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Applying Failure Mode and Effects Analysis for Sustainable Quality Development in Micro, Small and Medium Auto Parts Manufacturers

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Abstract

Failure Mode and Effects Analysis (FMEA) is a systematic approach utilized by industry experts to determine possible failures in processes and products and their potential effects. It is chiefly a preventive approach to foreseeing and averting risks before they arise. By tackling these possible failure areas, companies are able to stimulate continuous product and process improvement in terms of quality.

This research paper explores the function of FMEA as a catalyst for Continuous Quality Improvement (CQI) based on a case study performed in an SME-sized auto manufacturing firm. The paper provides the process of FMEA implementation and indicates improvements noticed in quality output. Findings reveal that incorporating FMEA in manufacturing activity identifies several areas for improvement, which, when rectified, play a valuable role in continuous quality improvement. Through the implementation of FMEA and the implementation of identified improvements, the case companies saw a dramatic decline in rejections.

Keywords:

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Failure Mode and Effects Analysis (FMEA), Continuous Quality Improvement (CQI), Micro, Small and Medium Enterprises (MSMEs)

1. Introduction

Continuous improvement of processes and products is essential for gaining a competitive edge in today's manufacturing industry, especially in increasingly dominant and high-pressure sectors likes automotive. Unfortunately, continuous quality improvement has not been successfully implemented in small scale manufacturing industries, it remains a concept to be endeavored for. There are many quality tools available which make more difficult to choose the right tool to achieve improvement. If the wrong tool is selected, then it may lead to failure of the improvement project or may not produce the intended results. It is, therefore, important to know how, when and which tools should be used in problem-solving or improve processes. Failure Mode and Effects Analysis (FMEA) is one of the tools used for continuous quality improvement. FMEA is a structured analysis used for identification of failure modes and their effects (Pickard K *et al.,* 2005, p. 457–462). It is a very prevailing tool, extensively used in manufacturing processes design, to scrutinize failure modes and to reduce effects of respective failures. Hence it helps in identifying measures necessary to improve the product and processes by concentrating on failure modes and its impact (Xiao et al., 2011, p. 1162–1170). Continuous quality improvement can be achieved by initiating quality improvements which may be identified based on the implementation of quality tools. Six sigma and lean tools are extensively used in the automobile industries, but very minimum work has been done in using ACTs – FMEA, SPC, MSA, APQP and PPAP (Doshi J A et al., 2014, p.245–255).The positive results achieved after the solution of the problems lead to continuous quality improvement. FMEA can be deployed to find the causes of the problem, in some cases a potential problem, along with the solution to be implemented which may improve quality (Teixeira et al., 2012, p.1117–1122). Positive outcomes resulting from problem resolution drive continuous quality improvement.

This research primarily aimed to was to evaluate the effectiveness of Failure Modes and Effects Analysis (FMEA) as a tool for continuous quality

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improvement (CQI) within small-to-medium-sized enterprises (MSMEs). Establishing measurable performance metrics is crucial to monitor ongoing improvements in quality. Among these metrics, rejection rates serve as a key indicator. Therefore, in-process rejections and customer returns were selected to assess the impact of FMEA implementation on quality outcomes. This study specifically focused on the preventive capabilities of FMEA within the context of small and medium automotive enterprises. The structure of the paper mirrors the actual steps taken during the research. It begins with a review of existing literature to understand previous work and provide a foundation for the study. This is followed by a description of the research methodology, and then the practical application of FMEA within selected case companies.

The selection of two enterprises aimed to enhance the reliability and broader applicability of the results.The implementation process involved forming a Cross-Functional Team (CFT), conducting brainstorming sessions and process evaluations, identifying potential areas for improvement, and carrying out corrective actions. Subsequent sections of the paper detail the research findings, analytical insights, and concluding remarks.

2. Literature review

Continuous improvement in manufacturing is a widely acknowledged principle, rooted in the Japanese industrial production model.Despite its popularity, there remains a need for more accessible and straightforward methods to implement its improvement strategies. Real-world applications in manufacturing often encounter various challenges, clearly revealing gaps that still need to be addressed (Federico Mauria et al., 2010, p. 695 - 717). This indicates there is a need for the tool which detects the causes of hitches and offers the means for improvements. FMEA is a one of the useful tools for pinpointing and minimizing—or in some cases, completely preventing—the causes of actual and potential failures. (Liu et al., 2011, p.4403–4415). FMEA application enhances chances of the improvements and advances integration of employees (M. Dudek-Burlikowska, 2011, p. 89-102).

FMEA is conventionally carried out by a team, consisting of members from all processes of organizations. Using their knowledge and past data, risk priority number (RPN) value is assigned for each failure component (Zhang and Chu, 2011, p. 206–214).The different types of FMEA are presented in the diagram below (B R Pathak et al., 2011, p. 25-38).Process FMEA concentrates on solving

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difficulties associated with manufacturing processes. The first step is to study and analyze each step of the manufacturing process and prepare the flow chart. The risks of these effects are then assessed accordingly (Mariajayaprakash, 2013, p. 1-10). The next step involves identifying potential failure modes and their respective causes, determining existing controls, and then assessing the effects of these failures on both manufacturing line operators and end-users.

- System
- (Focuses on global system functions)
- Design
- (Focuses on components & Sub-systems)
- Process
- (Focuses on manufacturing and assesmbly processes)

Fig. 1 – Types of FMEA

RPN is the product of the occurrence (o), severity (s), and detection (d) of a failure,
RPN = S x O x D.
The three risk factors are evaluated on a ten-point scale. The guideline for evaluation is published by AIAG. Failure modes with higher RPN values are assumed to be more important and are given higher priorities than those with lower RPN values (Wang et al., 2009, p. 1195–1207).

The primary goal of FMEA is to reduce failure modes and ensure the production of high-quality products; however, it does not explicitly address the financial impact of potential process issues.Making decisions during emergencies is critical, especially within manufacturing environments. Failure Modes and

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Effects Analysis (FMEA) plays a key role by identifying potential risks linked to specific options, which is essential during both the manufacturing process and its implementation stages (B Almannal, et al., 2008, p. 501 – 504).This limitation highlighted the need for a method that could recognize and prioritize failures based on their economic impact (Vladimir Popović et al., 2010, pp. 1–7). One of the shortcomings of the FMEA prioritization process is that different combinations of severity, occurrence, and detection ratings can lead to the same Risk Priority Number (RPN), potentially causing disagreements among team members when determining the priority level. In such cases, teams may settle on an average or higher value (N. Sellappan et al., 2013, pp. 27–36).

3. Research methodology

Two small-to-medium-sized companies are selected as part of case study base studies. The aim of the case study is to quantify and monitor quality improvement through FMEA selected businesses. The information about the selected SMEs is provided in Table 1. The case-study approach enables a researcher to preserve the whole and meaningful nature of actual events (J A Doshi, et. al). In every one of the chosen MSMEs, a Cross-Functional Team (CFT) was formed to execute the FMEA process. The teams made a detailed analysis of the manufacturing procedures to gain a comprehensive understanding of their specific characteristics, which were then systematically documented in the FMEA worksheet, following the guidelines outlined in the AIAG FMEA Manual. Subsequently, through a series of brainstorming sessions, the CFTs identified potential failure modes and their associated effects for each step of the process. The ranking method has been deployed to priorities for each failure using severity, occurrence and detection method. The risks identified through the FMEA process were documented, and corresponding corrective actions were developed during brainstorming sessions. The following section outlines the methodology employed in the case study-based research.

Step 1. Selection of SMEs
Step 2. Preparation of CFT in each MSMEs
Step 3. Conducting Manufacturing process study
Step 4. Implementing FMEA – by brainstorming sessions
Step 5. Identification of quality improvement opportunities

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Company	Critical Measurement	Manufacturing method
CS – 01	Hole - Diameter	Blow Molding
CS – 02	tube - Diameter	Various Mechanical (Manual cutting, bending, brazing, etc)

Table 1 - Details of Case Companies

4. FMEA Implementation in small and medium companies

FMEA implementation in each of the identified companies commenced with gathering insights from management on process-related issues and key focus areas.

4.1 Preparation Team (Cross Functional Team)

The Cross-Functional Teams was formed based on the competencies of available personnel at each company, as outlined in Table 2.

Company	CFT members
CS - 01	Manufacturing, QC, Director (Marketing/Sales & Purchase), Authors
CS - 02	Manufacturing, QC, Maintenance, Sales, Purchase, Authors

Table 2 - CFT members

4.2 Assessment of Manufacturing Operations

A comprehensive study of the manufacturing process was carried out by the Cross-Functional Teams (CFTs) formed at each case company, with the findings systematically recorded in the FMEA spreadsheet. Every stage of the process, from the receipt of raw materials to the dispatch of finished products was carefully examined to evaluate its impact on subsequent steps, as well as on product and process characteristics and associated concerns. A thorough

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understanding of the processes is essential for the effective execution of FMEA.

4.3 Ideation and FMEA Process

The rollout of FMEA started with the first meeting of the Cross-Functional Team (CFT) formed at each case company, as shown in Table 03. Team members received training on the FMEA methodology, with a particular focus on using the FMEA worksheet and conducting effective brainstorming sessions to identify potential failure modes and their effects. To reinforce understanding, each step of the manufacturing process based on the earlier process study was presented to the team. Through in-depth brainstorming sessions, potential defects related to each step were identified, followed by determining the root causes of these defects. In certain sessions, customers and suppliers were also invited to provide their perspectives. Several meetings and brainstorming sessions were conducted in each company, with the team leaders as well as the authors keeping minute by minute records of all that went on.

The risk rating associated with each of the failure modes and effects were calculated based on the formula below.

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

S- Severity, O- Occurrence, D- Detection

Each category was rated on a scale from 1 to 10. A process step with a calculated Risk Priority Number (RPN) exceeding 100 was classified as a significant risk. It is essential to address such high-risk areas through suitable corrective measures. To mitigate these risks, the Cross-Functional Team (CFT) proposed and documented appropriate preventive and detection actions in the FMEA workbook. The FMEA workbook from one of the case companies is included in the annexure as a sample study. Due to space limitations, only the key process steps are presented.

4.4 Opportunities for Improvement and Their Effect on Quality

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Different brainstorming sessions were carried out by both SMEs to determine failure modes and their effects, subsequently actions to mitigate failures which are possible opportunities to improve quality of the product and processes. Key improvement opportunities identified as result of FMEA are given in Table 3 and 4 with action plan.

Identified Risk	Action Plan for Improvement
Parting line or flashes on the product surface, less weight of the product	Process parameters for each product shall be set and validated. Mechanism to stop alteration in process parameters may be implemented, e.g. access control to panel.
Moulding / Dimensional defects in the component	Go/No Go Fixture shall be developed Defective samples of the product shall be made available (sample bank) to improve the awareness of employees
Improper Assembly	Visual signage of process to be displayed in the assembly area Documented SOP for the assembly to be prepared Regular training to workers for assembly shall be given

Table 3 - Identified Improvement Opportunities for CS-01

Identified Risk	Action Plan for Improvement
Fin opening and fin bend	A clamp maintenance system shall be prepared.
faulty corner radius	Use of a gauge with dimples on it
Cracking of AL sheet in forming process	Proper RM Testing through reputed laboratory

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Table 4 - Identified Improvement Opportunities for CS-02

Alongside the measures mentioned above, one critical improvement initiative is to ensure regular training and competency evaluation of workers.

MSMEs have executed a couple of point implement, not all, during the implementation duration of six months. The result and its impact were visible through KPIs. The data of before FMEA and after FMEA with interim implementation are shown in Table 6 & 7. The improvement is quite visible, and it is going to increase more as lots of improvement opportunities are still being implementation.

CS – 01 – KPIs trends

Sr	Performance Parameters	Measurement Method	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11
1	Reduction in internal rejections	manufactured / rejected	3.04%	3.22%	3.56%	3.00%	3.19%	2.80%	2.16%	1.81%	1.77%	1.79%	1.78%
2	Reduction in customer returns / complaints	dispatch / rejected	1.14%	1.23%	1.01%	1.17%	0.34%	0.29%	0.26%	0.26%	0.24%	0.22%	0.21%
3	Potential failure identified - Improvement points	Based on FMEA (Risks)	18										

CS – 02 – KPIs trends

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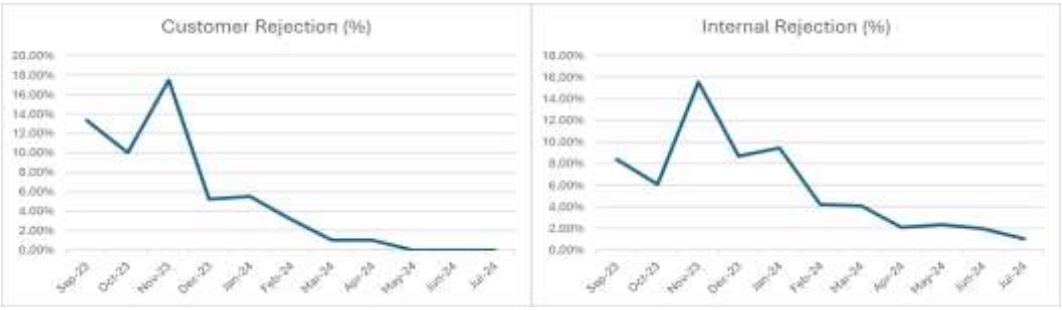
Sr	Performance Parameters	Measurement Method	Month 1	Month 2	Month 3	Month 4	Month 5	Month 6	Month 7	Month 8	Month 9	Month 10	Month 11
1	Reduction in internal rejections	manufactured / rejected	8.42%	6.12%	15.56%	8.70%	9.47%	4.21%	4.08%	2.11%	2.35%	2.00%	1.05%
2	Reduction in customer returns / complaints	dispatch / rejected	13.33%	10.00%	17.50%	5.26%	5.56%	3.16%	1.02%	1.05%	0.00%	0.00%	0.00%
3	Potential failure identified	Based on FMEA (Risks)	16										



5. Conclusion

Several case study-based research has its own advantages; results of one case study support the others, even though single case study can also produce the results excellently and add the value of research (J Doshi, et al; 2016). In this research, the data demonstrates that continuous quality improvement is achievable through the implementation of FMEA. However, the extent of improvement may vary between SMEs, depending on various contextual factors. Both qualitative and quantitative improvements were observed in each participating SME. A minimum improvement of 10% was evident, as shown in Tables 6 and 7. The progress was tracked over an eleven-month period, showing steady gains in each company. In Company 1, internal rejection rates dropped to 1.78%, while in Company 2, they decreased to 1.05%; almost more than 50% in both companies. The same improvement was observed in customer returns as well.

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There is also room for further improvement in case companies if they execute all the improvement points identified and overcome their time, money, and competence constraints. One can easily illustrate that FMEA is one of the most important tools for continuous quality improvement in MSMEs.

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