Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/BA08.20250086
Published: December 20, 2025

Fault Diagnosis and Reliability Assessment in the Bangladesh Motorbike Industry: An FMEA-FTA Approach

S M Sayeed Anowar, Lutfun Nahar Meem, Arpita Saha, Abdul Matin and Md Mahfuzur Rahman
Department of Industrial and Production Engineering
Jashore University of Science and Technology
Jashore - 7408, Bangladesh
sayeedanowar.just@gmail.com, lutfunnaharmeem90@gmail.com, arpita48kgc@gmail.com, abdulmatin.buet@gmail.com, mrahman.ipe@just.edu.bd

Abstract

The motorbike industry in Bangladesh is experiencing rapid growth due to increasing demand and urbanization. However, recurring parts failures during the warranty period (first six months or 6,000 km) have led to higher maintenance costs and lower customer satisfaction. This study aims to optimize motorbike production and maintenance by systematically analyzing reliability issues using a modified Failure Mode and Effects Analysis (FMEA). The traditional FMEA is modified by introducing a dependency (D2) factor alongside severity (S), occurrence (O), and detection (D). Risk prioritization used the Risk Priority Number (RPN) based on a four-year failure dataset, validated by expert evaluations. The result reveals that battery failure is the highest-risk event (RPN = 2457), followed by carburetor fuel overflow, speedometer wetness, crankshaft failure, and fuel tank color degradation. Additionally, this study explored the causal relationship among the failures with system dynamics-based causal loop diagrams (CLD) and followed by fault tree analysis (FTA). Finally, the implementation of a kaizen-based action plan resulted in a 30% reduction in battery warranty claims and eliminated Pre-Delivery Inspection (PDI) failures. Therefore, the integration of FMEA, FTA, and Lean Kaizen strategies provides a robust, real-world solution that enhances system reliability, manufacturing efficiency, and customer satisfaction.

Keywords
Lean-Kaizen, Failure Mode and Effects Analysis, Reliability Assessment, Fault Tree Analysis, Motorbike Industry,

1. Introduction
The motorbike industry in Bangladesh is rapidly expanding with the market expected to reach US$2.00 billion by 2025 which is due to urbanization, economic growth, and rising consumer demand. Currently, 96% of local demand is met through domestic production, pushing manufacturers to enhance cost efficiency, reliability, and production scalability (Statista). However, sustaining this growth faces significant challenges, including frequent parts failures, high maintenance costs, and inefficient production processes, leading to increased operational expenses and reduced profitability. In Bangladesh, one of the most pressing challenges lifespan over the last 4 years (FY 2019-2024) has been the failure of critical components during the warranty period (first six months or 6,000 km), which affects system functionality and product lifespan. Early-life failures, occurring in the "infant mortality" phase of the bathtub curve, require immediate measures to prevent high maintenance costs in the long run and enhance overall reliability. These failures not only elevate maintenance costs but also impact system reliability and customer satisfaction. So, addressing these issues through systematic fault diagnosis and reliability assessment is crucial for preventing severe failures, improving long-term sustainability, and reinforcing consumer confidence. Additionally, to ensure competitive edge, manufacturers must implement systematic risk mitigation strategies to enhance overall productivity.

Systematic risk prevention strategies include structured methodologies which are designed to identify, assess, and mitigate risks through proactive measures, continuous monitoring, and seamless integration into the in-plant production process. These strategies are designed to mitigate potential threats and enhance resilience by integrating risk management principles into decision-making processes and operational frameworks. Therefore, it is useful to optimize resource utilization, minimize waste, and enhance overall productivity. Over the last two decades, various approaches have been employed to mitigate risks, ranging from traditional quality management tools to advanced analytical frameworks. Techniques such as Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), and Root Cause Analysis (RCA) are most popular to identify and prioritize risks. Among them, FMEA is a widely used quality management tool for identifying, evaluating, and prioritizing failure events based on severity, occurrence, and detectability. This approach evaluates the Risk Priority Number (RPN) to rank and prioritize the identified risks. It was originally developed for the aerospace industry, is now widely applied in the automotive and manufacturing sectors globally and has proven highly effective in improving reliability and preventing costly breakdowns (Stamatis 2003).

In Bangladesh, one of the most pressing challenges over the last four years is the failure of critical components during the warranty period, which affects system functionality and product lifespan. To mitigate this concern, this study integrates FMEA with Fault Tree Analysis (FTA) and a System Dynamics-based Causal Loop Diagram (CLD) to systematically analyze risks and formulating preventive measures. Among them, FTA provides a hierarchical approach to identifying root causes and CLD models interdependencies among failure causes, offering a more comprehensive risk mitigation framework. This combined approach enables a deeper understanding of the root causes and interdependencies of failures, facilitating proactive risk mitigation strategies. Furthermore, Kaizen, a lean tool for continuous improvement, has been widely adopted to optimize motorbike production processes (Banduka 2018). It reduces inefficiencies and enhances operational reliability (Ghelani 2021, Tiwari, Sharma et al. 2022). However, existing studies often address either continuous process improvement or risk prioritization separately, lacking a comprehensive framework that connects failure identification with proactive mitigation strategies. Therefore, traditional FMEA models also fail to account for interdependencies among failure causes, limiting their effectiveness in complex industrial environments (Mutlu and Altuntas 2019, Shaker, Shahin et al. 2022). This study bridges existing research gaps with this integrated risk prevention framework. This approach not only determines risk prioritization but also incorporates continuous improvement strategies through Lean Kaizen and PDCA to ensure iterative process enhancements. By integrating qualitative and quantitative failure analysis, this study provides a robust decision-making tool for manufacturers that enhances sustainable productivity improvements optimized resource utilization, and long-term competitiveness.

1.1 Objectives

The objective of this study is to develop a systematic risk prevention framework specifically designed for motorbike production in Bangladesh. This study introduces a new combination of FMEA, FTA, and Lean Kaizen methodologies to develop a practical and effective risk prevention approach for enhancing system reliability, production efficiency, and customer satisfaction.

2. Literature Review

FMEA has been a cornerstone in reliability engineering which evaluates failure risks using the Risk Priority Number (RPN). In FMEA, RPN techniques are widely used to prioritize the risk associated with the failure event. The RPN value is traditionally calculated by finding the probability of failure occurrence, the severity of failure effect on the system and detection of design control (Cho, Lee et al. 2022) (Kechagias, Miloulis et al. 2021). Recent studies highlight its effectiveness in identifying critical failures but also reveal limitations in dynamic risk interdependencies. Doshi and Desai (2017) employed FMEA for sustainable quality improvement in automobile Small and Medium Enterprises (SMEs) in Gujarat, India. Tolontan, Orhei et al. (2024) applied FMEA to assess technical risk and ensure safety in the automotive industry. A study demonstrated the effective application of FMEA in identifying critical measurement failures by pinpointing high-risk failure events and implementing corrective measures that led to sustainable improvements in product quality (Sumasto, Nugroho et al. 2024). Although FMEA has been extensively applied in the automotive and manufacturing sectors, its traditional application focuses on risk prioritization rather than proactive risk prevention. Yousaf, Aized et al. (2023) employed FMEA to identify potential risks and implement risk mitigation strategies in automotive manufacturing processes, enhancing product reliability and performance. Aized, Ahmad et al. (2020) utilized FMEA to improve automotive leaf spring design and manufacturing process.

Haekal (2022) employed FMEA-FTA combinedly to identify in-site production deficiencies and root causes of defects in the Japanese Automotive Corporation. Researchers have seen this combined approach is highly effective for identifying vehicle failure events and conducting a detailed analysis of root causes leading to component failures, making it an ideal method for enhancing reliability and mitigating risks. Febriana and Hasbullah (2021) Utilized FMEA, and FTA to recommend improvements in automobile tire manufacturing process mixing process. To identify failure causes of goods transport vehicles' brake systems, a recent study employed FMEA and FTA-based approaches and recommendations based on the results improved the scenario (Ansori, Waskito et al. 2023). On the other hand, a recent study revealed effective risk mitigation strategies that enhanced risk management through integrated FMEA with system dynamics in the automotive industry. Liu, Li et al. (2021) proposed integrating system dynamics with FMEA to model complex interactions in supply chain risks. A study employed a system dynamics model coupled with FMEA to investigate causal relationships among failure modes, effects, and causes, indicating how causal loop diagrams (CLD) can enhance failure analysis and facilitate effective corrective actions in industrial systems. After finding the root causes associated with each failure events, both preventive and corrective actions should be formulated and followed to ensure systems' reliability and mitigate risk.

From the above, the existing studies overlook causal relationships between failures. Therefore, traditional FMEA models also fail to account for interdependencies among failure causes, limiting their effectiveness in complex industrial environments. Additionally, they address either continuous process improvement or risk prioritization separately, leaving room for the development of comprehensive framework that connects failure identification with proactive mitigation strategies in the context of motorbike industry Bangladesh.

3. Methods

In this study, a structured methodology is followed to enhance motorbike production and maintenance efficiency by integrating FMEA-FTA and system dynamics-based CLD for risk prevention. The approach is visually summarized in Figure 1. From the figure, firstly, all failure modes were identified from production and maintenance records. In the next step, the risks were ranked based on the modified FMEA's RPN. For the highest-RPN failure modes, a system dynamics-based cause-and-effect relationship model and FTA were formulated to analyze the root causes of high-risk failures. Based on the findings from the root cause analysis, Lean Kaizen-based risk prevention strategies were implemented to reduce failure frequency and optimize preventive maintenance. The implementation follows a PDCA cycle to ensure that each improvement is effectively tested, monitored, and refined. Finally, the effectiveness of these interventions is assessed through a comparative evaluation of failure rates and maintenance costs before and after implementation, ensuring system reliability, cost reduction, and continuous productivity improvement.

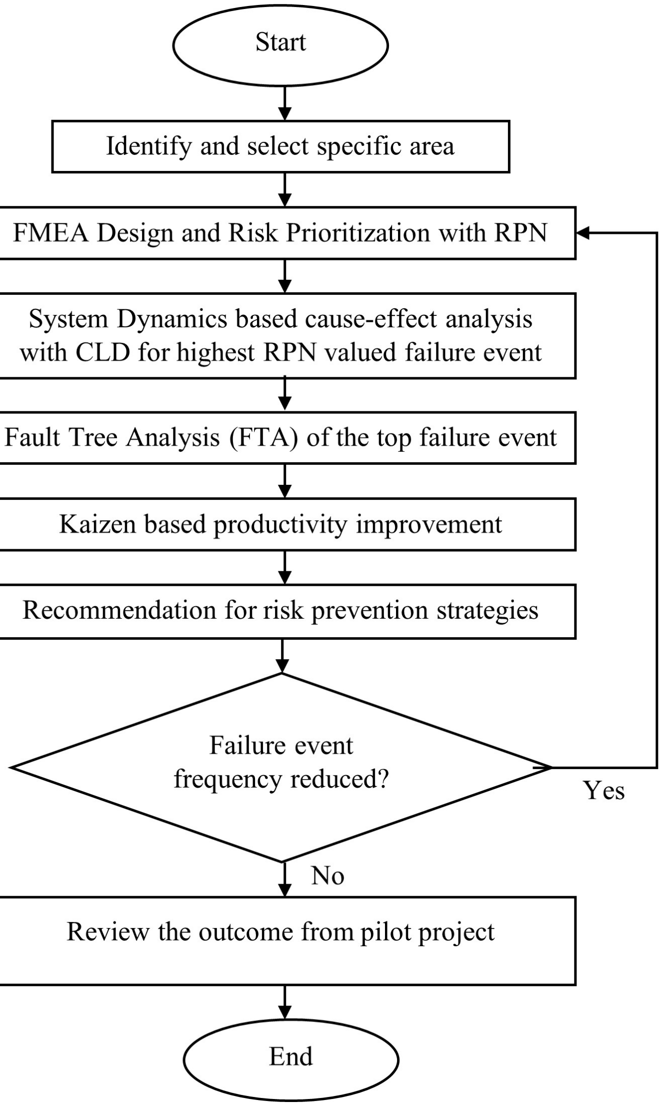

Figure 1. Process flow chart and kaizen-based productivity improvement workflow.

4. Data Collection

This study is based on a four-year dataset of failure records of six megacities of Bangladesh which are Dhaka, Chattogram, Jashore, Rangpur, Bogura, and Sylhet. The dataset derived from warranty claim reports for widely used motorbike models in Bangladesh, such as Hero Glamour, HF Deluxe, Hero Hunk 150, Hero Ignitor, Passion X-Pro, Hero Pleasure, Hero Splendor+, Splendor I-Smart, Hero Thriller 160R, and Thriller 160R (BS6, Self-ABS, Cast-DDS).

Over the past four fiscal years (2019-2023), customers had reported various motorbike component failures within warranty periods, primarily for batteries, speedometers, crankshaft components, fuel tank, and carburetor issues. Figure 2 (a-d) represents an analysis of recurring parts failure over the four years. Annual motorbike sales were 1,02,217 units in FY 19-20, 67,064 units in FY 20-21, 92,991units in FY 21-22, and 78,008 units in FY 22-23.

It is obvious from the figure that battery failure is the most prevalent issue. The failure rate increased sharply from 55% in FY 19-20 (Figure 2(a)) to an all-time high of 72% in FY 21-22 (Figure 2(c)), while slightly decreasing to 69% in FY 22-23 (Figure 2(d)). Over the four years, the average number of battery warranty claims was 3006, which is substantially higher than any other failure category. Other notable recurring failure issues included speedometer malfunction due to moisture ingress (215 cases), crankshaft component failures (207 cases), and fuel tank color deterioration (73 cases).

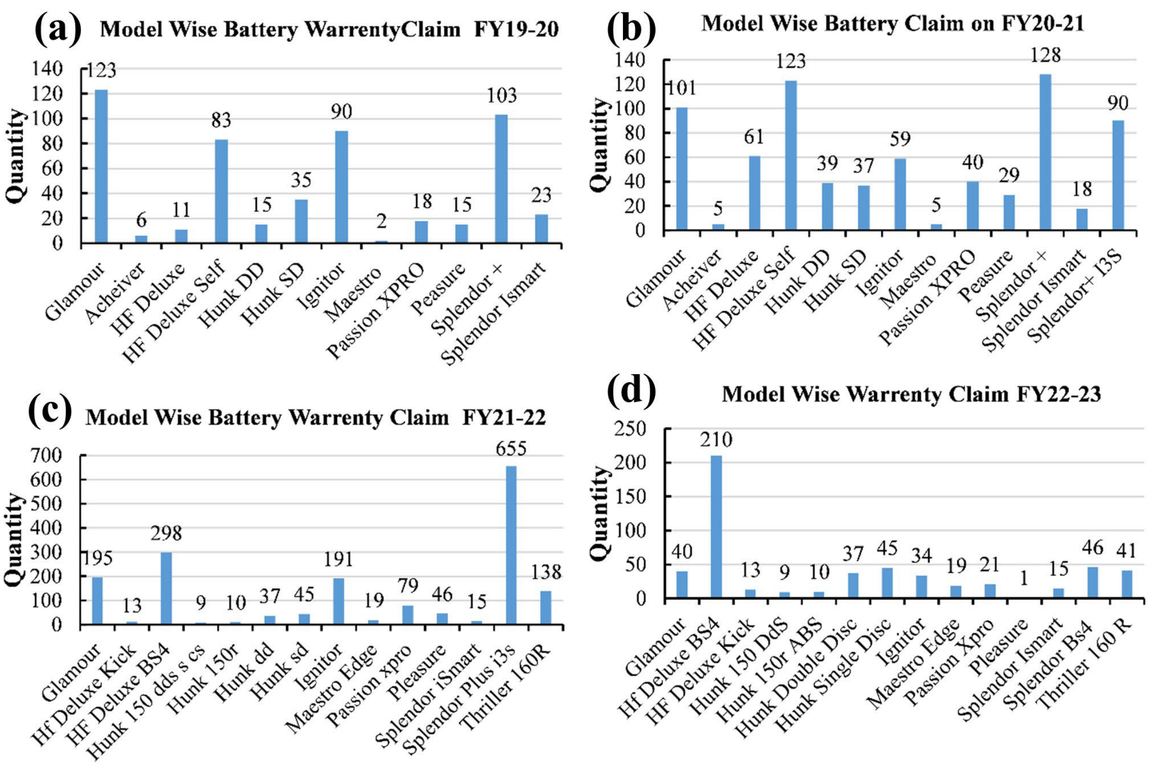

Figure 2. Motorbike component failure frequency at four fiscal years within the warranty periods.

So, it is obvious from Figure 2(a–d) that the battery-related failures remain the most pressing issue and recurring problem within the warranty period. Therefore, immediate measures should be formulated for improved material quality and after-sales maintenance activities.

4.1 Model-Wise Warranty Claims

It is crucial to consider model-wise battery warranty claims to understand bike sales trend and their impact on customer satisfaction. Figure 3 (a-d) shows that the consumers of Hero Glamour and Splendor+ models reported the highest number of battery-related warranty claims, which indicates a recurring issue with battery reliability in these models. Besides, the Splendor Plus i3s model recorded the highest number of claims in FY 2021-22 (655 claims), followed closely by the HF Deluxe BS4 model (298). On the other hand, the lowest warranty claims were noticed for the Achiever and Maestro models.

Recurring parts failures and quality issues had directly impacted sales trends, with declines of 33.39% in FY 20-21, 9% in FY 21-22, and 23.69% in FY 22-23, attributed to both customer dissatisfaction and post-COVID economic challenges. To restore consumer confidence and market stability, immediate corrective and preventive measures are required, which will enhance system reliability, reduce maintenance costs, and ensure long-term market competitiveness, particularly for Glamour, HF Deluxe Self, HF Deluxe BS4, Splendor i3s, Splendor+, Ignitor, and Pleasure models.

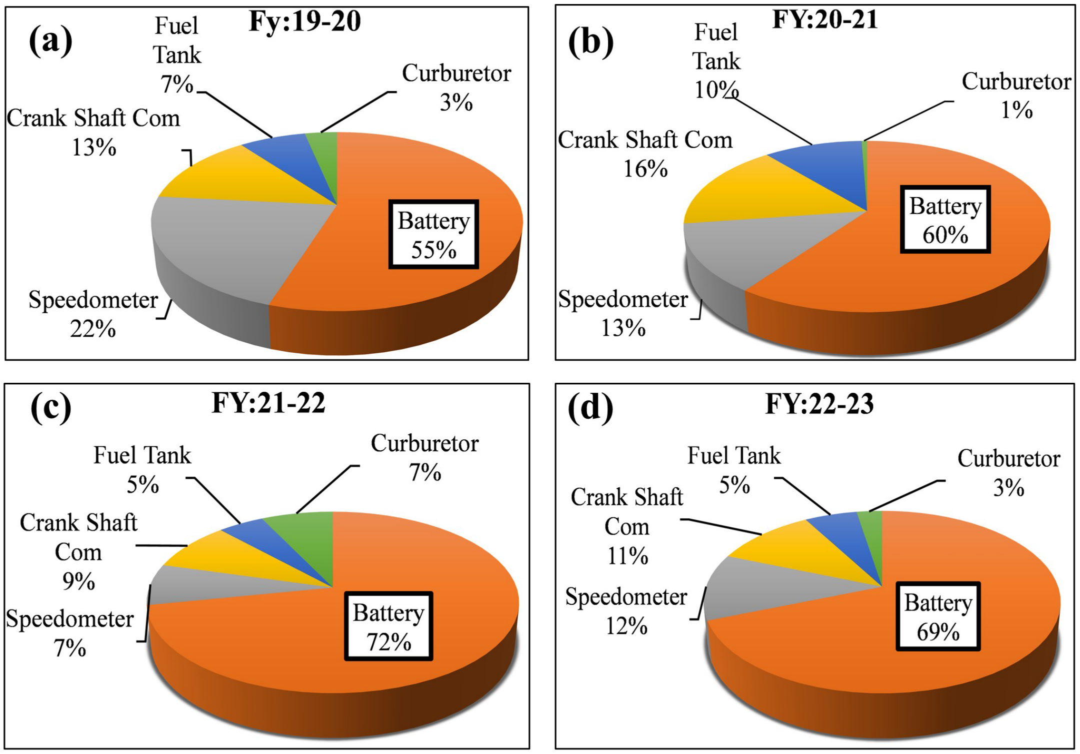

Figure 3. Model wise and year basis warranty claim within the warranty period for the last four fiscal years (a) FY 19-20 (b) FY 20-21 (c) FY 21-22 and (d) FY-22-23.

4.2 Failure Mode and Effect Analysis

The FMEA, a popular lean tool, has been widely used in reliability engineering to find the potential failure mode and the effect of these failures on the system's reliability. In this study, FMEA is implemented systematically to assess and mitigate high-risk failures in motorbike production and maintenance.

While the computation in this study follows the conventional FMEA approach, a minor modification has been introduced by incorporating a fourth factor (D_2) to enhance the precision of risk assessment particularly in complex manufacturing systems like the motorbike industry, where inter-component dependencies play a crucial role in determining failure impact. The RPN calculation steps are described in Figure 4 and Figure 5 represents the rating range on a scale of 10. The details of each factor are given below.

- S (Severity): Assesses the impact of failure on motorbike functionality, safety, and performance. On a 1–10 scale, 1 indicates negligible impact and 10 represents catastrophic failure.
- O (Occurrence): Measures the likelihood of a failure happening based on historical data. A probability-based scale is assigned, where higher values indicate more frequent failures.
- D (Detectability): Represents the ease of detecting a failure before it causes significant damage. A lower score means high detectability, while a higher score suggests that the failure is difficult to detect.
- D_2 (Dependency): An additional factor introduced in this study to assess the cascading effect of a failure on other components. A high dependency score indicates that failure in one component significantly affects other parts of the system.

  Figure 4 Process of RPN calculation for various motorbike component failures (Salah, Alnahhal et al. 2023)

Occurrence	1	2	3	4	5	6	7	8	9	10
(O)	Almost Impossible					Failure Nearly Certain				
Severity	1	2	3	4	5	6	7	8	9	10
(S)	No Impact					Dangerous Impact				
Detectability	1	2	3	4	5	6	7	8	9	10
(D)	Almost Certain					Absolute Uncertainty				
Dependency	1	2	3	4	5	6	7	8	9	10
(D2)	Low Dependency					High Dependency				

Figure 4. Process of RPN calculation for various motorbike component failures (Salah, Alnahhal et al. 2023)

Risk assessment with FMEA is a structured process that involves five key steps such as system subdivision, identification of failure modes, RPN calculation, formulation of preventive action, and analysis reporting. Though frequent parts failure reveals which components require more attention, it is crucial to consider the FMEA approach

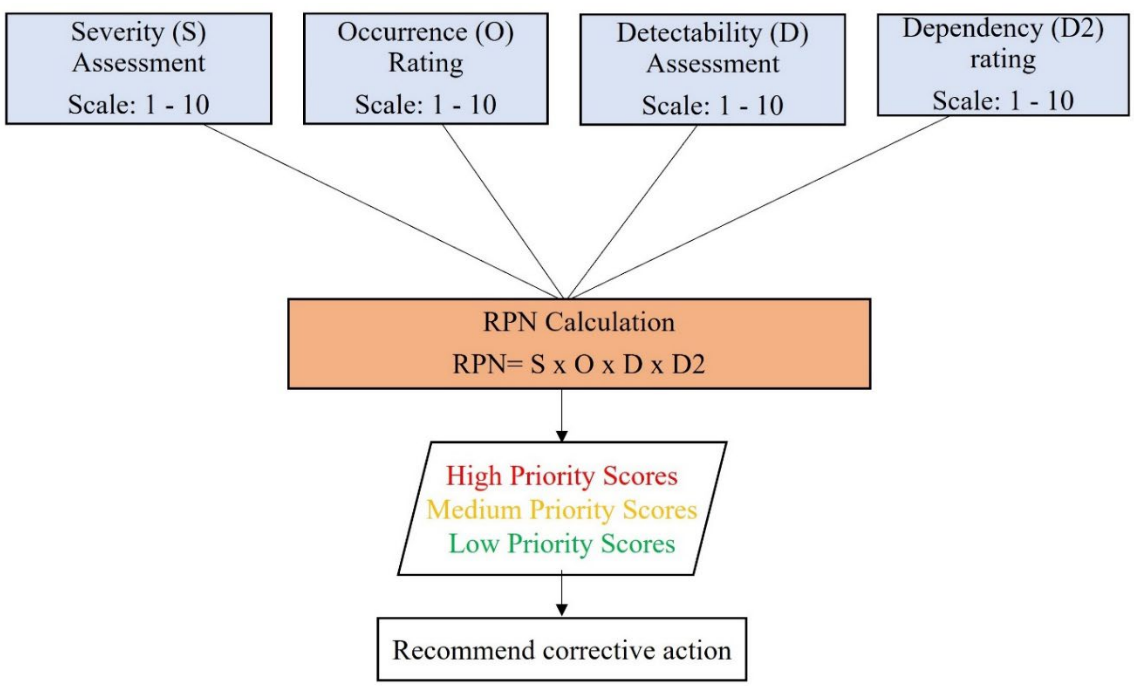

Figure 5. RPN assessment scale for FMEA design

for prioritizing risks, identifying root causes, and implementing preventive measures in order to enhance system reliability and customer satisfaction. In the system subdivision step, all components are divided into subsystems to facilitate a detailed assessment of individual components. For the second stage, the identification of failure mode and cause of failure analysis of each failure event and their consequences is conducted. The severity factor evaluates the potential consequences of a component failure, including injuries, fatalities, property damage, and environmental risks, helping to identify high-risk components. The occurrence factor assesses the likelihood of failure based on the component's age, operational conditions, and manufacturer specifications, prioritizing those prone to failure for maintenance or replacement. The detectability factor determines how easily failures can be identified by analyzing physical wear, corrosion, and structural damage, ensuring that even less visible risks are considered. The dependency factor examines the interdependence of components and the potential cascading effects of a failure, which is essential for recognizing critical system elements that require prioritized maintenance. Once these factors—severity, occurrence, detectability, and dependency—are assessed, the RPN is calculated by multiplying their respective scores, incorporating expert evaluations (Huang, You et al. 2020). In the next step, proactive measures are developed to mitigate failures and enhance system reliability and finally analysis reporting. By integrating multiple risk factors, FMEA's RPN calculation provides a comprehensive risk assessment, strengthening preventive strategies and improving overall system performance.

4.3 Fault Tree Analysis

Fault Tree Analysis (FTA) is a visual tool that analyzes the failure logic through a top-down approach. It is used to identify and map potential causes of industrial system failures in various disciplines (Bracke 2024) (Soleimani, Shahbeigi et al. 2024). The defect type, represented as the top event, is traced back to its root causes through branching sources. The fault tree diagram visually illustrates how failure events and their combinations contribute to the top event, ensuring accurate identification of defect origins (James, Gandhi et al. 2018). The analysis consists of three layers: complex system events at the top, functions, and system failures in the middle and basic events and component failures at the bottom.

The study is initiated by systematically analyzing warranty claims, maintenance records, and field reports to identify recurring issues in motorbike performance. To strengthen failure analysis, this study integrates FTA with FMEA, focusing only on the top RPN event. While FMEA prioritizes failure modes, it lacks a structured approach to analyzing causal relationships. To address this, FTA is applied to systematically break down the root causes of the highest-risk failure event (battery failure), mapping failure pathways in a top-down hierarchy.

4.4 Causal Loop Diagram

A causal loop diagram (CLD) is known as a system thinking diagram. A causal loop diagram is a diagram which illustrates complicated issues or variables that are causally interdependent and discovers the major feedback loops of a system. It (CLDs) is a visual tool used in system dynamics tool that visualizes relationships between variables and identifies feedback loops. It uses arrows to depict causal links, with positive (+) indicating direct proportionality and negative (–) indicating inverse effects. CLDs highlight reinforcing (R) and balancing (B) loops, aiding in the analysis of complex systems, prediction of unintended consequences, and strategic decision-making across various fields (Sterman 2000, Haraldsson 2004).

In this study, CLD is developed to visualize feedback loops and dynamic interactions related to the top RPN failure. It is employed in fault diagnosis and reliability assessment to model the dynamic interactions and feedback loops among motorbike components. It facilitates the identification of cascading failures, elucidates complex system interactions, and improves the prediction of system behavior. This approach supports the prioritization of critical faults and the development of more effective mitigation strategies. In order to improve motorcycle reliability and production efficiency, this study integrates FMEA, FTA, and CLD to provide a comprehensive failure analysis framework that goes beyond risk prioritization towards data-driven root cause identification and preventive measure formulation.

5. Results and Discussion

The FMEA results in Table 1 and the corresponding Pareto chart in Figure 6 highlight that battery failure has the highest RPN value (2457), accounting for 19.56% of the total failure events. Therefore, it is one of the most critical failure modes and requires immediate corrective action to improve motorbike reliability. The crankshaft component failure ranks second, with an RPN of 960 and a cumulative contribution of 56.82%. Next, carburetor failure, with an RPN of 819, further increases the cumulative percentage to 88.61%. These three failure modes collectively account for more than 88% of the overall risk contribution. It highlights that they dominate reliability issues and should be prioritized for improvement. On the other hand, the rest of the component failures, such as the speedometer and fuel tank, contributed the least to the cumulative RPN, reaching 96.06% and 100%, respectively, with relatively lower risk. This analysis indicates the urgency of implementing preventive measures, particularly targeting battery reliability improvements through enhanced quality control, optimized charging systems, and preventive maintenance strategies.

Table 1. RPN for each component of the motorbike

Failure Criteria	Severity	Occurrence	Detectability	Dependency	RPN
Battery	7	9	6	6.5	2457
Crankshaft Components	5	8	4	6	960
Carburetor	6.5	6	3	7	819
Speedometer	4	8	6	1	192
Fuel Tank	1.3	6.5	6	2	101

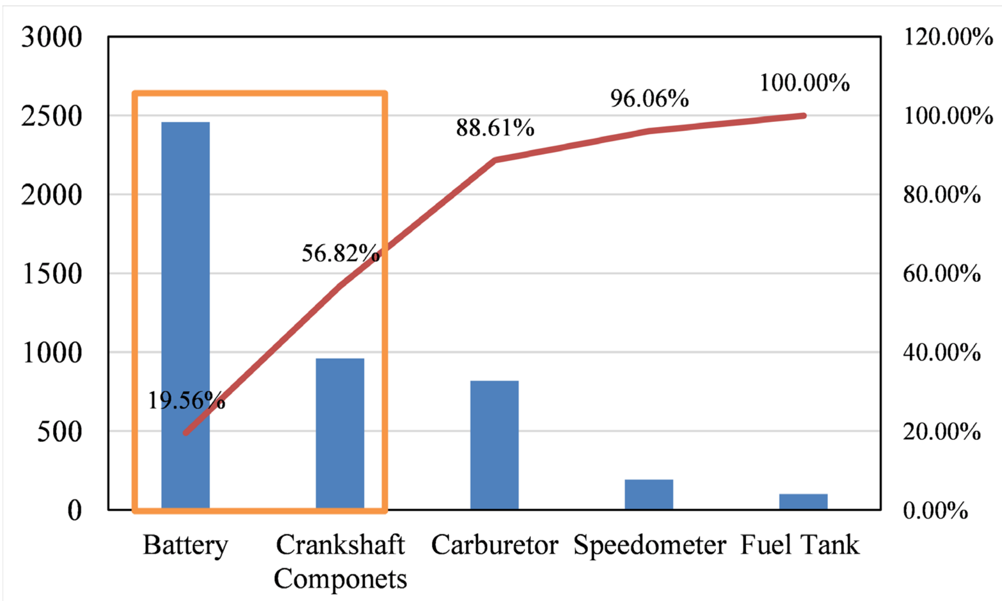

Figure 6. RPN Pareto analysis for risk prioritization

5.1 Fault Tree Analysis of Top Failure Event

Frequent battery failures have resulted in insufficient cost-cutting measures, increasing warranty claim expenses and reducing overall profitability. After conducting FMEA to analyze the causal structure behind this failure, FTA was performed to investigate the logical relationship between the top failure event (insufficient cost-cutting in battery failure) and its underlying causes. FTA is a qualitative top-down risk assessment tool used to systematically map failure pathways and contributing factors. It provides a graphical and logical representation of faults, identifying the root causes and their interdependencies.

The FTA diagram in Figure 7 illustrates how multiple failure contributors escalate to the top event - insufficient cost-cutting due to motorbike battery failure. From the figure, the contributing factors were divided into four intermediate causal categories: lack of process optimization, improper Pareto analysis and RPN assessment, defective FMEA implementation, and limitations in Kaizen initiatives. All these intermediate causes are influenced by multiple operational and managerial shortcomings, which are inadequate maintenance awareness, poor scheduling, incomplete data collection, misinterpretation of analytical tools, weak follow-up of FMEA activities, and insufficient workforce skills.

The findings highlight that addressing process inefficiencies and weak risk management, along with implementing Kaizen-based improvements, is essential for enhancing system reliability and achieving long-term cost reduction in motorbike production. The key initiatives that should be implemented are (i) Kaizen-based corrective actions must be formulated to optimize standard operating procedures (SOPs), enhance training, and improve maintenance practices; (iii) Improving cross-functional collaboration, enforcing structured maintenance schedules, and enhancing data accuracy will mitigate failure triggers. So, Kaizen-based process improvements are necessary to eliminate high-impact failure events, ensuring better system reliability and long-term cost reduction in motorbike production.

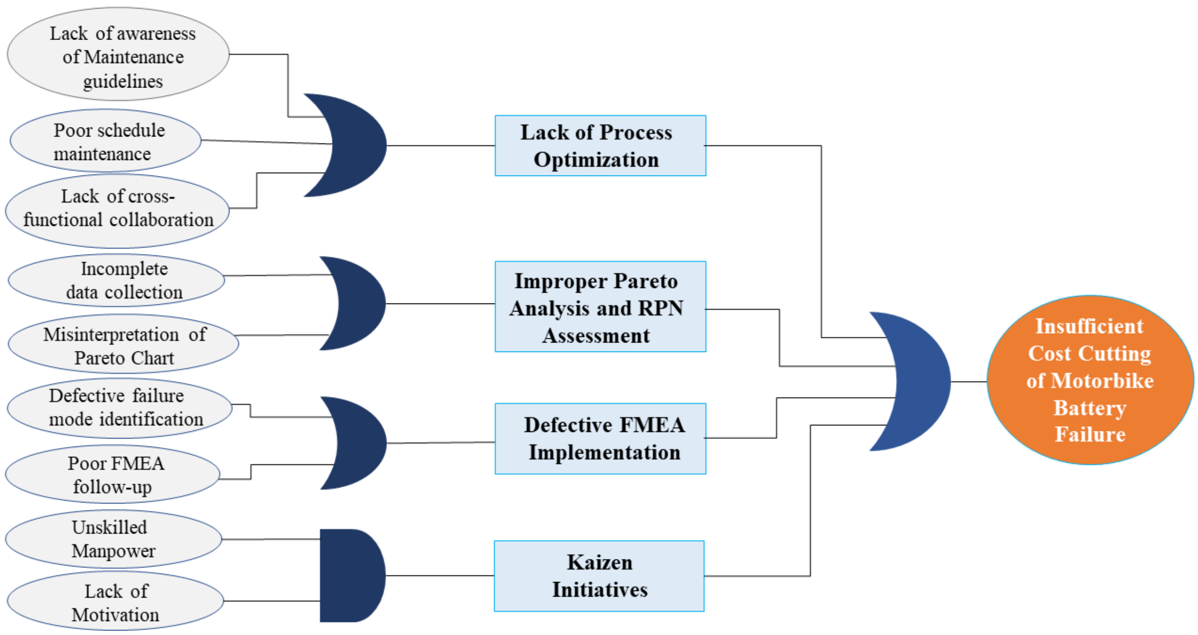

Figure 7. Fault Tree Analysis for costly motorbike battery failure and maintenance within the warranty period.

5.2 Battery Failure Claim Cause-Effect Relationship

A comprehensive analysis was conducted to investigate the underlying causes of battery failure. Figure 8 presents a CLD, mapping the interdependencies and feedback loops affecting battery performance within the warranty period. Here, positive loops indicate reinforcing effects (increasing failure risk over time), while negative loops show balancing effects (helping to control failure rates). Here, balancing loops primarily involves human factors such as effective training enhances workforce competency, reduces human error, and minimizes irresponsibility in battery handling. Conversely, insufficient training increases mistakes in installation, maintenance, and acid-level checking, which lead directly to premature failures.

One of the key balancing loops relates to training, skilled workforce, and human error. Effective training programs enhance technical expertise, thereby reducing human errors and irresponsibility in battery handling. However, inadequate training leads to poor maintenance practices, such as incorrect battery installation and failure to check acid levels, increasing failure rates. Similarly, another negative loop relates to workforce efficiency and diagnosis issues. A shortage of skilled technicians results in poor failure diagnosis and ineffective repairs, leading to misdiagnosed faults, improper installations, and increased human errors, all of which contribute to premature battery failure. Likewise, material quality influences battery stability, where high-quality electrodes improve performance, but inconsistencies accelerate degradation and premature failure. Additionally, measurement-related issues, such as inaccurate voltage monitoring and overcharging, further exacerbate performance deterioration.

On the other hand, a reinforcing feedback loop exists concerning SOPs and battery reliability. A well-defined SOP ensures proper installation, routine acid level checks, and adherence to charging protocols, all of which enhance battery reliability and lifespan. When SOPs are consistently followed, the frequency of early battery failures is significantly reduced, leading to improved performance and customer satisfaction. Overall, the CLD underscores the need for improvement in training, strict SOP enforcement, and better material quality control to minimize battery failures and enhance motorbike reliability. Overall, the figure underscores that reducing the frequency of battery failures requires improving technical training, strengthening diagnostic skills, enforcing SOP compliance, and ensuring material quality control.

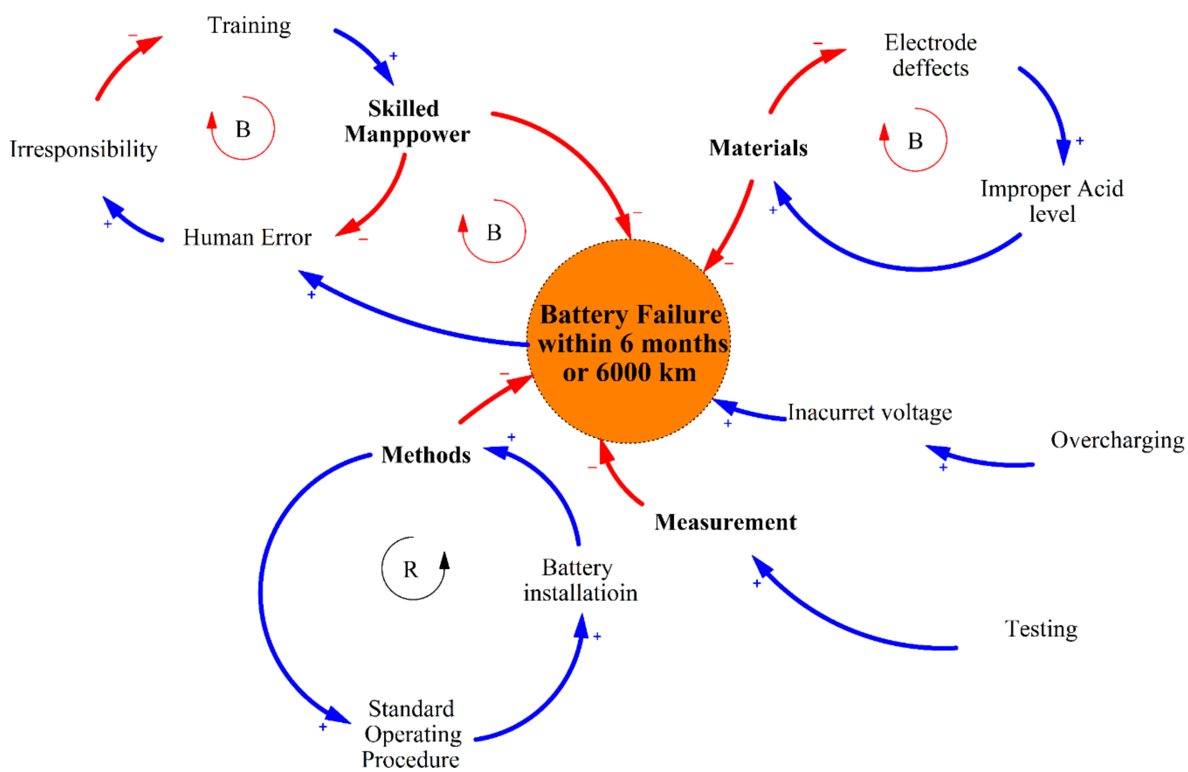

Figure 8. Causal loop diagram for battery failure within the warranty period.

5.3 Kaizen-based Performance Improvement Strategies

To mitigate these high-RPN failures, the following Kaizen-based performance improvement strategies are recommended to enhance system reliability, reduce failure recurrence, and minimize warranty claims. Additionally, early detection mechanisms such as predictive maintenance strategies can significantly reduce failure recurrence, ensuring a more reliable and efficient motorbike system.

Table 2. Root Cause Analysis and Proposed Improvements

Failure Mode	Potential Root Causes	Kaizen-Based Improvement Strategies
Battery Failure	• Lack of standard battery charging procedures (SOPs). • Failure to check sulfuric acid levels. • Battery voltage below 13.5V requires full charge, but customers sometimes skip post-purchase charging (time required 5-6 hours)	• Implementing battery charging stations in the bike production sites. • Formulating standardized battery charging SOPs. • Checking battery acid level and voltage before selling. • Train technicians on maintenance. • Introducing Pre-Delivery Inspection (PDI) for battery validation and

		implementing structured failure documentation for feedback.
Crankshaft Component Failure	• Crankshaft bearing lock. • Consumers skipped free after-sales service (preventive maintenance), leading to early wear and failure.	• Implement strict crankshaft alignment checks. • Introduce predictive maintenance schedules and educate consumers about their importance. • Ensure proper lubrication and service before bike delivery.
Carburetor Fuel Overflow	• Impure fuel leading to overflow issues in newly purchased motorbikes	• Training dealers and customers on high-quality fuel usage. • Implement structured maintenance schedules for carburetor monitoring.
Speedometer Wetness	• High-pressure water jets during bike washing, leading to moisture accumulation inside the speedometer unit	• Improve sealing mechanisms during the production process to enhance water resistance. • Prohibition of high-speed water jet washing;
Fuel Tank Color Degradation	• Issues on In-plant painting. • Environmental factors during manufacturing reduce paint durability	• Optimize fuel tank painting process for better adhesion. • Strengthening quality control in paint application

Additionally, cross-functional collaboration, real-time failure tracking, continuous technician training, and structured customer feedback loops will ensure sustained improvements. Applying the PDCA cycle will further refine defect mitigation strategies, optimize costs, and improve customer satisfaction.

5.4 Pilot Project Results

Despite its effectiveness, implementing FMEA practically is challenging, especially in developing countries, due to resources and limitations in expertise and interdepartmental collaboration. However, the developed kaizen-based measure was tested with PDCA cycle follow-up from November 2024 to February 2024.

Figure 9 shows that an in-plant battery charging station of five units was installed, and changes were made in the production process to ensure quality assurance. Figure 10 depicts the failure trend after adopting this framework. The quantity in the orange bars quantity of defective batteries, and the trend line indicates the warranty claim percentage relative to sales. Results from the figure revealed that the Kaizen-based interventions and FMEA significantly reduced battery warranty claims and improved cost efficiency.

As shown in the highlighted square section in Figure 10 (Nov-24 to Feb-25), a sharp decline in failure events is noticed compared to the pre-intervention period (where claims reached 232 units or 15%). The failure frequency reached a low of 10 units (1%) in January 2025, with a minor fluctuation in February 2025. Moreover, the key findings include a 30% reduction in battery warranty claims (previously 140–150/month), zero dealer PDI battery claims in the last three months (previously 30–40/month), and improved pre-dispatch battery checks, which contributed to savings in PDI warranty costs. Additionally, the sold bikes warranty cost savings were realized with fewer post-sale claims, leading to total yearly battery warranty cost savings from reduced failures, as a result, customer satisfaction was enhanced with fewer battery-related issues.

Figure 9. In-plant battery charging station with five units for enhanced battery maintenance and quality control.

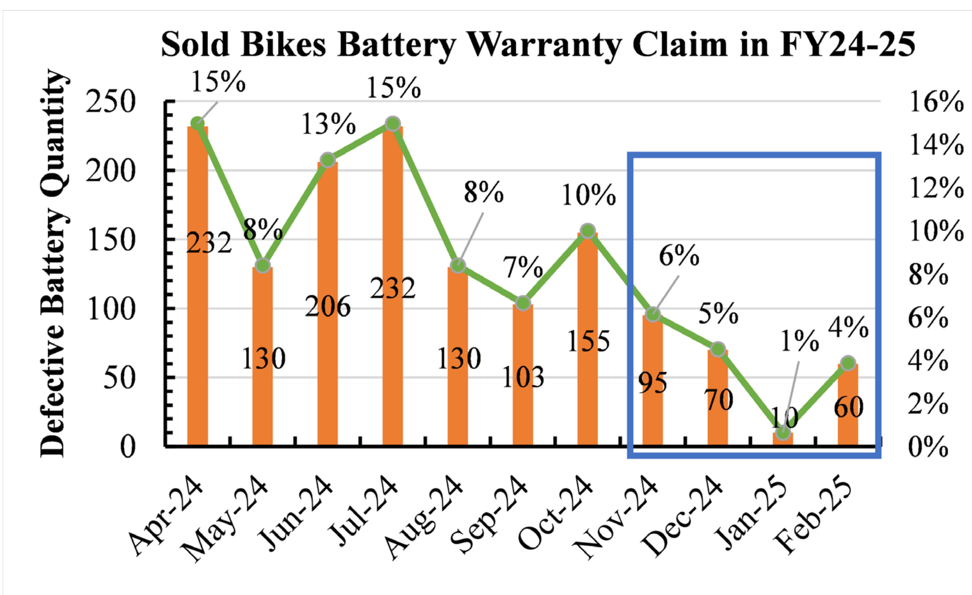

Figure 10. Implementations of kaizen-based performance improvement strategies in the last 3 months of FY22-24.

6. Conclusion

This study provides a deeper insight into the systematic identification, prioritization, and mitigation of failure risks in motorbike components using FMEA, FTA, and CLD methodologies. Beyond traditional risk assessment, these methodologies enabled data-driven root cause identification and preventive action formulation. The findings revealed that battery failure accounted for the highest percentage of warranty claims, necessitating immediate preventive measures. The implementation of Kaizen-based performance improvement strategies led to a 30% reduction in battery-related warranty claims, significantly lowering costs at both dealer and manufacturer levels. Additionally, targeted process optimizations for speedometer, crankshaft, fuel tank, and carburetor failures improved system reliability and customer satisfaction. The FTA and CLD frameworks provided deeper insights into failure interdependencies, ensuring a structured approach to preventive maintenance and continuous process enhancement. Kaizen-based improvement strategies, such as implementing standardized operating procedures, predictive maintenance, enhanced quality assurance, and comprehensive training for both technicians and customers, were identified as effective solutions for mitigating these issues.

The findings underscore the importance of continuous monitoring, the PDCA cycle, structured feedback loops, and cross-functional collaboration for sustaining long-term quality improvements. The study's outcomes validate the practical applicability of this approach in enhancing motorbike manufacturing processes, reducing operational costs, and boosting overall product reliability. Specifically, the 30% reduction in battery warranty claims, the elimination of dealer PDI battery claims before selling bike delivery, and the improved pre-dispatch checks highlight the tangible benefits of the Kaizen-based measures in reducing failures and enhancing cost efficiency.

However, the research was constrained by a limited sample size, focused only on specific motorbike brands, which limits the generalizability of the findings across the industry. Additionally, while the current methodology relies on historical data and expert assessments, integrating Machine Learning-based predictive maintenance models could further optimize failure detection, cost savings, and warranty claim reduction strategies. Future research should focus on scaling this approach across multiple brands, integrating AI-driven failure prediction models, and refining cost optimization frameworks to maximize long-term efficiency and reliability.

Reference

Aized, T., Ahmad, M., Jamal, M. H., Mahmood, A., Ubaid ur Rehman, S., and Srai, J. S. J., "Automotive Leaf Spring Design and Manufacturing Process Improvement Using Failure Mode and Effects Analysis (FMEA)," International Journal of Engineering, Business and Management, Vol. 12, 2020, Article ID 1847979020942438.

Ansori, I., Waskito, D. H., Mutharuddin, M., Irawati, N., Nugroho, S., Mardiana, T. S., Subaryata, S., and Siregar, N. A. M., "Enhancing Brake System Evaluation in Periodic Testing of Goods Transport Vehicles Through FTA-FMEA Risk Analysis," Journal of Advanced Engineering and Science, Vol. 6, No. 2, pp. 320–335, 2023.

Banduka, N., Improvement of Product Reliability During the Production Process in the Automotive Industry Using Improved FMEA Analysis, Fakultet elektrotehnike, strojarstva i brodogradnje u Splitu, 2018.

Bracke, S., "System Analysis: Function, Fault Tree and Failure Mode and Effects," in Reliability Engineering: Data Analytics, Modeling, Risk Prediction, Springer, pp. 201–230, 2024.

Cho, S. W., Lee, H. S., and Kang, J. J., "A Study on the Common RPN Model of Failure Mode Evaluation Analysis (FMEA) and Its Application for Risk Factor Evaluation," Journal of Korean Society for Quality Management, Vol. 50, No. 1, pp. 125–138, 2022.

Doshi, J., and Desai, D. J., "Application of Failure Mode & Effect Analysis (FMEA) for Continuous Quality Improvement – Multiple Case Studies in Automobile SMEs," International Journal of Quality Research, Vol. 11, No. 2, pp. 345, 2017.

Febriana, T. H., and Hasbullah, H. J., "Analysis and Defect Improvement Using FTA, FMEA, and MLR Through DMAIC Phase: Case Study in Mixing Process Tire Manufacturing Industry," Journal of Engineering and Decision Sciences, Vol. 54, No. 5, 2021.

Ghelani, H., "Advances in Lean Manufacturing: Improving Quality and Efficiency in Modern Production Systems," Journal of Value and Innovation in Design and Lean, pp. 611–625, 2021.

Haekal, J., "Quality Control with Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA) Methods: Case Study Japanese Multinational Automotive Corporation," International Journal of Safety and Automation, Vol. 3, pp. 227–234, 2022.

Haraldsson, H., Introduction to System Thinking and Causal Loop Diagrams, Department of Chemical Engineering, Lund University, Lund, Sweden, 2004.

Huang, J., You, J.-X., Liu, H.-C., Song, M.-S., and Safety, S., "Failure Mode and Effect Analysis Improvement: A Systematic Literature Review and Future Research Agenda," Journal of Reliability Engineering, Vol. 199, Article 106885, 2020.

James, A. T., Gandhi, O., and Deshmukh, S. J., "Fault Diagnosis of Automobile Systems Using Fault Tree Based on Digraph Modeling," International Journal of Safety and Environment Management, Vol. 9, pp. 494–508, 2018.

Kechagias, E. P., Miloulis, D. M., Chatzistelios, G., Gayialis, S. P., and Papadopoulos, G. A., "Applying a System Dynamics Approach for the Pharmaceutical Industry: Simulation and Optimization of the Quality Control Process," Journal of Applied Process Analysis, 2021.

Liu, Z., Li, Y., Zhang, N., Liang, Z., and Li, F., "Reliability Analysis of CFRP-Packaged FBG Sensors Using FMEA and FTA Techniques," Advances in Science Letters, Vol. 11, No. 22, Article 10859, 2021.

Mutlu, N. G., and Altuntas, S. J., "Risk Analysis for Occupational Safety and Health in the Textile Industry: Integration of FMEA, FTA, and BIFPET Methods," International Journal of Industrial Engineering, Vol. 72, pp. 222–240, 2019.

Salah, B., Alnahhal, M., and Ali, M. J., "Risk Prioritization Using a Modified FMEA Analysis in Industry 4.0," Journal of Engineering Research, Vol. 11, No. 4, pp. 460–468, 2023.

Shaker, F., Shahin, A., and Jahanyan, S. J., "Investigating the Causal Relationships Among Failure Modes, Effects and Causes: A System Dynamics Approach," International Journal of Quality and Reliability Management, Vol. 39, No. 8, pp. 1977–1995, 2022.

Soleimani, M., Shahbeigi, S., Esfahani, M. N. J. M. S., and Processing, S., "A Bayesian Network Development Methodology for Fault Analysis; Case Study of the Automotive Aftertreatment System," Journal of Manufacturing Science and Processing, Vol. 216, Article 111459, 2024.

Stamatis, D. H., Failure Mode and Effect Analysis, Quality Press, 2003.

Statista, "Motorcycles – Bangladesh," https://www.statista.com/outlook/mmo/motorcycles/bangladesh.

Sterman, J., Instructor's Manual to Accompany Business Dynamics: Systems Thinking and Modeling for a Complex World, McGraw-Hill, 2000.

Sumasto, F., Nugroho, Y. A., Solih, E. S., Arohman, A. W., Agustin, D., and Permana, A. K., "Enhancing Quality Control in the Indonesian Automotive Parts Industry: A Defect Reduction Approach Through the Integration of FMEA and MSA," International Journal of Management and Manufacturing, Vol. 23, No. 1, pp. 43–53, 2024.

Tiwari, K. V., Sharma, S. K. J. P. I., and Sustainability, O. f., "The Impact of Productivity Improvement Approach Using Lean Tools in an Automotive Industry," Journal of Productivity and Innovation in Sustainability, Vol. 6, No. 4, pp. 1117–1131, 2022.

Tolontan, M., Orhei, C., and Vasiu, R., "Overview of the Technical Risk Analysis and Risk Assessment Analysis in Automotive Industry," in Proceedings of the 2024 International Symposium on Electronics and Telecommunications (ISETC), IEEE, 2024.

Yousaf, M. U., Aized, T., Shabbir, A., Ahmad, M., and Nabi, H. Z., "Automobile Rear Axle Housing Design and Production Process Improvement Using Failure Mode and Effects Analysis (FMEA)," Journal of Engineering Failure Analysis, Vol. 154, Article 107649, 2023..

Biographies

S M Sayeed Anowar completed his BSc in Industrial and Production Engineering from Jashore University of Science and Technology, Jashore, Bangladesh. During his undergraduate studies, he contributed to multiple industrial-academia projects in collaboration with faculty members and funding authorities. He worked as a Consultant at Swiss contact, Bangladesh, focusing on testing and optimization of standardized light engineering products in collaboration with BITAC and SME Foundation. His research interests include Material Science Engineering, Mechanical Engineering, Manufacturing Engineering, with a focus on bridging theoretical knowledge with practical industrial applications.

Lutfun Nahar Meem is a dedicated student working towards her degree in Industrial and Production Engineering at Jashore University of Science and Technology (JUST), Jashore, Bangladesh. She has a deep interest in engineering and innovation and is focused on understanding the complexities of industrial systems and management workflow. She is developing her skills in areas such as problem-solving, optimization, and improving efficiency—essential aspects of her field. Meem actively engages in academics, aiming to apply theory to practice and address modern challenges in industrial engineering, contributing to research and industry advancements.

Arpita Saha is an undergraduate student majoring in Industrial Engineering at Jashore University of Science and Technology, Bangladesh. With a keen interest in the principles of industrial engineering and data analysis. She is passionate about the manufacturing process, supply chain, and logistics. She is committed to academic excellence and aims to contribute to the field of industrial efficiency and sustainable production.

Abdul Matin serves as the Head of Quality Assurance at Hero Motorcycle Manufacturing Plant, with over 15 years of experience in production, quality control, and engineering management. He holds degrees in Re-Engineering

(BUET), Supply Chain Management (IBA, University of Dhaka), an MBA in HRM (BOU), and an MSc in Industrial and Production Engineering (JUST). Abdul specializes in quality assurance, system compliance, and continuous improvement, leveraging strong leadership and time management skills to meet deadlines. He is known for his excellent communication abilities and dedication to enhancing operational efficiency.

Dr. Md Mahfuzur Rahman is an Assistant Professor at the Department of Industrial and Production Engineering, Jashore University of Science and Technology (JUST), Bangladesh. He completed his higher studies at the Masdar Institute for Science and Technology. His research interests include materials development, product design, sustainable technology, and industrial innovation. Dr. Rahman is actively participating in research and development (R&D) projects, focusing on bridging scientific innovation with practical industrial applications.