical OEM, for example, with the design concept, prototyping and production release of an ophthalmological instrument used to remove and deploy lenses in glaucoma and cataract procedures. Even in its "small form envelope" Foster Gears was able to minimize the insertion force of a surgical needle via significantly reduced wall thickness (i.e. <0.004") and taper angles. Offering the OEM options for multiple titanium material grades as well as needle features: angles, thickness, surface treatments, the new optimized design not only eliminated a multi-part assembly, but significantly improved performance, resulting in the successful launch of a new product platform.

1.7.5 Aerospace

The Embraer Legacy 500 is the first full fly-by-wire midsize business jet. Foster Gears' engineering team worked with the system integrator on the design and integration of the flight control actuation system, designing an angled bevel gearbox

that drives the business jet's wing flaps. It was a challenge for the system integrator to design an electromechanical actuator for the wing flaps versus the typical hydraulic actuated design, but Foster Gears was able to provide guidance on the angled bevel gearbox design including the choice of bevel type, advanced material selection for weight performance optimization, backlash and overall lifecycle testing and analysis. Foster Gears manufactures the four gearboxes that drive the flaperon and control actuation system on the Embraer Legacy 500 aircraft which made its first flight in November 2012.

1.8 FAILURE MODE AND EFFECT ANALYSIS

1.8.1 Introduction:

Failure Modes and Effects Analysis (FMEA) is methodology for analyzing potential reliability problems early in the development cycle where it is easier to take actions to overcome these issues, thereby enhancing reliability through design. FMEA is used to identify potential failure modes, determine their effect on the operation of the product, and identify actions to mitigate the failures. A crucial step is anticipating what might go wrong with a product. While anticipating every failure mode is not possible, the development team should formulate as extensive a list of potential failure modes as possible.

The early and consistent use of FMEAs in the design process allows the engineer to design out failures and produce reliable, safe, and customer pleasing products. FMEAs also capture historical information for use in future product improvement.

1.8.2 When should we use FMEA?

Ideally, you should begin using FMEA during the earliest conceptual design stages of a process or product, and then through the design or redesign process.

Alternatively, you can try using this approach in these cases:

- Before you develop control plans for a new or modified process, and for control before and during ongoing processes.
- When you plan to apply an existing process or product in a new way.
- When you want to improve the quality of an existing process or product.

- For optimal results, you should always examine and improve quality and reliability throughout the life of the process or product.

1.8.3 DFMEA

Design failure mode and effect analysis (DFMEA) is a systematic group of activities used to recognize and evaluate potential systems, products or process failures. DFMEA identifies the effects and outcomes of these failures or actions. It eliminates or mitigates the failures and provides a written history of the work performed. DFMEA helps engineers detect failures at the earliest possible moment so they can be corrected early, without significant cost. It is especially useful for disciplines in which risk reduction and failure prevention are crucial, including:

- Manufacturing
- Software
- Business processes
- Healthcare
- Service industries
- Regulated industries

1.8.4 PFMEA

Process failure modes effect and analysis. PFMEA is a methodical approach used for identifying risks on process changes. The Process FMEA initially identifies process functions, failure modes their effects on the process. If there are design inputs, or special characteristics, the effect on end user is also included. The severity ranking or danger of the effect is determined for each effect of failure. Then, causes and their mechanisms of the failure mode are identified. The assumption that the design is adequate keeps the focus on the process. A high probability of a cause drives actions to prevent or reduce the impact of the cause on the failure mode. The detection ranking determines the ability of specific tests to confirm the failure mode / causes are eliminated. The PFMEA also tracks improvements through Risk Priority Number (RPN) reductions. By comparing the before and after RPN, a history of improvement and risk mitigation can be chronicled.

There are difference between DFMEA and PFMEA, both are important in their ways and are used for specific reasons. Their differences are tabulated below in table

Table 1.1 Difference between DFMEA and PFMEA

Design FMEA	Process FMEA
Used for design risk analysis when designing a new product	Used for risk analysis in a process by analyzing the risk at each step of that process
It primarily talks about how a product can fail into serve its purpose.	It primarily talks about how a process could fail to produce the desired output.
Technical specifications is a pre-requisite for design FMEA	Process map or a process flow diagram is a pre-requisite for PFMEA.
It can be done at a system sub-system and a component level.	It is done at a process level.
High risk items from DFMEA could result in both design and process changes.	High risk items from PFMEA usually results in process changes
Key characteristics is the output.	Key characteristics is an input.

1.8.5 Benefits of FMEA

FMEA is designed to assist the engineer improve the quality and reliability of design. Properly used the FMEA provides the engineer several benefits. Among others, these benefits include:

- Improve product/process reliability and quality
- Increase customer satisfaction
- Early identification and elimination of potential product/process failure modes
- Prioritize product/process deficiencies
- Capture engineering/organization knowledge
- Emphasizes problem prevention
- Documents risk and actions taken to reduce risk
- Provide focus for improved testing and development
- Minimizes late changes and associated cost
- Catalyst for teamwork and idea exchange between functions

1.8.6 FMEA definitions to get you started

Use FMEA as a risk assessment tool to evaluate the severity, occurrence and detection of risks so you can prioritize the most urgent ones. Read on to learn what each term means. It will be most desirable to eliminate all failures and causes. However for practical considerations based on a ranking system. Each category has a scoring matrix with a scale from 1 to 10. The ranking is based on the probability of

- Occurrence
- Severity
- Detection

1.8.6.1 Severity number (S)

Severity is an estimate of the effect on the user. Severity is the factor that represents the seriousness of the failure to the customer after it has occurred. Severity numbers are ranked 1–10. Each assignable cause must be addressed and the probability of detection rated. Unlikely failures or low risks to the end customer are rated as 1, whereas 10 means a high likelihood of failure or high risk.

1.8.6.2 Probability of occurrence (O)

The probability of occurrence is how often this failure or problem happens. These are also ranked 1–10, so a failure happening every 3rd time a machine turns on could be rated a 10, while a failure happening every 500,000 times a machine turns on could be a 1 or 2. Once controls intended to prevent the cause of failure from occurring should be considered in this estimate

1.8.6.3 Likelihood of detection (D)

The likelihood of detection, also ranked 1–10, shows whether or not you have systems in place to detect the failure. Apply a scale of one to ten which will enable probability of detection to be rated. If you get an alert the second a failure happens, mark it as a 1, but if you never get alerts and instead find out on your own, rank it as a 10.

1.8.6.4 Risk Priority Number (RPN)

Risk priority number is a measure of design risk. Your Risk Priority Number is a combination of the above three. To get your RPN, multiply severity number by

probability of occurrence by likelihood of detection: $RPN = S \times O \times D$. Higher the 'RPN' the team must undertake efforts to reduce the risk

1.8.6.5 Failure

It means a component or a system or a process not functioning to the design intent. The parameters of design intent may be stated in life time cycles, load linear dimensions, tolerances coating thickness speed, force, torque, surface finish etc. It may also include static occurrences as sharp edges to glossy a finish.

1.8.6.6 Potential failure mode

It is the manner in which a component, system or a process failure occurs. It is also defined as a manner in which the part does not meet the design intent. Failure mode is the answer to the question 'How could the component, system or the process fail?', 'what could possibly go wrong with the process?', 'how can the part fail to meet the specification?' and 'how could the process fail to complete its intended function?'.

1.8.6.7 Effects of failure

Some of the questions that will highlight the effects of failure are 'Will be visually acceptable?', 'will it fail to fit a mating part?', 'Could it lead to failure early in service life?', 'will it affect the function of a related assembly?', 'Will it cause high/low operating effects?'

1.8.6.8 Recommended corrective action

An improvement part of the program, without which success will not be achieved is to establish specific corrective actions and assign responsibilities and timing.

- First type of action – Design change of components
- Second type of action – Process change
- Last type of action – Increase quality control inspection.

1.8.6.9 Corrective action

Corrective action is defined as the steps post failure mode and effect analysis. Its main aim is to eliminate the cause of failure, design changes can be made to a part to achieve this. And it also aims to reduce the probability that the cause of failure will result in the failure mode. Apart from that the severity of the failure should be reduced. This might be accomplished through redesign and to produce a fail safe mode, redundancy etc.

1.9 STAGES IN FMEA

There are two stages in FMEA

- Root cause analysis
- Chart process

1.9.1 Root cause analysis

It is also called as a brain-storming session where all the possible factors which are responsible for the rejection of the design or the process are discussed by the quality team in a company. The tools used in the root cause analysis are check sheet, pareto diagram, cause and effect diagram, P chart, C chart and Gleason's trident.

Table 1.2 Tools used in Root cause analysis

TOOLS	PURPOSE
Check sheet	Ease of completion Simplification of analysis
Pareto Diagram	Determine top problems, 80/20 rule Important few trivial Prioritization
Cause and effect diagram	Obtains potential causes Display possible causes Helps avoid oversights Structure for brainstorm
P and C Chart	Asses process stability and improvement Vital tool State of control Careful interpretation
Gleason's trident	Deals with three types of parameters like Machine, Manpower and Material Deals mostly with problem in mechanical company.

	It is time efficient compared to other tools in root cause analysis. It doesn't need any application, but it is applicable only for any anomalies in any small scale
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1.9.2 Steps to do a FMEA

STEP 1: Review the process

- Use a process flowchart to identify each process component.
- List each process component in the FMEA table.
- If it starts feeling like the scope is too big, it probably is. This is a good time to break the Process Failure Mode and Effects Analysis into more manageable chunks.

STEP 2: Brainstorm potential failure modes

- Review existing documentation and data for clues about all of the ways each component can failure.
- The list should be exhaustive – it can be paired down and items can be combined after this initial list is generated.
- There will likely be several potential failures for each component.
- Name them accordingly.
- Use any of the tools in root cause analysis to brainstorm the possible causes for rejections.

STEP 3: List potential effects of each failure

- The effect is the impact the failure has on the end product or on subsequent steps in the process.
- There will likely be more than one effect for each failure.

STEP 4: Assign Severity rankings

- Based on the severity of the consequences of failure.
- For each and every part or a machine there will be separate listings in the severity scales.

STEP 5: Assign Occurrence rankings

- Rate the severity of each effect using customized ranking scales as a guide.
- It is usually ranked according to the number of failure occurrences in the given orders

STEP 6: Assign Detection rankings

- What are the chances the failure will be detected prior to it occurring.

STEP 7: Calculate the RPN

- Severity X Occurrence X Detection

STEP 8: Develop the action plan

- Decide which failures will be worked on based on the Risk Priority Numbers. Focus on the highest RPNs.
- Define who will do what by when.
- Depending on the RPN values there will be separate action plans.

STEP 9: Take action

- Implement the improvements identified by your Process Failure Mode and Effects Analysis team.

STEP 10: Calculate the resulting RPN

Re-evaluate each of the potential failures once improvements have been made and determine the impact of the improvements.

1.10 OBJECTIVES OF THE PROJECT

(i) To draw Gleason's trident diagram for the problem and to elevate the analysis towards FMEA Chart

(ii) To derive Failure Mode Effect Analysis (FMEA) for the root cause.

- To find out occurrence, severity and detection values of the dugout error.
- To find out the RPN and to take the necessary actions.

(iii) To perform Production Inter – Inspection (PII) for the inspection procedure.

- To inspect each and every long shaft at regular intervals

(iv) To summarize the overall inspection report.

CHAPTER – 2

REVIEW OF LITERATURE

Jianxin Xu (2021), this paper deals with Supply chain risk management (SCRM). In this paper, three steps has been expressed, the first part, framework for risks analyzing in supply chains, and second, on building resilient supply chains, and some advices on how to build up resilient supply chains, has been expressed. In the third part, we provided Ericsson as a case to support our views. So, managing supply chain disruptions revolves around two goals: first, to thoroughly understand the potential of identified risks; and second, to increase the capacity of the supply chain — within reasonable limits— to sustain and absorb disruption without serious impact, a reality that creates greater demands on companies to keep supply chains flexible and integrate disruption risk management into every facet of supply chain operations.

Garikai Mlambo, Dr. Vusumuzi Sibanda (2021), the purpose of this study was to analyze the impact of supply chain management (SCM) on the competitiveness of the telecommunications industry in Zimbabwe. The objectives of the study were to figure out the extent to which SCM contributes to organizational competitive advantage in the telecommunications industry in Zimbabwe, to determine the level of bargaining power when making local and off shore purchases, the extent of risk exposure due to global transactions and finally, to ascertain the strategies used on supplier ratings. Interviews and questionnaires were used as the main instruments for data collection.

Sukanta Sen1, Md Akramuzzaman Shaikh (2021), in this paper, an effort has been taken to examine the efficiency of Chittagong Port and the causal factors of inefficiency. The impact of inefficiency at Chittagong port on the supply chain of Bangladesh has also been identified. To do this, at first a relationship has been built between port efficiency and supply chain in respect of Bangladesh. Relevant data has been gathered through extensive review of the literature, field surveys, interacting with top management of different business entities such as shipping agency, freight forwarder, logistics companies, exporter, importer as well as Government regulatory. The study has revealed that the inefficiency at Chittagong port causes serious consequences on the supply chain of exporter and importer and lead to loss and disruption of trade and ultimately incur extra costs and time. This paper, therefore,

recommends a substantial infrastructure improvement to Chittagong port along with other related measures in order to facilitate the supply chain of exporter and importer.

Kevin Kmenta, Brent Cheldelin (2021), this paper describes the Assembly FMEA procedure and illustrates its use on a conceptual design and on an existing product. “Assembly FMEA” is a novel technique developed specifically to identify manual assembly errors. Assembly defect levels are related to assembly complexity, which can be estimated using “Design for Assembly” (DFA) time penalties. Hence, Assembly FMEA uses a series of DFA-related questions to elicit potential assembly defects. The questions help to focus, standardize, and expedite the FMEA process. Assembly FMEA quickly identifies a large number of assembly errors with significantly less effort than conventional FMEA. However, performing FMEA is widely considered to be tedious and time-consuming, and not always worth the effort. In response, many researchers have attempted to automate FMEA using Artificial Intelligence (AI) to make it less arduous. Unfortunately, automated techniques are limited to systems with predictable behaviors (e.g., electronic circuits) and are rarely used on unpredictable processes such as manual assembly.

Seung J. Rhee (2021), a case study of a large scale particle accelerator shows the advantages of the proposed approach in predicting life cycle failure cost, measuring risk and planning preventive, scheduled maintenance and ultimately improving up-time. Failure Mode and Effect Analysis (FMEA) is a design tool that helps designers identify risks. The traditional FMEA involves ambiguity with the definition of risk priority number: the product of occurrence, detection difficulty, and severity subjectively measured in a 1 to 10 range. Life-cost Based FMEA alleviates this ambiguity by using the estimated cost of failures. Yet, the methods still relies on judgment of experts in determining variables such as frequency, detection time, fixing time, delay time, and parts cost. To resolve this subjectivity, this paper proposes a systematic use of empirical data for applying life-cost-based FMEA.

Elizabeth Scarlett, Marvin Zaluski (2021), the paper presents the developed methodology for FMEA validation and experimental results for fault identification. The results show that the updated FMEA can provide more reliable and accurate

information that could benefit the decision-making process and improve maintenance efficiency. The paper then shows how the validated FMEA can be used with data mining for fault detection and identification of root contributing component for a given failure mode or failure effect. This paper argues that historical maintenance and operational data could be used to help address this problem. Building on data mining and database techniques, the paper introduces a FMEA validation and updating technique. The proposed technique derives statistics from real world historical operation and maintenance data and uses these statistics to update key FMEA parameters such as Failure Rate and Failure Mode Probability.

Rajesh kumar, Shiena Shekhar (2020), in this study Multi-Criteria Decision Making (MCDM) tools like Interpretive Structural Modeling and MICMAC analysis have been used. The state of Chhattisgarh in India has a very large number of steel plants causing pollution in the region. The effect of this pollution exceeds the geographical territory of a unit, and goes much beyond it, so it becomes essential to find the reasons for the pollution and the enablers for the green supply chain management, which in turn will help in providing a cleaner environment. The methods available for Multi-Criteria Decision Making (MCDM) were studied, and Interpretive Structural Modeling (ISM), first proposed by J.N. Warfield in 1973, was found to be simple and easy to understand and use, which makes it a favorite amongst its users. Thus, ISM has been used to understand and analyze complex socio-economic systems, making it an important tool for structuring directly related elements into a comprehensive structuring model.

Ryan L. Skiver (2020), the aim of this study is to answer four specific research questions: 1) what are the reasons for going global in today's economy? 2) How can a global supply chain lead to increased innovation? 3) What are the specific ways that companies can gain product and process innovation in a global supply chain? 4) What is a model that can be examined for future research? This literature review examines areas of human resource management and supply chain management through the theory of absorptive capacity in a rapidly expanding global environment. In addressing the four main questions, this review will present emerging research issues for global supply chains. While successful performance in terms of cost savings for firms expanding beyond their home boundaries has been well noted in the literature.

Bryony Dean Franklin, Nick Barber (2020), the aim of this study was to explore the validity of FMEA outputs within a hospital setting in the United Kingdom. Failure Mode and Effects Analysis (FMEA) is a prospective risk assessment tool that has been widely used within the aerospace and automotive industries and has been utilized within healthcare since the early 1990s. Two multidisciplinary teams each conducted an FMEA for the use of vancomycin and gentamicin. Four different validity tests were conducted

- Face validity: by comparing the FMEA participants' mapped processes with observational work.
- Content validity: by presenting the FMEA findings to other healthcare professionals.
- Criterion validity: by comparing the FMEA findings with data reported on the trust's incident report database.
- Construct validity: by exploring the relevant mathematical theories involved in calculating the FMEA risk priority number.

Zobia Rehman, Farhana Jabeen (2020), In this piece of research, we have presented an approach to populate Failure Mode and Effect Analysis (FMEA) ontology from existing worksheets prepared by experts. FMEA is a commonly used method for risk assessment in any organization. This method is initiated by domain experts who analyze all the associated risks to a product or process, their causes, severity, effects and mitigation actions. Besides domain experts, time and cost are the other two factors involved in successful completion of FMEA. Reusability of the knowledge produced at the end of this method can bring numerous benefits to an organization. Major contribution of this work is to identify an existing FMEA ontology and its evaluation for schema and relationship richness, then its automatic population using proposed algorithm without human intervention, and finally making it a part of complete knowledge management system. Our proposed algorithm correctly mapped 1357 instances to FMEA ontology from manually prepared FMEA spreadsheets. This FMEA ontology has been queried by domain experts and it was proved to be very helpful in experts like decision-making.

Pedro A. Gracia, Luis Perez (2020), This document aims to reveal a novel integrated method, where Failure Mode and Effect Analysis, Pythagorean Fuzzy Sets and Dimensional Analysis are cohesive into a model that minimize the uncertainty of the ranking and prioritization over the Failure Mode and Effect Analysis execution, helping to identify risks within an accurate grade over possible failures in the Product Design process. A real practical example is used to show the proposed method, where it is identified a robust methodology integration and solid and results using a sensitivity analysis. Product Design is getting nowadays new challenges on developing new products, since the industry is in a rush to introduce products into the marketplace, where customers demand products faster, cheaper, and free of failures. In the meantime, global companies are always trying to improve their Product Design process to get advantages over their competitors using proven tools like FEMA and mixing methodologies like Fuzzy theories with FMEA. Even today using all this tools and combination of methodologies there is a gap to address and it is required a robust risk analysis solving current issues in the electronic industry.

Sung Ho Park, Yeelyong Noh (2020), This study proposes a fuzzy-based FMEA (failure mode and effect analysis) for a hybrid molten carbonate fuel cell and gas turbine system for liquefied hydrogen tankers. An FMEA-based regulatory framework is adopted to analyze the non-conventional propulsion system and to understand the risk picture of the system. Since the participants of the FMEA rely on their subjective and qualitative experiences, the conventional FMEA used for identifying failures that affect system performance inevitably involves inherent uncertainties. A fuzzy-based FMEA is introduced to express such uncertainties appropriately and to provide flexible access to a risk picture for a new system using fuzzy modeling. The hybrid system has 35 components and has 70 potential failure modes, respectively. Significant failure modes occur in the fuel cell stack and rotary machine. The fuzzy risk priority number is used to validate the crisp risk priority number in the FMEA.

Mandela Govinda Raj, Jakku Balaraju (2020), this study focused on the Root Cause Analysis (RCA) of underground mining machinery such as Load-Haul-Dumper (LHD). 16 potential risks of various sub-system breakdowns were identified in Fuzzy FMEA. The highest value of RPN 168 (for potential failure mode-F9) was obtained for

the electrical subsystem (SSE), as was the highest FRPN 117 (F9). There is a difference between the RPN and FRPN values. The FRPN value is obtained from Fuzzy field generation with consideration of the degree of importance of the given input data. In addition, the recommendations were made based on the analysis to reduce the uneven occurrence of failures. Improvement of productivity has become an important goal for mining industries in order to meet the expected targets of production and increased price competitiveness. Productivity can be improved in different ways. The effective utilization of men and machinery is one such way. Equipment is prone to numerous unexpected potential failures during its operation. Failure Mode and Effect Analysis (FMEA) is one of the suitable techniques of reliability modeling used to investigate the failure behavior of a complex system.

Davin Sigmund, Martin Octavianus Astardi (2020), This study demonstrated that root cause and FMEA, based on an orthogonal classification scheme, can be applied to derive feasible solutions for reducing vehicle safety recalls, and such analysis can be generalized to other products or manufacturing processes. The defect types were classified into manufacturing defects, design flaws, and mis labelling. Each of the above categories was expanded into smaller subcategories and items. Following the root cause analysis, the functional block diagram, and failure modes and effects analysis (FMEA) were applied to translate defective recall cases into FMEA tabular statements. Cramer's V and Phi coefficient analyses were applied to identify significant associations between defective components and defect types to prevent the future recurrence of recalls and improve vehicle quality.

Yuntian Ge , Lin Li , Lingxiang Yun (2020), this paper is used to demonstrate the effectiveness of the proposed model. It is manifested that the model can select appropriate conversion pathways for bio refineries given the abundance of local resources to minimize the overall cost. Compared to the two cases adopted a single conversion pathway, the optimal result achieves 14.6% and 4.6% reductions on the unit biofuel cost, respectively. In addition, the results of sensitivity analysis indicate that the bio refinery construction cost and the biofuel throughput are the main economic drivers in the current supply chain design. Cellulosic biofuel is considered a promising alternative to traditional fossil fuels. Currently, the commercialization of cellulosic

biofuel is proceeding at a slower pace than expected due to the high cost of the cellulosic biofuel supply chain (CBSC), especially in the manufacturing process. In this paper, a new model for a four-echelon CBSC incorporating 12 conversion pathways is proposed to minimize total supply chain cost by considering multiple time periods, various biomass types and spatial distributions, biomass and biofuel inventories, logistics, and different demand levels.

Bohong Wang, Yee Van Fan, Hon Huin Chin (2019), the aim of this study is to develop a novel framework for the optimization of downstream oil supply chains with emission-cost nexus and performance analysis. A P-graph based model has been developed to support the decisions of the distribution plan in the supply chain. This created the possibility to consider constraints, including the material balance, the sending capacity of refineries and storage depots, and the transport capacity of railways, barges and pipelines. Three scenarios, covering standard conditions, pipeline disruption, and demand increase, are analyzed. The proposed novel method supports the decision-making of downstream oil supply chains and provides insight into the reduction of environmental influences. The results reveal that priority should be given to measures for reducing NO_x emission (both Greenhouse and dangerous pollution gas) and the emission factors of barge transport, as this can bring great environmental benefit. When NO_x emission for railways and barges is reduced by 5%, 1,435 kCNY/month could be saved. If the emission of the barges is reduced by 5%, this can save 1,289 kCNY/month of environmental cost. The proposed method is handy for analysis under non-standard conditions, such as transport facility disruption and demand increase. It would help in the design a distribution plan from a more comprehensive view, and to provide further direction for reducing the environmental footprint.

Rajiv Kumar Sharma, Pooja Sharma (2019), the main research intent of this paper is to introduce the use of fault tree analysis (FTA) and failure mode and effects analysis (FMEA) in conjunction to analyze the risk and reliability of a complex mechatronic system in both qualitative and quantitative manner. The major focus is on handling imprecise and vague information with the help of fuzzy synthesis of information. A complex mechatronic system, i.e. modular automated production system

(MAPS), composed of mechanical, electronic, and embedded software subsystems is considered to study the reliability aspects using hybrid FTA. From the results, it is found that the proposed approach models both subjective issues such as human errors along with hardware failures. The in-depth analysis and prioritizing of failure modes using a risk ranking approach based on fuzzy inference system and grey relation approach not only integrate expert judgment, experience, and expertise in more flexible and realistic manner, but also address the limitations associated with traditional procedure of FMEA.

Jae Wook Ko (2019), In this study, a method is proposed for prioritizing safety standard priorities on the basis of minimal cut sets. In addition, safety standards obtained through fault tree analysis are applied to the breakdown modes and accident cause removal methods of failure mode and effects analysis to develop a validity verification method for safety standard sets. The developed method was applied to a gas-boiler exhaust system as a case study, and the validity of the safety standard sets and improvements in the safety standards were verified on the basis of the established safety standard priorities. Scientific and technological advances have yielded a plethora of benefits, but the associated risks have increased as well. Although numerous safety standards have been established for various applications, these standards have not been adequately verified.

Stefan Iglauer, Amir H. Mohammadi (2019), this paper deals with fish-bone diagram of economic and productivity evaluation of different horizontal drilling scenario. Development of high-density oil and gas fields presents a great challenge to the energy industry due to the low productivity of individual wells and their high drilling cost. We thus compared the productivity, associated costs and economical revenues gained from two field development scenarios, with multilateral and horizontal drilling, to evaluate the optimal drilling and completion conditions in a giant heavy oil reservoir in the Middle East. Well path design was identified as one of the most complex parameters depending on the well-testing results, field production and reservoir simulation data. The fishbone well of four branches with a length of 300 m each and 30° deviation from the main hole was identified to be drilled and completed using open-hole sidetrack as the best approach. The fishbone structure raised production by 393%,

while drilling cost only increased by 130% compared with a conventional horizontal well.

Ádám Budai and Gábor Bohács (2019), this article explores the multiple platoon collaboration. For the reconfiguration of two platoons a heuristic and a reinforcement learning (RL) based models have been developed. To our knowledge, this work is the first attempt to apply an RL-based decision model to solve the problem of controlling platoon cooperation. Vehicle exchange between platoons is provided by a virtual hub. Depending on the various input parameters, the efficiency of the model was examined through numerical examples in terms of the target function based on the transportation cost. Models using platoon reconfiguration are also compared to the cases where no vehicle exchange is implemented. We have found that a reinforcement learning based model provides a more efficient solution for high incoming vehicle numbers and low dispatch interval, although for low vehicle numbers heuristics model performs better. Physical Internet based supply chains create open, global logistics systems that enable new types of collaboration among participants. The open system allows the logistical examination of vehicle technology innovations such as the platooning concept.

Oskari Lähdeaho, Olli-Pekka Hilmola (2019), This research aims to shed light on the environmental sustainability of companies involved in maritime logistics at the major Finnish seaport, HaminaKotka. This seaport is a part of International Maritime Organization's (IMO) Baltic and North Sea emission control area, with special emission-reducing measures contributing directly to United Nations' Sustainable Development Goals (SDGs) by mitigating negative impacts of industrial activity on environment and climate change. Two semi-structured interviews with companies at HaminaKotka were carried out to construct a case study examining the sustainability challenges at hand. In addition, experience of one of the authors in a managerial position at the studied seaport complex, as well as the sustainability communications of the companies situated in the area were used to support the findings. The companies improve environmental sustainability by using multimodal transport chains, alternative fuels in the transports, and environmental sustainability demands towards their partners. However, the most important measures, according to these companies, are transport

mode selection and cargo load optimization. Moreover, companies have identified bottlenecks of cargo flow at the hinterland due to road infrastructure constraints. As regulations and customers are requiring environmental sustainability, companies are forced to renew their operations, strategy and business models. Especially, the emission-reducing regulations drive companies to implement means to control the produced emissions.

Kyimo Tanno, Seiji Bito (2019), this study aimed to elucidate patient factors affecting regret using the Japanese version of the Decision Regret Scale (DRS). To ensure that patients continue treatment, it is essential that the patient is satisfied with the decision-making process of the treatment. One way to address this is to assess the healthcare quality using the concept of regret, which can measure “Being convinced in decision-making.” A questionnaire survey was conducted with 197 patients with uterine myoma, ovarian tumors, and endometriosis. We then examined the relationship between the Japanese DRS, the Japanese SF-8 as a health related quality of life (QOL), and patient factors using latent class analysis and path analysis through a multi-group comparison. Our results suggest that it is necessary to present treatment methods with consideration to patients’ backgrounds and to obtain informed consent from patients.

Amanda Sofiana, Cucuk Nur Rosyidi (2019), the aim of this paper is to develop an optimization model for quality improvement by considering quality investment in rework policies and supply chain profit sharing. To improve product’s quality, the decision of process target and its tolerance is important since it directly affects the defective rate, manufacturing cost, and loss to customer due to the deviation of product from its specification. In this research, two rework policies are considered. In the first policy, the rework is done by using the same manufacturing facility, while in the second policy a new process facility was added for rework. Quality improvement in the supply chain environment is also necessary. Hence, profit sharing system is added in the model to strengthen the commitment of the suppliers in improving component quality. In the system, the manufacturer shares the profits to the supplier if the supplier can meet or exceed the quality target specified by the manufacturer. A comparison is given to determine the best quality improvement policy between those two policies

considering profit sharing system. From the results of the optimization, the managers can make economic investment decision economically to correct a defective product through cost optimization model and to choose the best option toward the goal of least unit production cost. By using this model, the decision-maker can evaluate any quality investment in order to achieve significant financial return.

Julia Galliers, Alistair Sutcliff (2019), the proposed method is demonstrated through a case study of an operator performing a task using the control system for a laser spectrophotometer. The BBN model predicts probabilities of different types of error slips and mistakes for each component action of a task involving user-system interaction. We propose an Impact Analysis Method that involves running test scenarios against this causal model of error in order to determine user interactions that are prone to different types of error. Applying the proposed method will enable the designer to determine the combinations of influencing factors and their interactions that are most likely to influence human error. Finally we show how such scenario-based causal analysis can be useful as a means of focusing on relevant guidelines for safe user interface design. In previous work we have proposed a taxonomy of influencing factors that contribute to error. In this article, components of the taxonomy are combined into a mathematical and causal model for error, represented as a Bayesian Belief Net (BBN). The BBN quantifies error influences arising from user knowledge, ability, and the task environment, combined with factors describing the complexity of user action and user interface quality. In previous work we have proposed a taxonomy of influencing factors that contribute to error. In this article, components of the taxonomy are combined into a mathematical and causal model for error, represented as a Bayesian Belief Net (BBN). The BBN quantifies error influences arising from user knowledge, ability, and the task environment, combined with factors describing the complexity of user action and user interface quality.

Manish gupta, shamik banerjee (2018), in this context, security has gained significance due to increased threats, as well as legislation and compliance issues. This article presents a framework for assessing the security of Internet technology components that support a globally distributed workplace. Four distinct information flow and design architectures are identified based on location sensitivities and placements

of the infrastructure components. Using a combination of scenarios, architectures, and technologies, the article presents the framework of a development tool for information security officers to evaluate the security posture of an information system. To aid managers in better understanding their options to improve security of the system, we also propose a three-dimensional representation, based on the framework, for embedding solution alternatives. To demonstrate its use in a real-world context, the article also applies the framework to assess a globally distributed workforce application at a northeast financial institution. As organizations increasingly operate, compete, and cooperate in a global context, business processes are also becoming global to propagate the benefits from coordination and standardization across geographical boundaries.

Stephen Roberts, Steven Wright (2018), in this article, we present the Power Optimized Software Envelope (POSE) model, which allows developers to assess the potential benefits of power optimization for their applications. The POSE model is metric agnostic and in this article, we provide derivations using the established Energy-Delay Product metric and the novel Energy-Delay Sum and Energy-Delay Distance metrics that we believe are more appropriate for energy-aware optimization efforts. We demonstrate POSE on three platforms by studying the optimization characteristics of applications from the Manteo benchmark suite. Our results show that the Pathfinder application has very little scope for power optimization while Tea Leaf has the most, with all other applications in the benchmark suite falling between the two. Finally, we extend our POSE model with a formulation known as System Summary POSE—a meta-heuristic that allows developers to assess the scope a system has for energy-aware software optimization independent of the code being run. Advances in processor design have delivered performance improvements for decades. As physical limits are reached, refinements to the same basic technologies are beginning to yield diminishing returns. Unsustainable increases in energy consumption are forcing hardware manufacturers to prioritize energy efficiency in their designs. Research suggests that software modifications may be needed to exploit the resulting improvements in current and future hardware. New tools are required to capitalize on this new class of optimizations.

Neeraj Suri, Stefan Winter (2019), this article focuses on the two level control CPS, a widely adopted control CPS architecture, and proposes an emulation based evaluation methodology framework. The framework uses hybrid model reachability to quantify the cross-domain noise impact, and exploits Lyapunov stability theories to reduce the evaluation benchmark size. We validated the effectiveness and efficiency of our proposed framework on a representative control CPS test bed. Particularly, 24.1% of evaluation effort is saved using the proposed benchmark shrinking technology. In control CPSs, in addition to the well-studied noises within the physical subsystem, we are interested in evaluating the impact of *cross-domain noise*: the noise that comes from the physical subsystem, propagates through the cyber subsystem, and goes back to the physical subsystem. Impact of cross-domain noise is hard to evaluate when the cyber subsystem is a black box, which cannot be explicitly modeled.

Jigar doshi, Darshak desai (2018), the purpose of this research paper is to showcase the contribution of FMEA to achieve Continuous Quality Improvement (CQI) by multiple case study research. The outcome research conducted by implementing FMEA; one of the Auto Core Tools (ACTs), in the automobile Small and Medium Enterprises (SMEs) in Gujarat, India is presented in this paper which depict various means of Continuous Quality Improvements. The case study based research was carried out in four automobile SMEs; all of them are supplied to automotive Original Equipment Manufacturer (OEM). The FMEA was implemented with the help of Cross Functional Team (CFT) to identify the potential failure modes and effects, in overall effect on Continuous Quality Improvement. The outcome of FMEA at four companies' reveals the scope of improvement exists in the manufacturing process. Implementation of those improvement points shows the definite signs of continuous improvement of the quality of process and product as well. The FMEA and subsequent implementations had reduced the quality rejections around 3% to 4% in case companies.

Muzakkir, Lijesh (2018), this paper deals with Failure mode and effect analysis of journal bearings. In the present research work the Failure Mode and Effect Analysis (FMEA) of a conventional radial journal bearing is presented. The FMEA process is applied to identify the various possible failures modes of a journal bearing and the

corresponding effects of these failures on the bearing performance. The severity, occurrence and detection of the failures modes are determined based on a rating scale of 1 to 10 to quantify the relative risk of a failure and its effects on the bearing performance. The Risk Priority Number (RPN) of the failure mode is quantified and it is utilized in ranking the failure. The methods to eliminate or reduce the high-risk failure modes are proposed and experimental investigations are conducted to validate the proposed solutions.

Shivani Sharma, Ravindra Pratap (2018) The main motive of this paper is risk Prioritization using FMEA method, which are more severe for the Company. The vital motive of this analysis to review the literature in the field of various risk factors for supply chains to understand current practices and to help Industry to sustain its continue win in flat market where the competition is slit throat in current market. A comparative analysis of various risks factors reduces the chance of its occurrence. It indicates that validity of many of the measurement frameworks need to be established through further study. The process of choosing appropriate supply chain performance measures is difficult as a result of the complexity of these systems. The rising capabilities and functionality of many products are creating it additional complex for producer to keep up the quality and reliability, which not only satisfies him but also delights him. Considerable research has been carried out and literature available in the field of Supply Chain Management since 1990. Successful supply chains use integrated measurement systems as a tool to achieve their organizational objectives.

Himanshu Pardeshi, Bhimashankar Dhavle (2018), this paper applies the FMEA to the plan for accessibility of a 2.3MW, wind turbine configuration. The procedure will be utilized to look at the forthcoming reliabilities of the equipped turbine. Arrangements have been proposed to diminish generally wind turbine failure rate and raise its accessibility. The paper proposes changes to the FMEA technique to investigations accessibility. Failure Modes and Effects Analysis (FMEA) has been appeared to be a viable method for enhancing apparatus structure dependability.

Kushal v. Gawande, Prof.A. B. Amale (2017), the presented paper deals with the review of various industrial case studies and their implementation of FMEA. This project discusses and implementation of Process Failure mode and effect analysis for

improvement in welding process. This work is performed in the “LEMKEN India Agro Equipment Private Limited.” MIDC Buttibori Nagpur. We consider various parameters and examine them. The parameters which we focused ranked them according to the Ford Motor Company Reference Manual of Fourth Edition. Severity, Occurrence and Detection are ranked to calculate the Risk Priority Number (RPN). The Risk Priority Number (RPN) is the product of Severity, Occurrence and Detection which gives the idea about the most affecting parameter in the existing welding process. Studying that parameter we take the corrective action and calculate the RPN again so those to confirm the affecting parameter are minimized or not. In this way we can eliminate the failure. Failure mode and effect analysis (FMEA) is systematic, proactive method for evaluating the process to identify where and it might be fail to assist the relevant impact of different failures in order to identify the part of processes that are most needed of the change. The FMEA process consist of step wise process starting from potential failure causes ,study existing and complete the working of mechanism , calculate the risk priority number (RPN)of existing and modified.

Prakhil Kalraiya ,Mr.Sanjay Kalraiya (2017) In this study defects cause by welding process is studied and suitable solutions are used to remove these defects And failures. This study is conducted in industrial area sagar for welding Process. FMEA discovered the weak processes in the form of higher risk priority number in the welding process of Product, which required reducing by identifying and implementing improvement actions and thus the product superiority & productivity will improved. In this paper we discuss about the implementation of PFMEA to enhance quality of product by us. By using PFMEA we can easily detect failures and can perform beneficial operations to improve manufacturing industries growth. They can take steps to reduce product failure and improve the production process. This document is presented all detailed execution details of product failure modes and analysis effects (PFMEA) in welding process to improve the quality of the product. This study studies defects generated by the welding process and uses appropriate solutions to eliminate these defects and failures. By using PFMEA we can detect the manufacturing defects and easily take actions to overcome from these defects and improve the product quality.

Tejaskumar S. Parsana and Mihir T. Patel (2017), This paper aims to identify and eliminate current and potential problems from a manufacturing process of cylinder head in the company through the application of Failure Mode and Effects Analysis (FMEA) for improving the reliability of sub systems in order to ensure the quality which in turn enhances the bottom line of a manufacturing industry. Thus the various possible causes of failure and their effects along with the prevention are discussed in this work. Severity values, Occurrence number, Detection and Risk Priority Number (RPN) are some parameters, which need to be determined. Furthermore, some actions are proposed which require to be taken as quickly as possible to avoid potential risks which aid to improve efficiency and effectiveness of cylinder head manufacturing processes and increase the customer satisfaction. The prevention suggested in this paper can considerably decrease the loss to the industry in term of both money time and quality. The study has attempted to present an effective tool for solving the problem of manufacturing process quality by executing process FMEA with proposed process control practices.

Kapil Dev Sharma (2017) this paper highlights the various approaches and applications of FMEA have been developed so far. FMEA is widely used in manufacturing industries in various phases of the product life cycle and it now extensively used in a variety of industries including semiconductor processing, food service, plastics, power plant, software, and healthcare. A successful FMEA activity enables a team to identify potential failure modes based on past experience with similar products or processes, enabling the team to design those failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs. In 1960s it was used by the aerospace industry as a design methodology, with their obvious reliability and safety requirements. In the late 1970s, the Ford Motor Company introduced FMEA to the automotive industry for safety and regulatory consideration. They also used it to improve production and design.

Gary Ka Kwai Poon, Jian-Bo Yang (2017), the proposed FMEA measures the maximum and minimum risks of each failure mode. The two risks are then geometrically averaged to measure the overall risks of failure modes. The risk priorities are determined in terms of overall risks rather than maximum or minimum risks only. Two

numerical examples are provided and examined using the proposed FMEA to show its potential applications and benefits. Failure mode and effects analysis (FMEA) is a method that examines potential failures in products or processes and has been used in many quality management systems. One important issue of FMEA is the determination of the risk priorities of failure modes. In this paper we propose an FMEA which uses data envelopment analysis (DEA), a well-known performance measurement tool, to determine the risk priorities of failure modes.

Rishav Kumar, Dr. R. K. Mondloi (2017) in this paper Risk Priority Number (RPN) methodology is used to identify the critical parts which are more vulnerable to failure and needs more maintenance. Design Improvement can be planned according to the FMEA work table, especially for most severe failure mode with high prevention difficulty. For successful preventive maintenance of a Maruti Suzuki Swift Car Failure Mode and Effect Analysis required to perform on it. FMEA is an effective method used for identifying the possible failures and mollifying their effects.

Reza Fattahi, Mohammad Khalilzadeh (2017), in this method, fuzzy weighted risk priority number (FWRPN) is considered instead of RPN for each failure. The weights of the three factors and the weights of failure modes are computed by extended fuzzy AHP and fuzzy MULTIMOORA methods, respectively. The proposed fuzzy MULTIMOORA method calculates the weight of each failure based on three criteria of time, cost, and profit through fuzzy linguistic terms. After calculating FWRPN for each failure, corrective actions are performed for eliminating the identified failures or decreasing the effects of them. Then, corrected fuzzy weighted risk priority number (CFWRPN) is computed for each failure. Finally, the average of FWRPNs (AFWRPNs) with the average of CFWRPNs (ACFWRPNs) are compared to evaluate the effectiveness of corrective actions by a novel ranking fuzzy numbers method. In addition, the proposed ranking fuzzy number method is also used in both previously mentioned fuzzy multi-criteria decision making (MCDM) methods. Eventually, Kerman Steel Industries Factory is considered as a case study to demonstrate the applicability and benefits of the proposed fuzzy hybrid method. A sensitivity analysis is performed to validate the obtained results. Findings show that AFWRPNs decreased by 56% compared to ACFWRPNs.

H. Oraee, P.J. Tavner (2017), Comparison is made between the quantitative results of an FMEA and reliability field data from real wind turbine systems and their assemblies. These results are discussed to establish relationships which are useful for future wind turbine designs. The main system studied is an existing design 2 MW wind turbine with a Doubly Fed Induction Generator (DFIG), which is then compared with a hypothetical wind turbine system using the Brushless Doubly Fed Generator (BDFG) of the same rating. The Failure Modes and Effects Analysis (FMEA) method has been used to study the reliability of many different power generation systems. This paper now applies that method to a wind turbine (WT) system using a proprietary software reliability analysis tool.

Yongchuan Tang, Wen Jiang (2017), these studies mentioned make contribution to improve the conventional FMEA method or extend it to different particular fields as an efficient risk analysis tool. Based on the empirical knowledge from the FMEA team members, each failure mode will get a risk priority number to define its risk level, as well as some suggestions on how to control these failure modes to prevent them from having a bad effect on the customers. FMEA is an effective preventive approach to reduce the possibility of a failure. So far, FMEA has become a useful method in risk analysis being widely used in many real applications, like nuclear safety systems. Failure mode and effects analysis (FMEA) starts from aerospace industry in 1960s. It is a structural tool for analyzing the potential failure modes in a process, designing activity, service process, and so on.

ApangDjafar Shieddieque (2017), this paper explains about FMEA with Six Sigma implementation in electronic capacitors. In an increasingly competitive global competitive situation, the issue of product quality becomes a central issue for every company. The ability of the company to provide quality products will be a weapon to win the competition, because by providing products that the quality of customer satisfaction will be achieved. Therefore, attention to product quality can give a positive impact to the development and progress of the company's business; this condition requires a company to process all resources owned optimally and make continuous improvement to the existing working system effectively and efficiently. This research was conducted at PT. XYZ by implementing Six Sigma with FMEA (Failure Mode and

Effect Analysis) method, which aims to identify any non-conformity product available in the capacitor electronic component product, measure initial condition and analyze the cause of existing problems and can be made possible measure of improvement outstanding quality with an actual breakthrough strategy. Six Sigma step is defined, Measure, Analyze, Improve and Control (DMAIC) and one of the methods used in analysis phase is FMEA (Failure Mode and Effect Analysis). The use of FMEA is used for cause and determination analysis with a DPMO (Defect per Million Opportunities) decrease based on priority scale on RPN (Risk Priority Number) value. Implementation of Six Sigma method successfully implemented well this is marked by the existence of improving product quality. This condition can be clearly seen from the decrease of DPMO (Defect Per Million Opportunities) of 15,410 ppm to 2,8 ppm along with a continuous improvement result from cause analysis by using FMEA (Failure Mode and Effect Analysis) where priority scale based on Value RPN (Risk Priority Number). With the decline of DPMO dramatically then in itself there is a significant decrease in failure costs, which impact on improving the company's business and brought a good reputation within the company in accordance with the vision of the company became the world's number one Capacitor and Varistor manufacturing company.

Khushboo jain (2016), This journal tells about the failure mode and effect analysis to improve medication management process. FMEA is an effective proactive risk-assessment tool useful to aid multidisciplinary groups in understanding a process care and identifying errors that may occur, prioritizing remedial interventions and possibly enhancing the safety of drug delivery. It is based on the concept that a risk is related not only to the likelihood of a failure occurring, but also to the severity of the failure's consequences and the feasibility of detecting and intercepting a failure before it occurs. A major advantage of FMEA over other quality improvement schemes is the unique information gathered that makes it easy to identify the priorities of any actions required for improvement, lowering the riskiness of the medication use process. It focuses on system design rather than on a single incident such as in Root cause analysis (RCA). RCA is retrospective and dissects a case, while FMEA is prospective and dissects a process.

Vitthal Jumbad, J. J. Salunke (2016), this paper will give a brief view of rules and flow of FMEA to apply it in sheet metal industry. Every automobile industry is striving for growth in today's competitive world and for that each brand is developing new techniques and tools to deliver defect free products to the customer at minimum cost. Failure mode effect analysis (FMEA) is one of the effective documented tools used in every automotive industry to avoid defects in design or manufacturing of the product. This FMEA when applied to process of the production then it is called as Process Failure Mode and Effect analysis. PFMEA is the integral standard document of all automotive companies in the world. This was developed first time by NASA in 1960 for Apollo project to avoid any accident of spaceship in space and on earth. After that it was developed for automobile industries and today every automotive industry is using it as a standard tool. An FMEA is analytical technique employed by a team as a means to assure that, to extent possible, potential failure mode and their causes have been considered and addressed.

Jose Eduardo Munive-Hernandez (2016), The proposed approach combines the analytic hierarchy process (AHP) technique with the exponential and weighted geometric mean method (EWGM) to support risk analysis. AHP is applied to estimate the weights of three risk factors: Severity (S), Occurrence (O) and Detection (D), which integrate the RPN for each risk. The EWGM method is applied for ranking RPNs. Combining AHP with EWGM allows avoiding repetition of FMEA results. The results of the developed methodology reveal that duplication of RPNs has been decreased, facilitating an effective risk ranking by offering a unique value for each risk. The proposed methodology not only focuses on high severity values for risk ranking but it also considers other risk factors (O and D), resulting in an enhanced risk assessment process. Furthermore, the weights of the three risk factors are considered. In this way, the developed methodology offers unique value for each risk in a simple way which makes the risk assessment results more accurate. This methodology provides a practical and systematic approach to support decision makers in assessing and ranking risks that could affect long-term strategy implementation. The methodology was validated through the case study of a power plant in the Middle East, assessing 84 risks within 9 risk categories. The case study revealed that top management should pay

more attention to key risks associated with electricity price, gas emissions, lost-time injuries, bad odor and production.

Yonas Mitiku Degu¹, R. Srinivasa Moorthy (2016), in this work, an attempt has been made to implement Machinery FMEA in UPVC pipe production unit of Amhara Pipe Factory, P.L.C., Bahir Dar, Ethiopia. The failure modes and their causes were identified for each machine, the three key indices (Severity, Occurrence and Detection) were reassessed and the analysis was carried out with the help of MFMEA Worksheet. Finally, the necessary corrective actions were recommended. Failure Mode and Effect Analysis (FMEA) is a pro-active quality tool for evaluating potential failure modes and their causes. It helps in prioritizing the failure modes and recommends corrective measures for the avoidance of catastrophic failures and improvement of quality.

CHAPTER – 3

METHODOLOGY

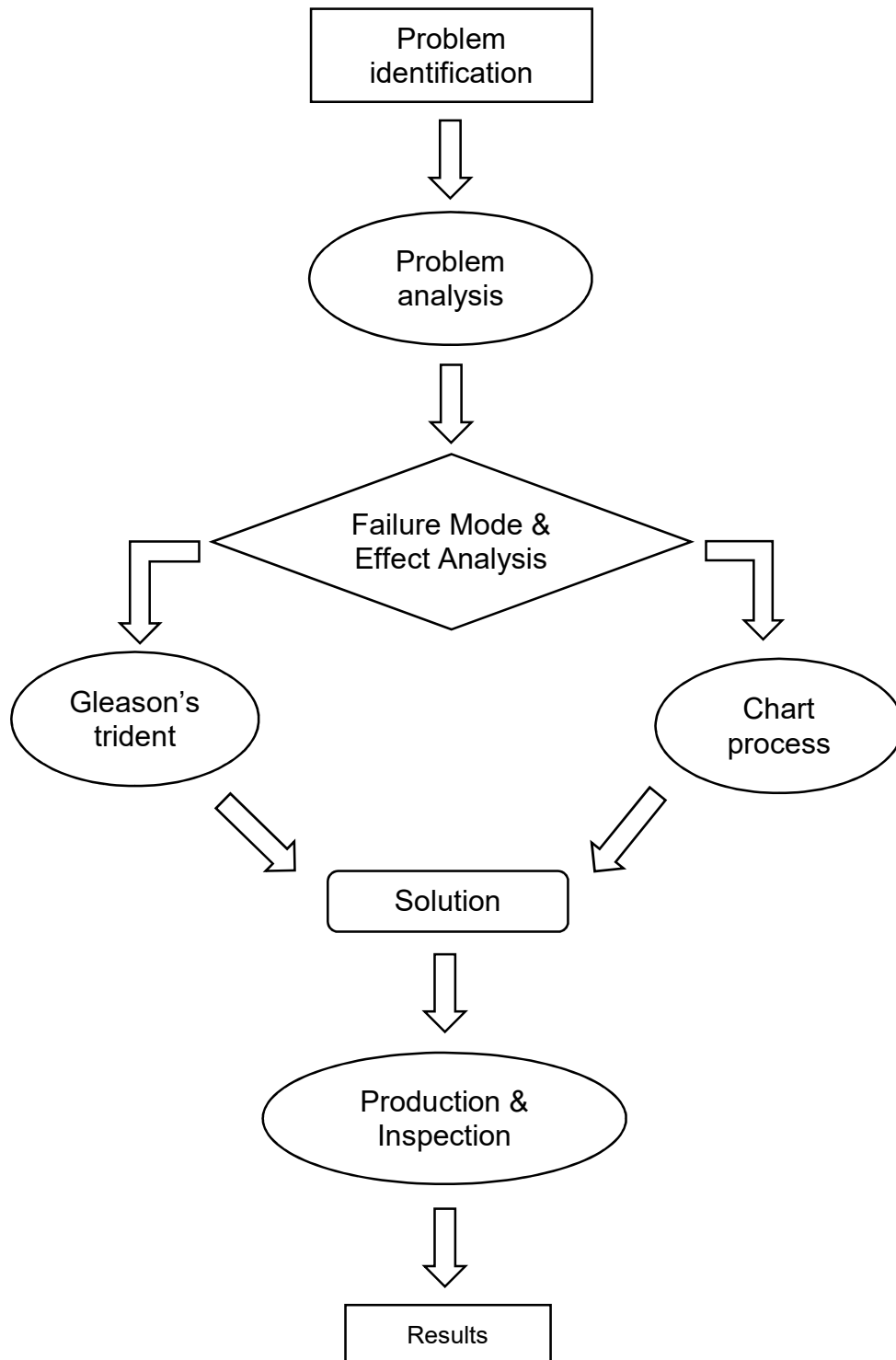


Fig 3.1 Process Flowchart

3.1 ELUCIDATION

Explanation on the project flowchart begins with the problem identification in the machined products. Further the identified problem is analyzed and an analytical tool namely failure mode and effect analysis which has two stages namely Gleason's trident followed by the chart process, has been used for a solution. With that solution the machine has been rectified. Production thus began, along with the inspection process in parallel. Thus the inspection reports were published.

3.2 PROBLEM DESCRIPTION

On November 16th 2020, new orders were received. The company was ordered to machine hundred long shafts. But before that, ten trial shafts were to be machined in order to check the various conditions.

3.2.1 Design parameters

Those ten shafts were machined according to the design parameters given in the table below. The diameter of the shaft is to be between 41.50mm and 42.50mm. Anything which goes beyond this parameter is considered as rejection.

Table 3.1 Design Parameters

Diameter of the shaft	41.50mm to 42.50mm
-----------------------	--------------------

So ten shafts were machined accordingly on 18/11/2020. And the diameter were checked using vernier caliper. The measurements of the ten shafts are listed below in table

Table 3.2 Long shafts trials

LONG SHAFTS	REQUIRED THICKNESS	ATTAINED THICKNESS
LGS11/20 -1	41.50mm – 42.50mm	41.89mm
LGS11/20 – 2		42.05mm
LGS11/20 – 3		42.26mm
LGS11/20 – 4		43.80mm

LGS11/20 – 5		42.50mm
LGS11/20 – 6		42.61mm
LGS11/20 – 7		42.10mm
LGS11/20 – 8		42.85mm
LGS11/20 – 9		41.78mm
LGS11/20 – 10		42.92mm

3.2.2 Trial results

Four long shafts out of ten shafts were rejected as their diameter weren't according to ideal conditions that is, their diameters were above 42.50mm. Those four shafts are mentioned in the below table 5.3.

Table 3.3 Rejected trial shafts

LGS 11/20 – 4	43.80mm
LGS 11/20 – 6	42.61mm
LGS 11/20 – 8	42.85mm
LGS 11/20 – 10	42.92mm

As four out of ten shafts were rejected in trial production, the company decided to go for analysis in order to find out what went wrong during the trial production. So on 22/11/2020, the company formed a team to find out the reasons for the rejections and to find a solution. And so the quality team opted for Failure modes and effect analysis (FMEA).

CHAPTER – 4

PROBLEM ANALYSIS AND INTERPRETATION

4.1 INTRODUCTION

As the analytical stage was driven by failure mode effect analysis, There will eventually be two stages under it. First one is the brainstorming session followed by the chart process.

4.2 GLEASON'S TRIDENT (FMEA STAGE ONE)

First stage of FMEA began on 19/11/2020. In the first stage that is the brainstorming session many techniques will be used such as Statistical process chart, Pareto diagram, and Gleason's trident diagram. Now since the rejection was caused by the disorientation that is, due to change in the diameter of the shaft it will be called as a second tier error,

In this case Gleason's trident diagram will be used for the root cause analysis. One of the various charts used for root cause analysis developed by the Gleason Corporation. Also known as '3M Chart'. For any second tier errors in a mechanical company this chart is used, as it is more effective and time efficient.

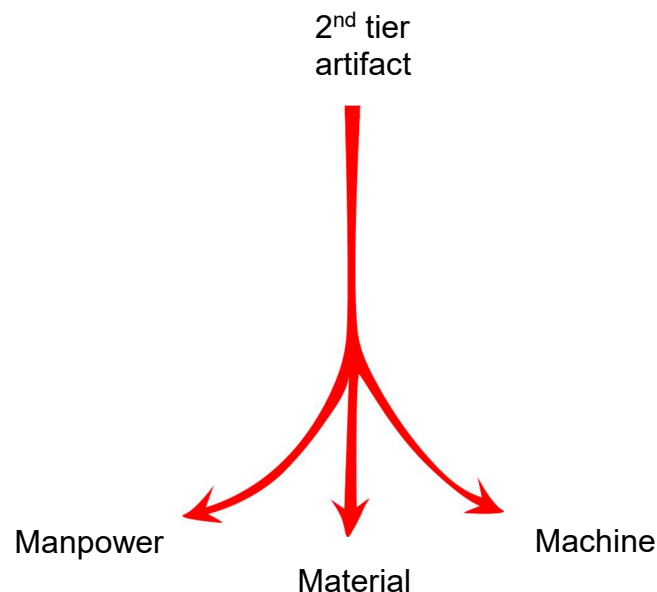


Figure 4.1 Gleason's trident diagram

It is an inverted trident as that of a Poseidon's trident indicating three different causes such as machine, manpower and material. These three causes are further analyzed as which would be the main cause for the rejection.

4.2.1 Manpower:

The analysis begin with the first parameter the manpower. This machine is programmable. And it is programmed to complete all the 10 shafts. The program is pre-stored and has been cross checked by Gleason Kisoftware. Null errors were observed during the testing process, therefore this is not a man-made error.

4.2.2 Material:

Moving on to the second parameter material of all the ten trial shafts has been hardness tested. Material of all the samples has been hardness tested and the results are furnished below in the table. For hardness testing Rockwell hardness test has been used. Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. More simply put, when using a fixed force (load) and a given indenter, the smaller the indentation, the harder the material. Shafts have been hardness by the machine as shown in the figure 5.2

4.2.2.1 Rockwell hardness test

The Rockwell hardness test method, as defined in ASTM E-18, is the most commonly used hardness test method for the mechanical companies. The Rockwell test is generally easier to perform, and more accurate than other types of hardness testing methods.



Figure 4.2 Digital Rockwell hardness tester

The Rockwell test method is used on all metals, except in condition where the test metal structure or surface conditions would introduce too much variations; where the indentations would be too large for the application; or where the sample size or sample shape prohibits its used. Hence all the trial shafts were tested. The ideal hardness condition for the machine to perform on the shaft is 13HRC to 16HRC. The machine can perform its activities if and only if the hardness of the products were between these conditions, The hardness values of the ten trail shafts are tabulated below in the table 6.1 Since all the hardness values falls between the ideal counts, this is not a material error

Table 4.1 Hardness values of the ten shafts

SHAFTS	HARDNESS VALUES
LGS 11/20 – 1	14.11
LGS 11/20 – 2	14.06
LGS 11/20 – 3	14.12
LGS 11/20 – 4	14.18
LGS 11/20 – 5	14.29
LGS 11/20 – 6	14.50
LGS 11/20 – 7	14.72
LGS 11/20 – 8	14.01
LGS 11/20 – 9	13.92
LGS 11/20 – 10	14.22

Results: No error in the hardness values of the trail shafts as all the ten shafts has its hardness 13HRC to 16HRC.

4.2.3 Machine:

Finally the third parameter the machine was analyzed. The name of the machine is Gleason 13-B. When it comes to the point of machine there will be two major parts that has to be analyzed first one is the cutting portion that is the blade or the cradle region, the second major part is the holding portion or the cluster. Apart from these parts the other regions are miniature gears that helps to transmit energy and the electrical portions. Accordingly all such regions such as cradle, cluster gears and electrical regions were analyzed. And finally a defect was found on the cradle. As mentioned, Cradle is the part which helps to grind or the machine the shafts. A crack was found at the stem of the cradle. It was indicated by a change in color.

This type of breakage is called as the cradle breakdown. It is a common type of failure that occurs in machines manufactured by the Gleason Corporation. Thus the rejection is known as Cradle breakdown.

4.2.4 Results of stage one:

Thus the results from Gleason's trident or the 3M chart has been shown below in the table 6.2. The cause for the over sizing of the shafts is due to the cradle breakdown in the machine.

Table 4.2 Results of Gleason's trident

Manpower	No errors	Programs checked
Material	No errors	Hardness tested
Machine	Error Found	Cradle Breakdown

4.3 FMEA STAGE TWO

FMEA Stage two began on 23/11/2020. Second stage in the failure mode effect analysis is the further analysis of the cause that is responsible for the order rejections. In other words this stage is also called as the chart process where all the problems and solutions are listed out in brief cases

Our main aim is to find out the Risk priority number (RPN), we got to calculate the RPN by cross referencing the anomalies found in the rejections with the standardized tables.

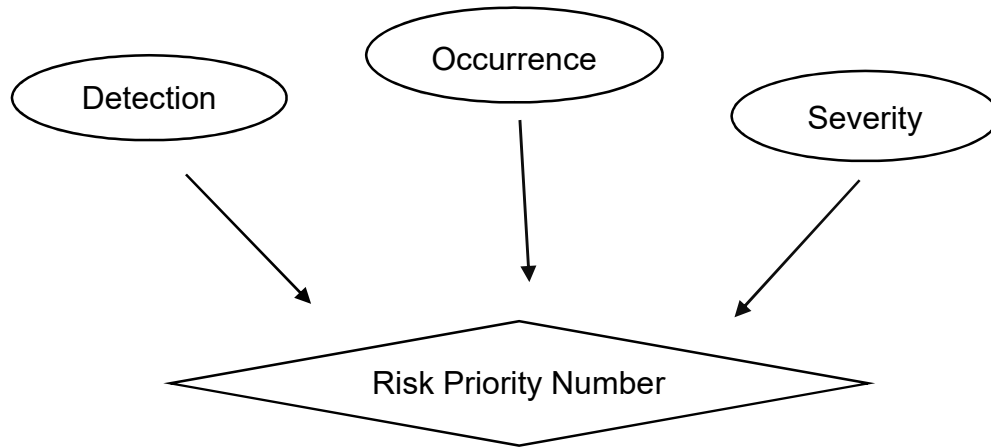


Figure 4.3 FMEA Second stage flow-chart

And so we have to find the values of occurrence, severity and detection.

4.3.1 Occurrence

From the descriptive listings along with the ranks as per mentioned in the below table 6.3, the rank of occurrence for the corresponding failure has to be found out. Since the four trail shafts were rejected out of ten, the corresponding occurrence rank will be four. That is, the effect of occurrence is slight and the concerned criteria is ‘few failures’. Source of this table is from the Gleason Corporation.

Occurrence rank = ‘4’

Table 4.3 Occurrence table

EFFECT	RANK	CRITERIA
Almost Never	1	Failure Unlikely
Remote	2	Rare number of Failures
Very Slight	3	Very few failures
Slight	4	Few failures
Low	5	Occasional no. of. Failures
Medium	6	Moderate no. of. Failures
Moderately High	7	Frequent failures
High	8	High no. of. Failures

Very High	9	Very high no. of. Failures
Almost Certain	10	Failure almost certain

4.3.2 Severity

From the descriptive listings along with the ranks as per mentioned in the below table 6.4, the rank of severity for the corresponding failure has to be found out. Since the stem of the cradle has an airline stress crack surrounded by the dark blue color change, the corresponding severity rank falls at six. It is a significant effect.

Source of this table is from Gleason Corporation.

Severity rank = '6'

Table 4.4 Severity table

EFFECT	RANK	CRITERIA
No effect	1	Red corners
Very Slight effect	2	Cradle bend-over
Slight effect	3	Overall Bulge
Minor effect	4	Air-lined cracks
Moderate effect	5	Midline crack with metallic blue appearance
Significant effect	6	Midline crack with dark blue appearance
Major effect	7	Midline crack with mild orange appearance
Extreme effect	8	Midline crack with mild red appearance
Serious effect	9	Midline crack with brownish appearance
Hazardous effect	10	Part Disengaged

4.3.3 Detection

From the descriptive listings along with the ranks as per mentioned in the below table 6.5, the rank of detection for the corresponding failure has to be found out. There are various levels of inspection as mentioned below in the table now since the product failure was detected at the first stage itself that is, during the inspection of the shafts with the vernier caliper, the rank will fall at two. It stands at the high detection rate with the criteria showing 1st level inspection mesh. Source for this table is given by the Gleason Corporation.

Detection rank = '2'

Table 4.5 Detection table

DETECTION	RANK	CRITERIA
Almost certain	1	Product overlook
Very high	2	1 st level inspection mesh
High	3	2 nd level inspection mesh
Moderately high	4	Thermal exposure
Medium	5	Aerodynamic ensnarl
Low	6	Assembly mismatch
Slight	7	Over-Vibrations
Very slight	8	Acoustic error
Remote	9	Testing failure
Almost impossible	10	Long run failure

4.3.4 FMEA Chart

Filling up the failure mode effect analysis chart is the last step in this stage. With the known values found out from the table 6.3, table 6.4 and table 6.5, this chart is completed. Machine name is filled under the part's name, the defective product is filled up in the product name, and the failure which happened in the machine is filled up in

the product failure column, the reasons for the failure in the potential cause of failure column, effects of failure in the potential effect of failure column. The occurrence, severity and detection values are filled in the O, S and D column.

Finally the ranks of occurrence (O), severity (S) and detection (D) are multiplied. And the multiplication factor represents the Risk priority number (RPN).

And RPN is also in the table 6.6 given below

Table 4.6 FMEA Chart

Product Name	Product Failure Mode	Potential Cause of Failure	Potential Effect of Failure	Existing Conditions			
				O	S	D	RPN =(O x S x D)
Shaft grinding	Cradle Breakdown	Crack at Spindle stem	Shaft size Disorientation	4	6	2	48

4.3.4.1 Calculation

Risk priority number = Occurrence × Detection × Severity

$$\begin{aligned} \text{RPN} &= 4 \times 2 \times 6 \\ &= 48 \end{aligned}$$

Therefore RPN is equal to '48'

4.3.4.2 Countermeasures

Thus there different counter measures or an anticipative measure according to the derived RPN values as mentioned in the below table. These counter measures differ for various machines. The below table 6.7 is sourced from Gleason Corporation.

Table 4.7 FMEA Recovery table

RPN RANGE	Measures
0 – 25	Heat treatment
26 – 100	Stem enhancement
101 – 500	Gears locum

501 – 750	Assembly rework
751 – 1000	Cradle replacement

Usually there will be five different measures for five different ranges, this might vary in other machines. The first countermeasure that is heat treatment includes the overall defective part to be heat treated at various temperatures, Stem enhancement is filling the airline stress crack with platinum fillings and re-heated.

Gears locum means the transplantation of the gears that processes transmission. In Assembly rework some of the parts are replaced and the last countermeasure that is the cradle replacement says that the entire cradle has to be changed. Now in this case as the risk priority is '48' and it falls between 26 – 100 ranges that is the second stage, the anticipative measure is Stem enhancement.

4.3.4.3 Results

Thus FMEA showed us that the RPN value of the defective part (Cradle) was '48' and it led to stem enhancement. FMEA was concluded on 30/11/2020. The completion of the FMEA led to preventive measure (Stem enhancement) which was completed on 7/12/2020.

4.4 INSPECTION REPORT

As FMEA was completed, giving out stem enhancement as a solution the machine was made ready on 09/12/2020. So the production work started on 14/11/2020 along with the inspection procedure.

4.4.1 Production Inter Inspection

The inspection procedure used here is known as 'production inter inspection'. It is a procedure where each and every shaft were inspected immediately after they were machined. It is not a batch process.

On 15th December 2020, first six shafts were machined. Those six shafts were inspected simultaneously. There were no rejections as the dimensions were in between 41.50mm and 42.50mm. And so the first trial post FMEA were successful. As there were no rejections the production along with the inspection continued parallel. This procedure usually consists of two phases first off and second off inspection. In the first

– off inspection phase the diameter, number of teeth in the shaft and the height of the shaft is checked using vernier caliper and scale. In the second – off inspection phase, any cracks, pits and holes are checked visually. Thus the production and inspection of the remaining long shafts continued. The inspection report of the remaining shafts are posted.

Table 4.8 Inspection report 1

INSPECTIONS		FIRST – OFF					
		SECOND - OFF					
PART NOS.		LGS 11/20 – 11 to 16					
DATE		15/12/2020					
		OBSERVANCE					
		SHAFTS					
		11	12	13	14	15	16
INSPECTIVE PARAMETERS	DIAMETER	41.90	41.85	42.13	42.12	42.25	41.97
	LENGTH	185	185	185	185	185	185
	NO. OF. TEETH	14	14	14	14	14	14
	CRACKS	NO	NO	NO	NO	NO	NO
	HOLES	NO	NO	NO	NO	NO	NO
	PITS	NO	NO	NO	NO	NO	NO
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION					
ALL UNITS ARE IN ‘mm’							

Table 4.9 Inspection report 2

INSPECTIONS		FIRST – OFF						
		SECOND - OFF						
PART NOS.		LGS 11/20 – 17 to 22						
DATE		16/12/2020						
		OBSERVANCE						
		SHAFTS						
			17	18	19	20	21	22
INSPECTIVE PARAMETERS	DIAMETER	42.03	42.11	42.17	42.21	42.36	41.98	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.10 Inspection report 3

INSPECTIONS		FIRST – OFF					
		SECOND - OFF					
PART NOS.		LGS 11/20 – 23 to 28					
DATE		17/12/2020					
		OBSERVANCE					
		SHAFTS					
		23	24	25	26	27	28
INSPECTIVE PARAMETERS	DIAMETER	42.10	42.26	42.38	41.56	41.99	41.76
	LENGTH	185	185	185	185	185	185
	NO. OF. TEETH	14	14	14	14	14	14
	CRACKS	NO	NO	NO	NO	NO	NO
	HOLES	NO	NO	NO	NO	NO	NO
	PITS	NO	NO	NO	NO	NO	NO
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.					
ALL UNITS ARE IN ‘mm’							

Table 4.11 Inspection report 4

INSPECTIONS		FIRST – OFF						
		SECOND - OFF						
PART NOS.		LGS 11/20 – 29 to 34						
DATE		18/12/2020						
		OBSERVANCE						
		SHAFTS						
			29	30	31	32	33	34
INSPECTIVE PARAMETERS	DIAMETER	41.84	41.60	42.10	42.44	42.37	41.89	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION						
ALL UNITS ARE IN ‘mm’								

Table 4.12 Inspection report 5

INSPECTIONS		FIRST – OFF						
		SECOND - OFF						
PART NOS.		LGS 11/20 – 35 to 40						
DATE		22/12/2020						
		OBSERVANCE						
		SHAFTS						
			35	36	37	38	39	40
INSPECTIVE PARAMETERS	DIAMETER	42.44	42.31	42.07	41.85	42.10	42.18	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION						
ARE UNITS ARE IN ‘mm’								

Table 4.13 Inspection report 6

INSPECTIONS		FIRST – OFF					
		SECOND - OFF					
PART NOS.		LGS 11/20 – 41 to 46					
DATE		29/12/2020					
		OBSERVANCE					
		SHAFTS					
		41	42	43	44	45	46
INSPECTIVE PARAMETERS	DIAMETER	42.39	41.67	41.89	41.75	41.77	42.10
	LENGTH	185	185	185	185	185	185
	NO. OF. TEETH	14	14	14	14	14	14
	CRACKS	NO	NO	NO	NO	NO	NO
	HOLES	NO	NO	NO	NO	NO	NO
	PITS	NO	NO	NO	NO	NO	NO
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION					
ALL UNITS ARE IN ‘mm’							

Table 4.14 Inspection report 7

INSPECTIONS		FIRST – OFF					
		SECOND - OFF					
PART NOS.		LGS 11/20 – 47 to 52					
DATE		30/12/2020					
		OBSERVANCE					
		SHAFTS					
		47	48	49	50	51	52
INSPECTIVE PARAMETERS	DIAMETER	42.15	42.26	41.88	41.70	42.35	42.40
	LENGTH	185	185	185	185	185	185
	NO. OF. TEETH	14	14	14	14	14	14
	CRACKS	NO	NO	NO	NO	NO	NO
	HOLES	NO	NO	NO	NO	NO	NO
	PITS	NO	NO	NO	NO	NO	NO
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION					
ALL UNITS ARE IN ‘mm’							

Table 4.15 Inspection report 8

INSPECTIONS		FIRST – OFF					
		SECOND - OFF					
PART NOS.		LGS 11/20 – 53 to 58					
DATE		31/12/2020					
		OBSERVANCE					
		SHAFTS					
		53	54	55	56	57	58
INSPECTIVE PARAMETERS	DIAMETER	41.55	41.86	42.06	42.36	41.98	42.10
	LENGTH	185	185	185	185	185	185
	NO. OF. TEETH	14	14	14	14	14	14
	CRACKS	NO	NO	NO	NO	NO	NO
	HOLES	NO	NO	NO	NO	NO	NO
	PITS	NO	NO	NO	NO	NO	NO
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION					
ALL UNITS ARE IN ‘mm’							

Table 4.16 Inspection report 9

INSPECTIONS		FIRST – OFF						
		SECOND - OFF						
PART NOS.		LGS 11/20 – 59 to 64						
DATE		04/01/2021						
		OBSERVANCE						
		SHAFTS						
			59	60	61	62	63	64
INSPECTIVE PARAMETERS	DIAMETER	42.27	42.09	42.15	42.17	41.78	41.86	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.17 Inspection report 10

INSPECTIONS		FIRST – OFF					
		SECOND - OFF					
PART NOS.		LGS 11/20 – 65 to 70					
DATE		05/01/2021					
		OBSERVANCE					
		SHAFTS					
		65	66	67	68	69	70
INSPECTIVE PARAMETERS	DIAMETER	41.72	42.44	41.87	41.85	42.28	42.30
	LENGTH	185	185	185	185	185	185
	NO. OF. TEETH	14	14	14	14	14	14
	CRACKS	NO	NO	NO	NO	NO	NO
	HOLES	NO	NO	NO	NO	NO	NO
	PITS	NO	NO	NO	NO	NO	NO
INSPECTION RESULTS			ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION				
ALL UNITS ARE IN ‘mm’							

Table 4.18 Inspection report 11

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 71 to 76						
DATE		06/01/2021						
		OBSERVANCE						
		SHAFTS						
			71	72	73	74	75	76
INSPECTIVE PARAMETERS	DIAMETER	42.25	42.30	41.86	41.90	41.92	42.38	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION						
ALL UNITS ARE IN ‘mm’								

Table 4.19 Inspection report 12

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 77 to 82						
DATE		07/01/2021						
		OBSERVANCE						
		SHAFTS						
			77	78	79	80	81	82
INSPECTIVE PARAMETERS	DIAMETER	42.16	42.28	42.10	41.89	41.78	42.00	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION						
ALL UNITS ARE IN ‘mm’								

Table 4.20 Inspection report 13

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 83 to 88						
DATE		08/01/2021						
		OBSERVANCE						
		SHAFTS						
			83	84	85	86	87	88
INSPECTIVE PARAMETERS	DIAMETER	41.90	41.96	42.25	42.31	42.47	42.10	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALLSHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.21 Inspection report 14

INSPECTIONS		FIRST – OFF					
		SECOND – OFF					
PART NOS.		LGS 11/20 – 89 to 94					
DATE		22/01/2021					
		OBSERVANCE					
		SHAFTS					
		89	90	91	92	93	94
INSPECTIVE PARAMETERS	DIAMETER	42.28	42.15	42.30	41.87	41.96	42.28
	LENGTH	185	185	185	185	185	185
	NO. OF. TEETH	14	14	14	14	14	14
	CRACKS	NO	NO	NO	NO	NO	NO
	HOLES	NO	NO	NO	NO	NO	NO
	PITS	NO	NO	NO	NO	NO	NO
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION					
ALL UNITS ARE IN ‘mm’							

Table 4.22 Inspection report 15

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 95 to 100						
DATE		25/01/2021						
		OBSERVANCE						
		SHAFTS						
			95	96	97	98	99	100
INSPECTIVE PARAMETERS	DIAMETER	42.31	42.21	41.90	41.85	42.36	42.05	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.23 Inspection report 16

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 101 to 106						
DATE		27/01/2021						
		OBSERVANCE						
		SHAFTS						
			101	102	103	104	105	106
INSPECTIVE PARAMETERS	DIAMETER	42.03	41.91	41.90	41.85	42.16	42.25	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.24 Inspection report 17

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 107 to 112						
DATE		27/01/2021						
		OBSERVANCE						
		SHAFTS						
			107	108	109	110	111	112
INSPECTIVE PARAMETERS	DIAMETER	41.93	41.81	42.05	41.85	42.16	41.95	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.25 Inspection report 18

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 113 to 118						
DATE		28/01/2021						
		OBSERVANCE						
		SHAFTS						
			113	114	115	116	117	118
INSPECTIVE PARAMETERS	DIAMETER	42.03	42.11	41.95	41.85	42.16	42.16	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.26 Inspection report 19

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 119 to 124						
DATE		29/01/2021						
		OBSERVANCE						
		SHAFTS						
			119	120	121	122	123	124
INSPECTIVE PARAMETERS	DIAMETER	42.23	42.11	42.35	41.74	42.16	42.23	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.27 Inspection report 20

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 125 to 130						
DATE		01/02/2021						
		OBSERVANCE						
		SHAFTS						
			125	126	127	128	129	130
INSPECTIVE PARAMETERS	DIAMETER	42.34	42.10	42.21	41.60	42.16	42.13	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.28 Inspection report 21

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 131 to 136						
DATE		02/02/2021						
		OBSERVANCE						
		SHAFTS						
			131	132	133	134	135	136
INSPECTIVE PARAMETERS	DIAMETER	41.94	41.80	41.71	42.40	42.16	42.23	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.29 Inspection report 22

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 137 to 142						
DATE		03/02/2021						
		OBSERVANCE						
		SHAFTS						
			137	138	139	140	141	142
INSPECTIVE PARAMETERS	DIAMETER	42.14	41.80	41.61	42.41	41.66	41.92	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.30 Inspection report 23

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 143 to 148						
DATE		04/02/2021						
		OBSERVANCE						
		SHAFTS						
			143	144	145	146	147	148
INSPECTIVE PARAMETERS	DIAMETER	42.26	41.88	41.75	42.02	41.56	41.89	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

Table 4.31 Inspection report 24

INSPECTIONS		FIRST – OFF						
		SECOND – OFF						
PART NOS.		LGS 11/20 – 149 to 154						
DATE		05/02/2021						
		OBSERVANCE						
		SHAFTS						
			149	150	151	152	153	154
INSPECTIVE PARAMETERS	DIAMETER	41.76	42.21	42.33	41.71	41.56	42.39	
	LENGTH	185	185	185	185	185	185	
	NO. OF. TEETH	14	14	14	14	14	14	
	CRACKS	NO	NO	NO	NO	NO	NO	
	HOLES	NO	NO	NO	NO	NO	NO	
	PITS	NO	NO	NO	NO	NO	NO	
INSPECTION RESULTS		ZERO ERRORS FOUND; ALL SHAFTS ARE IN IDEAL CONDITION.						
ALL UNITS ARE IN ‘mm’								

4.5 INTERPRETATION

Thus the inspection report of all the 154 shafts which were machined after FMEA are tabulated from table 6.1 to 6.23 and all the shafts are in the required dimensions that is between 41.50mm to 42.50mm. Hence there were no rejections found during the inspection procedure.

CHAPTER – 5

FINDINGS, SUGGESTIONS AND CONCLUSION

5.1 FINDINGS

The first phase of this project started on 16/11/2020 and ended finally with inspection procedures on 05/02/2021. Thus the trial shafts has been checked, the problem has been identified and a solution was reported using the analytical tool, Failure mode and effect analysis (FMEA). Production work of the remaining long shafts was started and all the given long shafts were machined. They have been inspected using the inspection procedure, Production Inter Inspection (PII).

Therefore inspection report has been tabulated. Thus from the inspection reports, tabulated from the tables 6.1 to 6.23 and it has been seen that there were no rejections, hence it has proved that FMEA was useful and so all the objectives of this project has been accomplished.

5.2 SUGGESTIONS

A suggestion would be the use of Relia Soft XFMEA, an application designed especially for all types of FMEA, in order to reduce the time taken for compiling FMEA in a manual way and performing regular analysis of all the machines even if in ideal condition, to keep them in check so that cost and time spent during the trial production might be reduced.

5.3 CONCLUSION

FMEA provides a discipline/methodology for documenting this analysis for future use and continuous process improvement. It is a systematic approach to the analysis, definition, estimation, and evaluation of risks. Following a standard setup procedure will reduce setup time and improve part accuracy thereby increasing the quality and efficiency of processes. The preventive measures mentioned in the table 5.7, can considerably decrease any losses in the manufacturing industry. FMEA analysis may easily help in improving the efficiency of the processes in the supply chain and quality of product thus decreasing the number of defective products and saving of rework cost and time.

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APPENDIX

Supply Chain Optimization in a Metal Manufacturing Industry using FMEA

Ms. Kavitha Rajayogan

kavitha2984@gmail.com

Assistant Professor

School of Management Studies

Sathyabama institute of science and technology, Chennai

Mr. Anderson Blesswin. P

andersonblesswin@gmail.com

Post graduate scholar

School of Management Studies

Sathyabama institute of science and technology, Chennai

ABSTRACT

Machine errors are a significant source of manufacturing defects. Such errors could deviate plans and place innumerable pressures in the supply chain. Therefore an efficient method is needed to identify and alleviate potential defects in the supply chain. Failure mode and effect analysis is one of the technique used to anticipate, evaluate and resolve potential process and design errors.

Successful supply chains use integrated measurement systems such as these to achieve their organizational objectives. Traditional use of Pareto chart, Cause and effect diagram and histogram involves ambiguity with the identification of root causes for the manufacturing errors. The 3M Pointer used in the root-cause analysis of FMEA reduces this ambiguity by using parameters like machine, manpower and material. Yet the chart process requires the definition of occurrence, severity, detection and risk priority number to complete FMEA. The proposed approach has been used in this company in order to detect the risk factors in production area and eliminate rejections through failure mode and effect analysis.

Keywords: *Supply chain, 3M Pointer, Failure mode and effect analysis, Severity, Occurrence, Detection, Risk priority number.*

1. INTRODUCTION

With the globalization of the economy, competition for market share increases, attention to the quality of products has increased in several industrial and service sectors. The failure rate of many mass produced products has been reduced to a few parts per million. Thanks to the some of the effective tools like FMEA. It is one of the most important early preventive action in system, design, process or service which will prevent failures and errors from occurring and reaching the customer. Effect analysis is the term which denotes all consequences of the failures [1]. The aim for understanding a failure mode is to continually develop products and process consistency thereby increasing customer satisfaction [2]. FMEA was developed and used for the first time in 1949 by American Army and was used to analyze risk in Apollo space program [3]. Finally after sometime it was addressed as vital tool for

quality improvement [4]. In the mid-seventies Ford motors reintroduced FMEA for analyzing the problems in their research and development team. Later many automobile companies in west stuck themselves to FMEA [5].

Apart from improvising the standards in the automobile industries, it has done wonders in wind turbines too [6]. Along with that FMEA procedure that was used in a sheet metal industry helped them to identify the potential problems and improvise their production. Similarly other analytical tools like six sigma can be used along with failure mode and effect analysis. Thus the enactment of six sigma with FMEA to improve product quality of electronic components has been discussed [7]. And not only does it do marvel in manufacturing, automobile and electrical fields, it also helps in medical field. An improvement in Medicare management finding out errors prescription, transcribing, and administration has been made out. [8]. so likewise it transforms the field wherever it touches.

2. DEFINITION AND TYPES OF FMEA

Failure mode and effect analysis is an engineering technique used to define, identify and eliminate known and/or potential failures, problems, errors and so on the system, design, process, and/or service before they reach the customer.

2.1 TYPES OF FMEA

- Design FMEA
- Process FMEA

2.1.1 DESIGN FMEA (DFMEA)

Design failure mode and effect analysis focuses anticipating errors in components, systems and subsystems. The main aim of DFMEA is to minimize failure effects on the system. The objective/goal is to maximize quality, reliability cost and maintainability. DFMEA is used in fields like

- Manufacturing
- Software
- Business process
- Health care
- Service industries
- Regulated industries

2.1.2 PROCESS FMEA (PFMEA)

PFMEA anticipates risks in manpower, machine, method, material, measurement, method and environment.. High risk items from PFMEA usually results in process changes. It primarily talks about how a process could fail to produce the desired output. The main key characteristic of process failure mode and effect analysis is an input whereas the key characteristic for DFMEA is an output.

2.2 BENEFITS OF FMEA

- Improve product
- Increase customer satisfaction
- Early identification and elimination of failures
- Prioritize product/process deficiencies.
- Emphasizes problem prevention
- Minimizes late changes
- Provides focus for improved testing and development.

2.3 STEPS IN FMEA

1. First step is to identify the problem, whether it is in the process stages or is it in the machines/product

2. Secondly brainstorming session has to be done in order to analyze the causes/reasons for the failure.
3. There are tools which are very helpful during the brain storming session such as Pareto diagram, cause and effect diagram and histogram.
4. Taking anyone or two into considerations, the root cause for the failure can be identified.
5. The main cause for the failure is then taken to the FMEA chart where different parameters are to be identified for the failure such as severity scale, detection scale, occurrence scale and risk priority number. The table 2.1 below is an FMEA chart

Table 2.1 Sample FMEA Chart

Part name	Failure mode	Cause of failure	Effect of failure	Existing Conditions			
				S	O	D	RP N

- **Product name:** The name of the rejected part
- **Failure mode:** The name of the failure which has occurred
- **Cause of failure:** Root cause failure is to be mentioned here
- **Effect of failure:** The side-effects which has happened due to this failure
- **Severity scale:** It is a factor that represents the seriousness of failure to the customer after it has occurred. Each and every process has different severity scales. Severity scale values varies from company to company. Industries will frame their own severity scale factors. Severity scale is below in the table 2.2

Table 2.2 Severity scale

Effect	Criteria	Rank
No effect	No effect on product	1
Very slight effect	Customer will not the effect	2
Slight effect	Customer slightly annoyed	3
Minor effect	Customer experiences minor nuisance	4
Moderate effect	Customer experience some dissatisfaction	5
Significant effect	Customer experiences discomfort	6
Major effect	Customer dissatisfied	7
Extreme effect	Customer very dissatisfied	8

Serious effect	Potential hazardous effect	9
Hazardous effect	Non-compliance with government regulations	10

- **Occurrence scale:** This scale estimates the probability of occurrence of the potential failure on a scale 1 to 10. Only controls intended to prevent the cause of failure from occurring should be considered in this estimate. Likewise each and every industry and company has their own occurrence table.

Table 2.3 Occurrence table

Effect	Criteria	Rank
Almost never	History shows no failure	1
Remote	Rare number of failures likely	2
Very slight	Very few failures	3
Slight	Few failures likely	4
Low	Occasional number of failures	5
Medium	Moderate number of failures	6
Moderately high	Frequent failures	7
High	High number of failure	8
Very high	Very high number of failures	9
Almost certain	History of failures exist from previous designs	10

Detection table: It applies a scale of 1 to 10 which will enable probability of detection to be rated. Each assignable cause must be addressed and the probability of detection rated.

Table 2.4 Detection table

Detection	Criteria	Rank
Almost certain	Current controls almost always	1

	will detect the failure	
Very high	Very high likelihood current controls will detect the failures	2
High	Good likelihood current controls will detect the failure	3
Moderately high	Moderately high likelihood current controls will detect the failure	4
Medium	Medium likelihood	5
Low	Low likelihood	6
Slight	Slight likelihood	7
Very slight	Very slight likelihood	8
Remote	Remote likelihood	9
Almost impossible	No known control methods	10

- **Risk Priority Number (RPN):** It is a measure of design risk. It is product of severity, occurrence and detection.

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

Higher the RPN values, the team must undertake efforts to reduce the risk through corrective actions.

3. METHODOLOGY

The objective behind this approach was to gather the reasons of rejections in a manufacturing industry. So the rejection data was collected. This led to the compilation of failure mode and effect analysis. Thus the 3M pointer was used to identify the root-cause analysis. And then the analysis was further taken to the last step in the FMEA. And finally a solution was established through it.

3.1 OBJECTIVES

- To find out the root-cause analysis using 3M pointer.
- To derive FMEA chart
- To find out the severity, occurrence, detection values and risk priority number
- To inspect the shafts which are machined after FMEA.

4. PROBLEM DESCRIPTION

Cylindrical shafts are long rods which are used as integral parts for the gear assembly. So FMEA technique has been applied to the shaft which has been machined by a manufacturing industry. Problem arose when a batch of ten shafts were machined with the required diameter of 41.50mm to 42.50mm. Out of the ten shafts four shafts

were rejected as their diameters went above 42.50mm. The table 3.1 tabulated below shows the diameter of shafts machined.

Table 4.1 List of shafts machined

Shafts	Required diameter	Attained diameter
LGS 1	41.50mm to 42.50mm	41.89mm
LGS 2		42.05mm
LGS 3		42.26mm
LGS 4		43.80mm
LGS 5		42.50mm
LGS 6		42.61mm
LGS 7		42.10mm
LGS 8		42.85mm
LGS 9		41.78mm
LGS 10		42.92mm

**LGS - Long shafts*

So from the table it can be seen that four shafts were rejected. The list if rejected shafts are tabulated below in table 3.2

Table 4.2 Rejected shafts

Rejected Shafts	Diameters
LGS 4	43.80mm
LGS 6	42.61mm
LGS 8	42.85mm
LGS 10	42.92mm

Therefore causes for these rejections were discussed in the brainstorming session. The ideology used here for the root-cause analysis is '3M Pointer'. When there is any rejections or errors especially in a manufacturing industry, the major causes will be machine, manpower and the material. So this 3M pointer tool reduces all unnecessary confusions and gives way to a direct cause responsible for the rejection/error.

5. PROBLEM ANALYSIS

Root cause analysis in FMEA is driven by 3M pointer here. The 3M refers to the machine, manpower and material. So all the three parameters were analyzed.

5.1 MATERIAL

For the material parameter all the ten shafts given in table 4.1 was subjected to hardness testing. Rockwell hardness test has been performed. The hardness of the shafts should be between 13HRC to 16HRC. Therefore the hardness values of the ten shafts has been tabulated below in the table 5.1

Table 5.1 Hardness value of shafts

Shafts	Hardness values
LGS 1	14.11HRC
LGS 2	14.06HRC

LGS 3	14.12HRC
LGS 4	14.18HRC
LGS 5	14.29HRC
LGS 6	14.50HRC
LGS 7	14.72HRC
LGS 8	14.01HRC
LGS 9	13.92HRC
LGS 10	14.22HRC

From the table 5.1 it can be seen that the hardness values of all the ten shafts were between 13HRC to 16HRC. Therefore there is no issues with the material of the shafts.

5.2 MANPOWER

The second parameter is hitting a checklist on manpower. The machine which machined the ten shafts given in the table 4.1 is programmable. Thus the program is rechecked and there were zero errors found. Therefore there are no issues with the manpower.

5.3 MACHINE

Moving on to the third parameter. The machine was analyzed. The cutting portion of the machine namely the blade compartment was analyzed. And then the miniature gears, the cluster gears and the electrical region was analyzed. And finally the job holding position namely the cradle compartment was analyzed. A crack was found at the stem of the cradle. Now because this crack the vibrations was too much during machining. And this leads to the change in position of the shafts, which in turn increases the diameter of the shafts. Thus the problem has been identified. And there was an issue with one of the machine parts. Now this problem has to be displayed in the FMEA chart.

5.4 FMEA CHART

The severity of the problem is ranked to be '6', the occurrence of the problem is '4', and the detection will be '2'

Table 5.2 FMEA Chart

Part name	Failure mode	Failure cause	Effect of failure	Existing conditions			
				S	O	D	RPN
Cradle	Cradle breakdown	Crack at spindle stem	Shaft size disorientation	6	4	2	48

5.4.1 Calculation

$$\begin{aligned}
 \text{Risk priority number} &= D \times S \times O \\
 &= 2 \times 6 \times 4 \\
 &= 48
 \end{aligned}$$

Therefore the RPN is equal to '48'

5.4.2 Action taken

Thus the corrective action which was taken according to the Risk priority number is listed below in the table 5.3

Table 5.3 Action taken

RPN range	Corrective action
48	Cradle replacement

Thus from then RPN range, the corrective action was the cradle replacement. According to the industry norms, as the RPN was above 40, a new cradle was bought and fitted to the machine.

6. PRODUCTION POST FMEA

Thus after the machine has been made ready with the new cradle, new shafts has been machined. The shafts has been inspected. The diameter has to be between 41.50mm and 42.50mm. The shafts which were machined post FMEA has been listed in the below table 6.1

Table 6.1 Machined shafts after FMEA

Shafts	Required diameter	Attained diameter
LGS 11	41.50mm to 42.50mm	41.50mm
LGS 12		41.85mm
LGS 13		42.13mm
LGS 14		42.12mm
LGS 15		42.25mm
LGS 16		41.97mm
LGS 17		42.03mm
LGS 18		42.11mm
LGS 19		42.17mm
LGS 20		42.21mm

6.1 RESULTS

Thus the diameter of the shafts which were machined after FMEA has been tabulated in the table 6.1. Therefore it has been seen that there were no rejections and the diameter of these shafts are in between 41.50mm and 42.50mm.

7. CONCLUSION

Thus the experimental analysis has shown that the failure mode and effect analysis will identify corrective actions to prevent failures from reaching the customer. Therefore particular procedures has to be followed in order to reduce setup time and to improvise quality of the orders. The corrective measures mentioned here can considerably decrease any losses in the manufacturing industry

A suggestion would be the use of Relia soft XFMEA, an application designed especially for all types of FMEA, in order to reduce the time taken for compiling failure mode and effect analysis in a manual way. Thus the entire analysis made helped to improve efficiency of the processes in the supply chain and quality of product thus decreasing the number of defective products and saving of rework cost and time.

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