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# Improving Automotive Accessory Development: A Warranty-Based Analysis of Material Defects and Process Enhancement

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## ABSTRACT

Automotive accessories play a crucial role in enhancing vehicle safety, aesthetics, and functionality; however, they account for a significant portion of recurring warranty claims at MNC Automotive. In 2022, analysis of warranty claims data revealed that 30% of total claims were attributed to a single accessory type, indicating systemic weaknesses in design validation, supplier performance, and quality assurance. To address these challenges, this study proposed an improved accessory part development process that emphasizes early supplier collaboration, comprehensive design validation, statistical validation methods (such as SPC, Regression Analysis and Confidence Intervals), and standardized manufacturing practices. The study integrated SPC (Control Charts) and regression analysis to validate defect trends and link supplier performance with defect rates, offering quantitative validation beyond qualitative tools like Pareto charts and Ishikawa diagrams. Confidence intervals were calculated to estimate defect reduction, providing a statistical basis for the improvement strategies. Furthermore, the study included a cost-saving analysis, indicating potential RM 1.5 million savings, which was estimated through a cost-benefit analysis that simulates the ROI from improved processes. Incorporating comparative benchmarking with historical data allows us to track the severity and progress of improvements in defect rates and warranty claims. Additionally, the study integrated a more detailed evaluation of supplier performance, where supplier audits and performance ratings were used to identify critical areas for improvement in quality control. The proposed part development process aligns with APQP, PPAP, and IATF 16949 frameworks, ensuring that the model conforms to globally recognized quality management standards. Key elements of these frameworks, such as early engagement, traceability, and continuous improvement cycles, were incorporated to address recurring quality issues, thereby improving product reliability, reducing defects, and strengthening supplier relationships. This study contributes to the broader field of automotive engineering by offering a data-driven approach to improving the manufacturing and supply chain processes, with implications for reducing long-term costs, enhancing product quality, and improving customer satisfaction. By addressing key weaknesses in supplier collaboration, design validation, and quality assurance, the proposed improvements are expected to lead to significant reductions in warranty claims, ultimately benefiting both manufacturers and consumers.

**Keywords**: Warranty claims; automotive accessories; SPC; supplier collaboration; quality control.

## 1.0 INTRODUCTION

The automotive industry has undergone significant growth in Malaysia, transitioning from vehicle assembly to advanced manufacturing with increased automation and lean processes aimed at optimizing production efficiency [1][2]. Alongside Original Equipment (OE) parts, automotive accessory parts have also been developed to enhance comfort, style, and functionality, playing an integral role in improving safety systems in modern vehicles. These accessories contribute to minimizing road hazards and improving the overall driving experience [3]. However, despite improvements, MNC Automotive continues to face significant challenges related to warranty claims for automotive accessories, which have become a major concern both financially and operationally [4].

In 2022, an analysis of warranty claims revealed that 30% of the total warranty claims were attributed to a single accessory type, indicating systemic weaknesses in design validation, supplier performance, and quality assurance. These recurring issues have resulted in increased costs and diminished customer satisfaction, highlighting the need for an improved part development process.

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Figure 1 illustrates a troubling trend in warranty costs over the past six years, showing a sharp rise in Year 6 (RM 7,276). This upward trend suggests that the issues are systemic, with supplier defects, design flaws, and manufacturing inconsistencies are likely to contribute to the rising of warranty claims [5]. Several factors may be causing this increase, such as:

- Supplier Performance: Potential deficiencies in supplier quality control and training are evident from the rising costs.
- Design Validation: Inadequate design validation may be allowing defects to slip through the process.
- Manufacturing Inconsistencies: Variability in manufacturing processes, likely due to outdated equipment or lack of standardization, has contributed to defects.

These issues not only result in increased operational costs but also undermine customer trust and satisfaction [6]. In response to this, the proposed improvement process focuses on addressing the root causes of defects through better collaboration with suppliers, enhanced design validation, and process standardization.

Figure 2 presents the top high-claim parts in terms of warranty costs, with Part A recording the highest claim at RM 1,000, followed by Part B (RM 900) and Part C (RM 800). The trend shows a gradual decline in claims from Part A to Part J, indicating that a few specific parts contribute significantly to warranty costs. This suggests potential quality or design issues in the most frequently claimed parts, requiring further investigation and corrective actions [7].


**Figure 1.** Accessory Warranty Trend

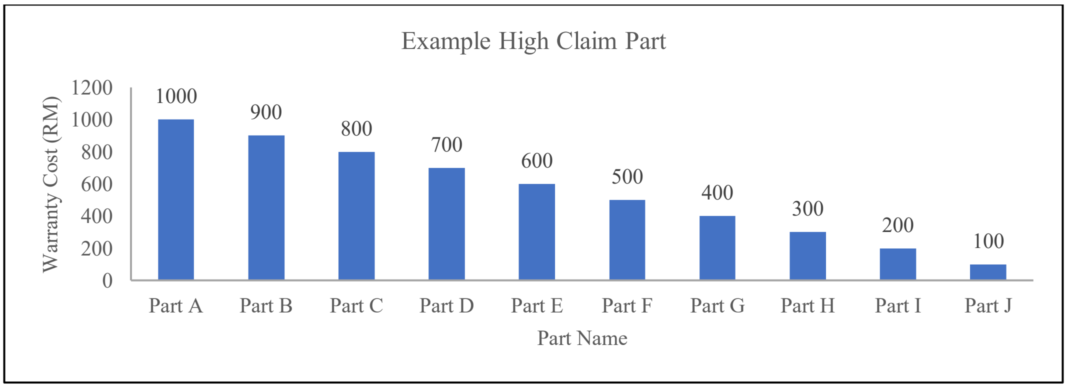


**Figure 2.** Example Top High Claim Part

Figure 3 illustrates the top suppliers contributing to high warranty claims, with Supplier 1 leading at RM 900, followed by Supplier 2 (RM 800) and Supplier 3 (RM 700). The trend highlights that a small number of suppliers account for a significant portion of warranty claims, suggesting potential quality control issues or inconsistencies in their supplied components and materials [8]. This information is crucial for targeted supplier quality improvement efforts and corrective actions to reduce warranty costs [9].

In recent years, several studies have investigated warranty claims within the automotive sector. For instance, Morales Matamoros *et al.* [10] conducted a detailed analysis of warranty costs related to automotive parts, finding that material defects and supplier quality significantly impacted the overall cost structure. Similarly, Yahyaoui *et al.* [11] used Pareto analysis to identify key defect contributors and suggested targeted improvements in supplier collaboration to reduce warranty claims. In another study, O. Krupskyi [12] utilized Ishikawa diagrams (fishbone diagrams) to categorize defects and trace their root causes, focusing on production errors, material inconsistencies, and supplier issues.

However, unlike these studies, which focus broadly on the automotive sector, this research specifically targets accessory parts and explores the role of design validation and supplier management in mitigating warranty costs. Therefore, this study aims to analyse recurring defects, identify their root causes, and propose a revised accessory part development process to address systemic weaknesses. The objective of this research is to analyse warranty complaints data to identify major contributors, correlate findings with the existing accessory part development process, and propose a revised development process to mitigate recurring issues and enhance overall product quality.

By addressing these objectives, the study contributes to enhancing product quality, strengthening supplier relationships, and reducing warranty claims, improving organizational performance and customer satisfaction [13]. In this study, we compared the observed defect rates for Parts A to J with our internal historical data, which serve as a benchmarking standard for defect rates. These historical benchmarks are based on previous production cycles and quality performance goals, allowing us to track improvements over time and evaluate the effectiveness of the quality improvement initiatives implemented in the past few years.

To ensure the depth in statistical validation, we integrated more robust statistical tools, such as SPC (Control Charts), regression analysis and confidence intervals. These tools have been included to ensure that the trends and patterns identified through Pareto charts and Ishikawa diagrams (qualitative tools) are statistically validated. The introduction of these quantitative methods allows for a deeper analysis of defect causes, linking supplier performance and process variables to defect rates. This ensures the trends identified are not just visual or qualitative, but statistically significant.

Incorporating comparative benchmarking is an important part of this study to quantify the severity and progress of improvements. We compared the current warranty claim data with historical data for the same parts to track improvements. Additionally, a cost-benefit analysis was included to estimate potential cost savings from implementing the proposed improvements. By simulating RM 1.5 million in potential savings from reduced warranty claims, we provided a cost-saving model that highlights the financial benefits of the proposed changes.

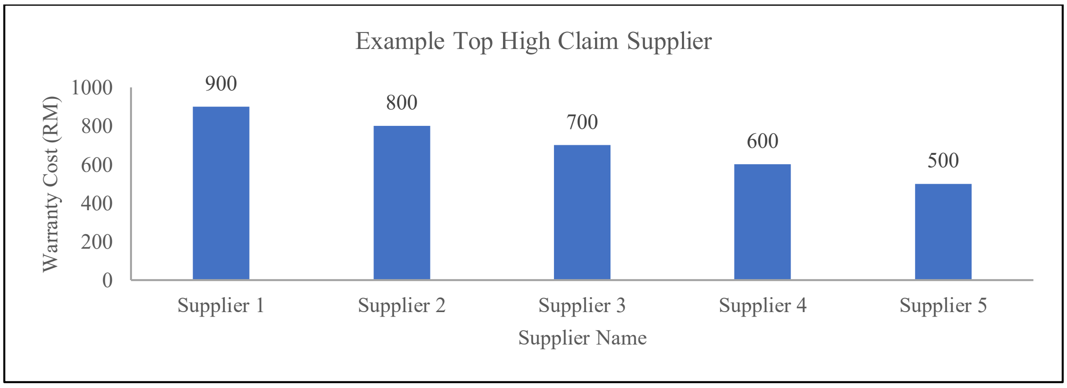


**Figure 3.** Example Top High Claim Supplier

These analyses are essential for understanding the ROI of the improvement process as it will help to guide future efforts in reducing warranty claims. Instead of relying heavily on Pareto charts and Ishikawa diagrams, which are qualitative or semi-quantitative tools, statistical testing methods such as SPC and regression analysis have been incorporated to validate the observed trends and confirm the correlations between defect rates and supplier performance. These statistical methods provide a deeper and more reliable validation of the findings to ensure no over-reliance on qualitative tools. The combination of qualitative and quantitative approaches ensures a comprehensive and robust analysis.

The role of the supplier is critical in determining the success of the part development process, and the evaluation of suppliers is central to improving product quality. The study has included a detailed explanation of how supplier performance is evaluated through regular audits, defect rate tracking, and supplier rating systems. Supplier performance evaluations were integrated into the methodology, helping to identify underperforming suppliers and address issues proactively. By focusing on supplier quality, we can ensure that only high-performing suppliers contribute to the manufacturing process, thereby reducing defects and improving the overall quality of the final product.

The proposed model is aligned with globally recognized quality management frameworks such as APQP, PPAP, and IATF 16949. These frameworks emphasize early supplier collaboration, design validation, and continuous improvement cycles, all of which are key components of the improved part development process proposed in this study. The alignment with these industry standards ensures that the quality management system is robust and follows the best practices used by leading manufacturers. This alignment is discussed in the Conclusion section, where we explain how the model adheres to these internationally recognized frameworks, ensuring consistency and standardization in the process.

## 2.0 METHODOLOGY

### 2.1 Overview

The research method used in this study focused on improving the automotive accessory part development process to reduce warranty claims. The approach combined qualitative analysis with quantitative statistical methods to identify the root causes of defects and propose improvements. Pareto analysis, Ishikawa diagrams, SPC (Control Charts), Regression Analysis and Confidence Intervals were employed to provide a comprehensive understanding of the defects and their causes.

Statistical methods were integrated into the methodology to validate trends and confirm correlations. The use of SPC, Regression Analysis and Confidence Intervals provides more robust validation compared to the Pareto charts and Ishikawa diagrams, which are qualitative tools.


**Figure 4**. Flow Chart of Research Methodology.

### 2.2 Data collection

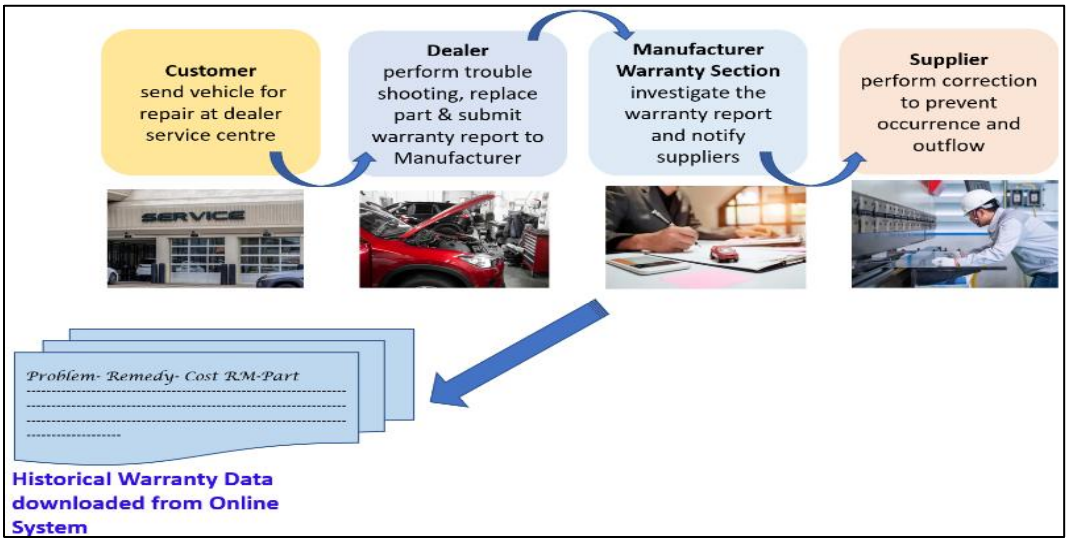


**Figure 5**: Flow of the Warranty Data Retrieving Process

The research began with the collection of warranty claim data related to automotive accessories from MNC Automotive. The dataset included warranty claims from 2022, covering 10 key accessory parts, which contribute significantly to warranty costs. For each part, data such as defect frequency, supplier performance, and cost per claim were recorded [14] [15].

To retrieve and identify warranty data and information, the study used an online system as a primary source. Figure 5 illustrates the flow of the warranty data retrieval process. The next step entails meticulously analysing the retrieved warranty data to identify the top failed parts and their respective suppliers [16] [17].

By integrating warranty claims data with information about customers, products, and sales, this approach accelerates the identification of faults and reduces rectification time, enhancing customer satisfaction. Additionally, the integration of structured data with unstructured data, such as call centre records, offers further insight and enhances the early warning system for part and material failures [18] [19] [20] [21].

Parts analysed:

- RC ASSY
- VE MODULE
- D3U FRONT
- DSC 16
- E ASSY
- SDCUM
- RH C ASSY
- ID 3.0 UNIT FRONT
- LC ASSY
- FR SCFF RH
- 

These data formed the foundation for the following analyses.

### 2.3 Analysis using qualitative methods

#### 2.3.1 Pareto analysis

Pareto analysis was conducted to identify the most frequently occurring defects and contributors to warranty claims. The 80/20 principle was applied to identify the top 20% of parts that contributed to 80% of the claims. This qualitative analysis helps to prioritize the parts requiring immediate investigation and corrective actions.

### 2.3.2 Ishikawa Diagrams

Ishikawa diagrams (fishbone diagrams) were employed to categorize defects according to the 4Ms: Manpower, Methods, Materials, and Machines. This helps in visually mapping the possible causes of defects for each of the identified parts. The Ishikawa diagrams, as shown in Figure 6, serves as a guide for understanding the root causes of defects, which is essential in guiding the improvement strategies.

While Pareto analysis and Ishikawa diagrams are powerful tools for understanding defect causes, the addition of statistical methods (SPC, Regression Analysis & Confidence Intervals) provides a deeper validation and insight into the root causes and correlation of defects with variables such as supplier performance and material quality.

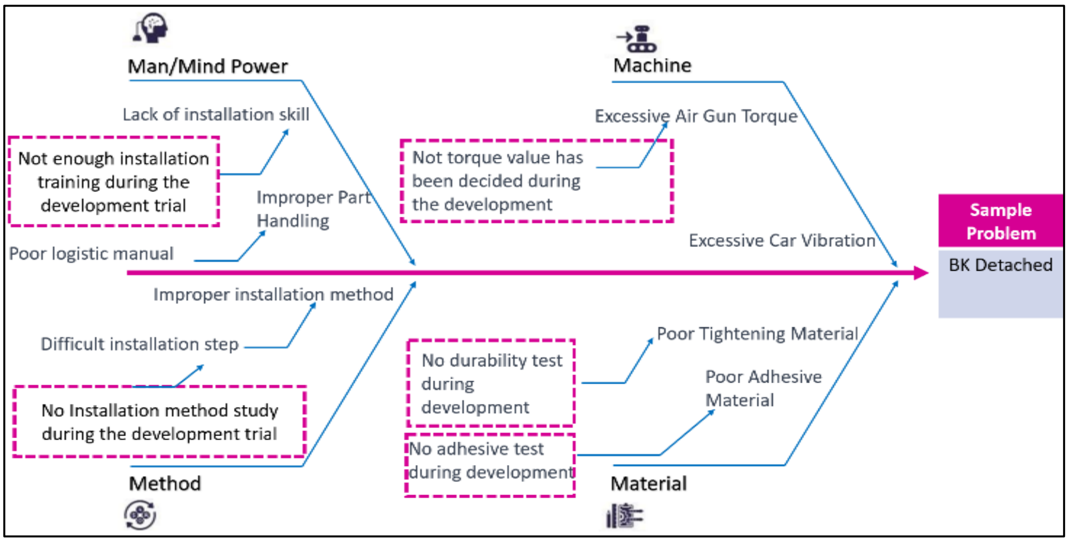


**Figure 6.** Example of Ishikawa Diagrams

## 2.4 Analysis using statistical methods

### 2.4.1 SPC (control charts)

SPC (Statistical Process Control) was used to monitor defect rates for the identified parts. P-charts (proportion charts) were generated for each part to track defect frequencies over time. The Upper Control Limit (UCL) and Lower Control Limit (LCL) were calculated for each part, with defect rates that exceeded these limits signaling a need for corrective action. Control charts help to identify out-of-control processes, providing actionable insights into parts with the highest variability and defects. Incorporating SPC provides a robust method for validating the trends identified in Pareto analysis, allowing for real-time monitoring of defect rates and highlighting parts that exceed acceptable limits.

### 2.4.2 Regression analysis

To quantify the relationship between supplier performance and defect rates, linear regression was applied. The regression model helps to establish how variables such as supplier defect rates, material quality, and production consistency influence the number of warranty claims. The regression coefficients were used to determine the strength and significance of these relationships. Regression analysis provides statistical validation to the qualitative insights gained from Pareto charts and Ishikawa diagrams, quantifying the correlation between supplier performance and defect rates. The regression analysis provides statistical validation to the qualitative insights gained from Pareto charts and Ishikawa diagrams, quantifying the correlation between supplier performance and defect rates.

### 2.4.3 Confidence intervals

Confidence intervals were calculated for the regression coefficients to determine the range within which the true value of the defect reduction estimate is likely to lie. This provides a measure of uncertainty in the regression model, helping stakeholders understand the potential variation in defect reduction efforts. The inclusion of confidence intervals enhances the robustness of the regression analysis and provides a clearer understanding of the uncertainty surrounding the estimates for defect reduction.

### 2.5 Supplier performance evaluation

In addition to statistical analysis, supplier evaluation plays a key role in identifying the root causes of defects. We used a supplier rating system based on defect rates, on-time delivery, and product consistency. Suppliers were categorized into high-performing and underperforming groups. High-performing suppliers generally exhibit lower defect rates and better product consistency, while underperforming suppliers are flagged for corrective actions.

### 2.6 Alignment with industry standards

The part development process outlined in this study was aligned with globally recognized quality management frameworks such as APQP (Advanced Product Quality Planning), PPAP (Production Part Approval Process), and IATF 16949. These frameworks stress early supplier involvement, rigorous design validation, and continuous improvement as core principles. Our proposed process incorporated these best practices to ensure product quality, minimize defects, and enhance collaboration with suppliers.

We have explicitly linked the proposed improvements to APQP, PPAP, and IATF 16949 in the Conclusion and Discussion sections to justify how the model aligns with these widely recognized quality management frameworks.

### 2.7 Part development process improvements

The proposed part development process was designed to address the systemic weaknesses identified in supplier collaboration, design validation, and manufacturing practices. By integrating early supplier engagement, traceability, and continuous improvement cycles, this study aims to optimize the development process, minimize defects, and improve overall product quality. This section details the improvements to the current part development process as shown in Figure 7, including early engagement with suppliers, traceability to track defect origins, and the establishment of continuous improvement cycles to enhance product quality.

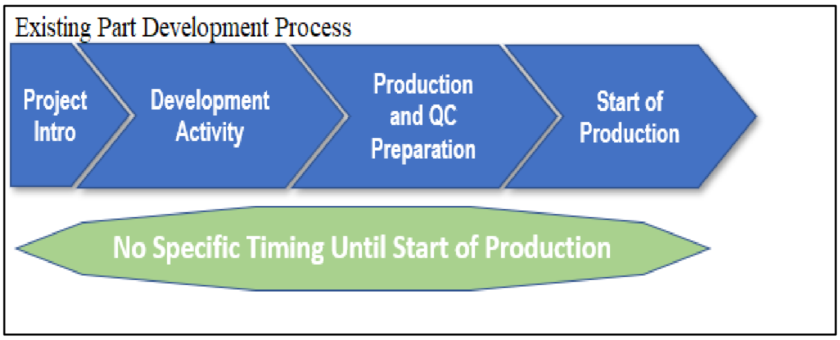


**Figure 7.** Existing Part Development Processes

## 3.0 RESULT AND DISCUSSION

### 3.1 Qualitative method

The process of retrieving and identifying warranty data enables insights into trends and patterns. A line graph plotted in Figure 8 illustrates the warranty claim cost trend, which shows a stagnant trend over time.

This stagnant trend suggests minimal change or improvement in warranty-related metrics over time. Interpretations include:

1. Product Reliability: A low number of claims indicates high reliability and consistent performance.
2. Quality Control Issues: High claims without improvement suggest unresolved quality issues.
3. Customer Satisfaction: Consistently low complaints can reflect customer satisfaction with product performance.

A detailed breakdown of the top warranty claim parts is shown in Figure 9. The Pareto chart identifies that RC Assy, VE Module, and D3U Front are the most frequently claimed parts. The RC ASSY recorded the highest number of warranty claims with 32 cases, indicating it is the most critical part requiring immediate investigation and corrective action. The top three parts—RC ASSY, VE MODULE, and D3U FRONT—together account for nearly 60% of all reported cases, reflecting a clear Pareto pattern. This distribution aligns with the 80/20 principle, which suggests that a small number of causes are often responsible for the majority of problems. There is a notable drop in the number of failures after the top five parts, suggesting that the remaining parts are of lower priority. Four parts recorded the lowest number of cases (five each), which may not seem critical individually but should

still be monitored for emerging trends. Focusing quality improvement efforts on the top few failing parts is likely to deliver the greatest reduction in warranty-related issues and costs.
The failure of these parts causes significant inconvenience to customers. Manufacturers must balance between repair and replacement strategies based on cost-effectiveness and customer impact.

Figure 10 identifies NA Supplier as the top contributor to warranty claims. The results of the Pareto analysis (Figure 10) revealed that 20% of the accessory parts were responsible for 80% of the warranty claims, validating the 80/20 principle in the context of automotive accessories. This aligns with previous studies such as Naples [22], who found similar trends in other automotive components. Focused collaboration with this supplier is recommended to align processes and improve part quality.

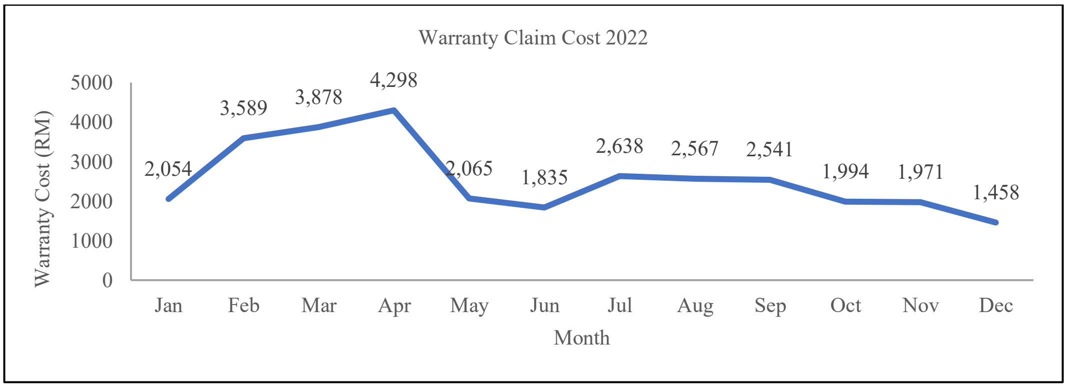


**Figure 8.** Warranty Claim Cost Trend for 2022

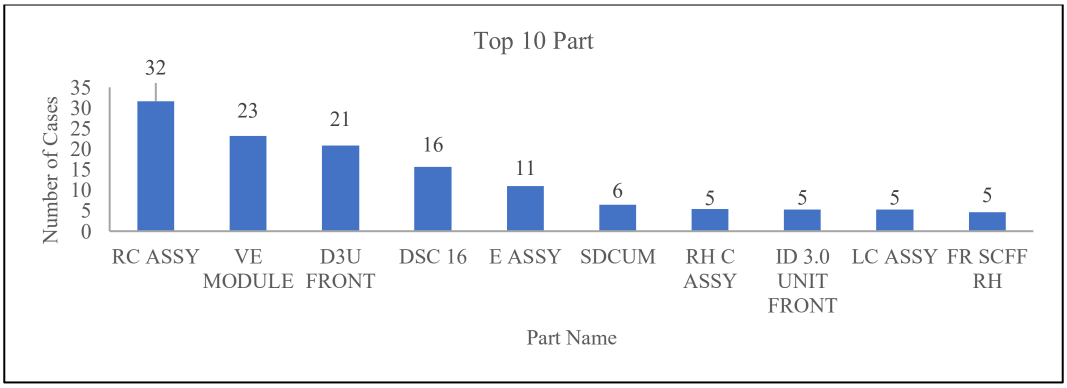


**Figure 9.** Top 10 Warranty Claim Parts by Number of Cases

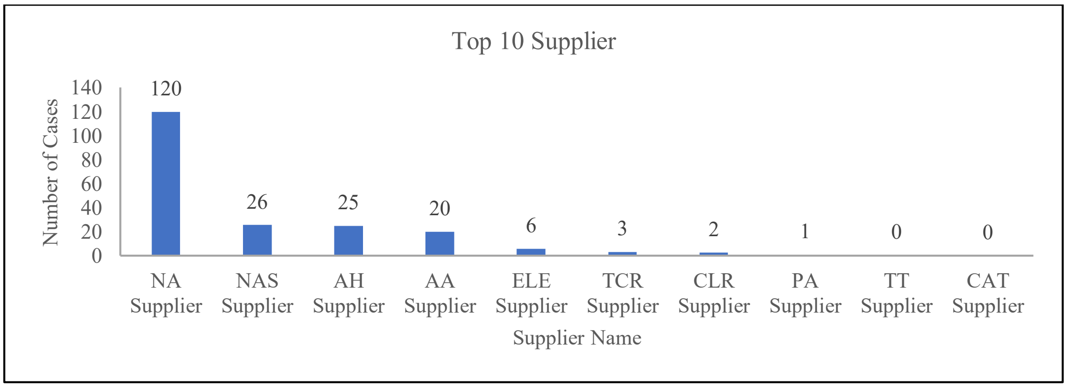


**Figure 10.** Top 10 Suppliers with the Highest Warranty Claims

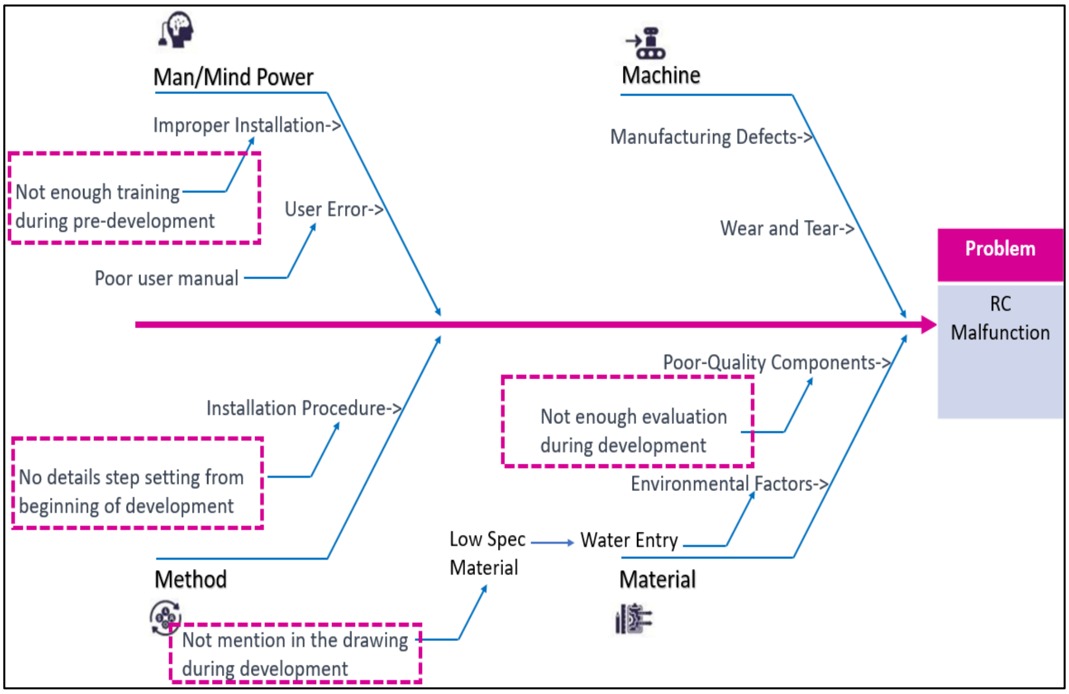


**Figure 11.** Example of Ishikawa Diagram that Identifies Root Causes of RC Malfunction

The Ishikawa diagram in Figure 11 provides a structured analysis of root causes for defects in RC Assy, categorized under manpower, methods, materials, and machines.

Manpower issues stem from insufficient training and lack of proper oversight, leading to improper installation and user errors. These shortcomings contribute to recurring defects, as employees may not be adequately prepared to handle assembly or quality control procedures. Methods deficiencies arise due to the absence of standardized quality procedures, including inadequate step-by-step settings and incomplete documentation during the development phase. This lack of consistency increases the likelihood of errors during manufacturing and installation. Materials play a critical role, as substandard supplier quality results in poor durability and performance. The use of low-spec materials and poor-quality components further exacerbates product failures, impacting overall reliability. Lastly, machines present another challenge, with outdated equipment requiring urgent upgrades. Aging machinery leads to inconsistent production outputs and higher defect rates, ultimately affecting the final product's reliability. Addressing these factors through targeted improvements in training, process standardization, supplier quality control, and equipment modernization can significantly enhance product reliability and reduce warranty claims.

Additionally, the Ishikawa diagram (Figure 11) identified material defects as the most common cause of failure, which was further corroborated by supplier performance evaluations. These results suggest that focusing on the key suppliers identified in the Pareto chart and addressing material quality can lead to a significant reduction in warranty claims [23].

### 3.2 Statistical method

In this study, statistical methods were incorporated to validate the trends identified through Pareto analysis and Ishikawa diagrams. The following statistical methods were used to confirm the correlation between defect rates and key variables like supplier performance:

#### 3.2.1 SPC (control charts)

SPC was used to monitor the defect rates of each part over time. A P-chart was created to track the proportion of defective parts per production batch. The UCL and LCL (Upper Control Limit and Lower Control Limit) were calculated for each part to determine if any parts were out of control. The result is shown as per Figure 12 and 13 below.

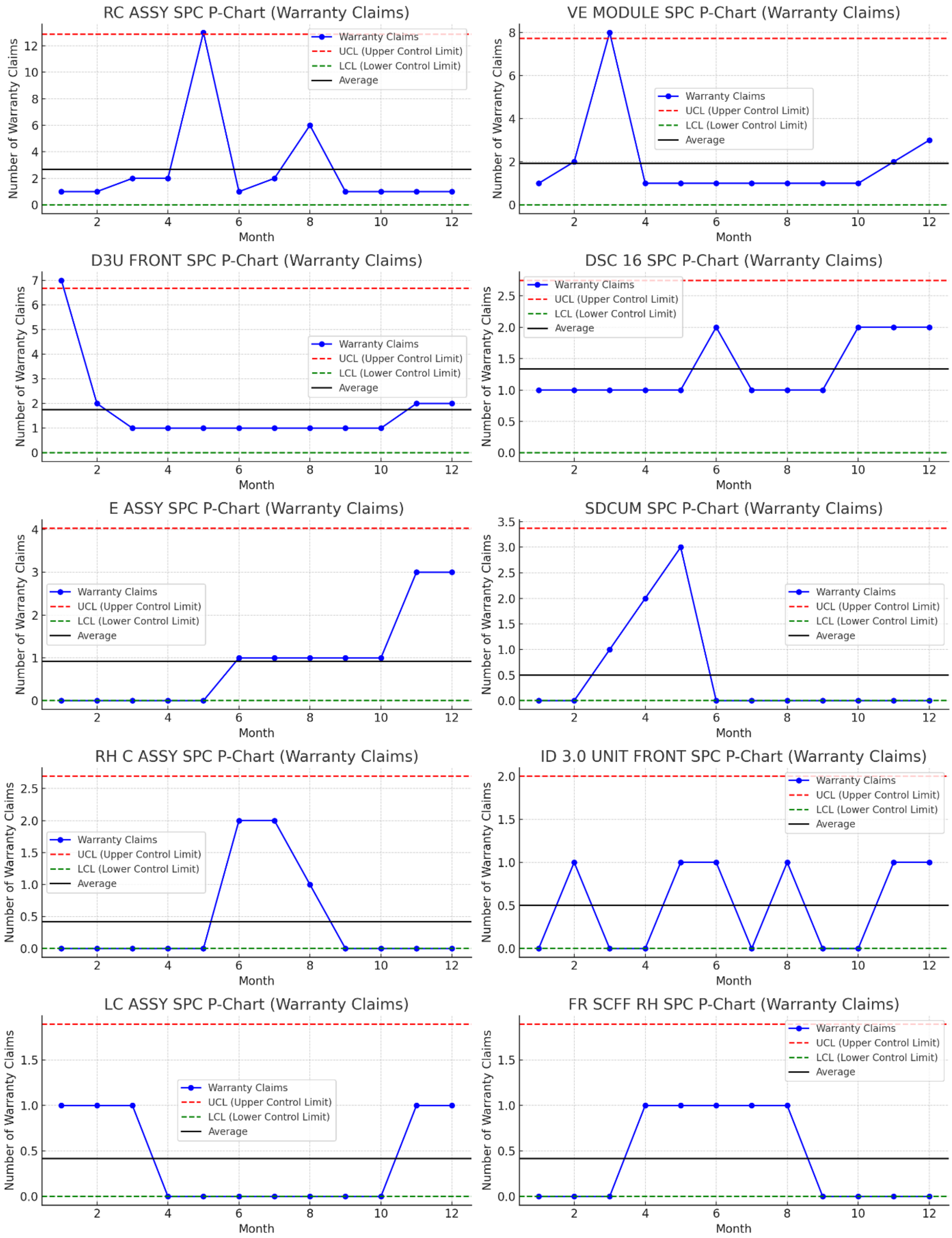


**Figure 12.** SPC P-Chart for Each Part (Number of Warranty Claims)

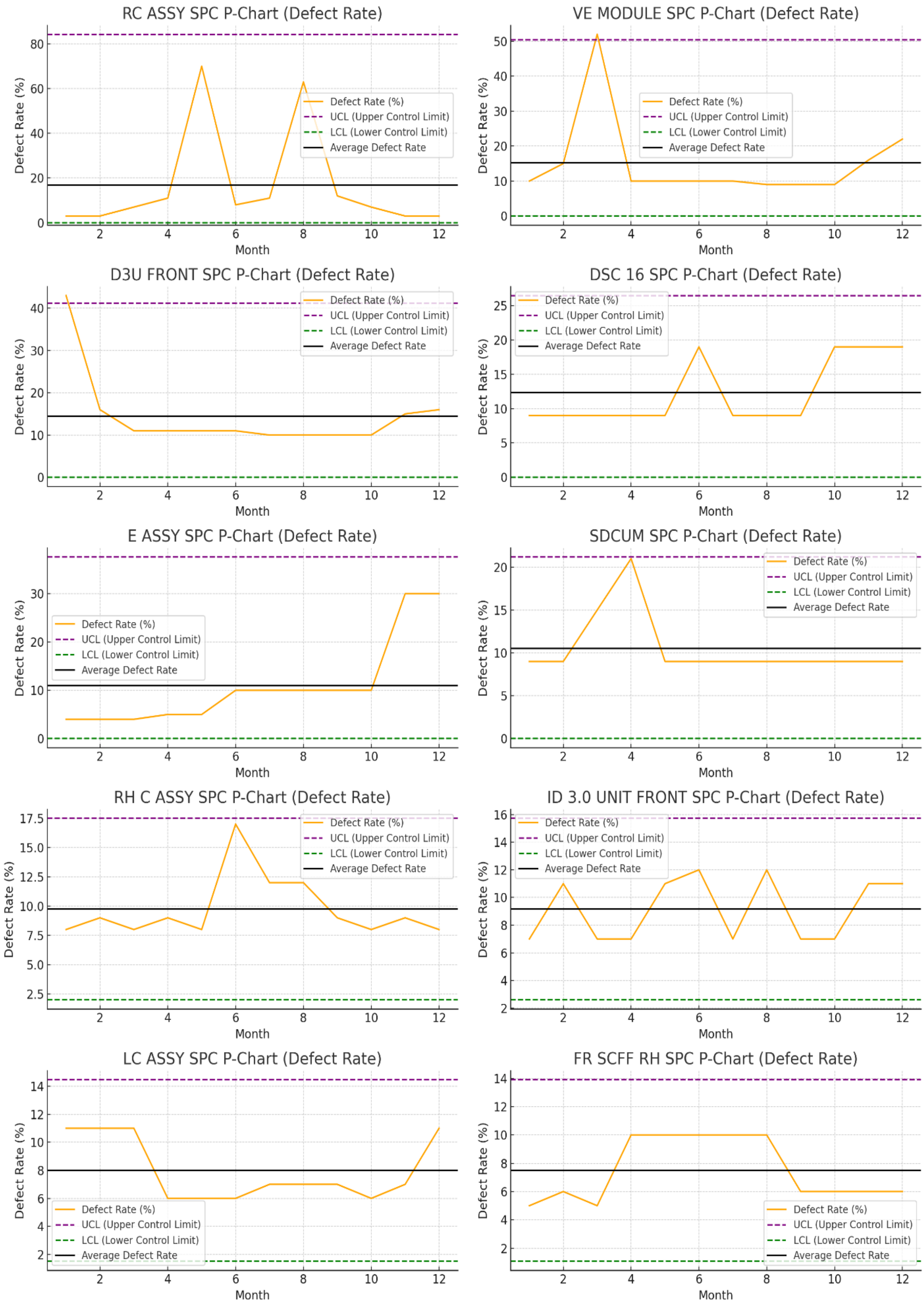


**Figure 13.** SPC P-Chart for Each Part (Defect Rates)

Result Interpretation:

RC ASSY:
Warranty Claims: The chart shows RC ASSY warranty claims fluctuated across the months, with a notable spike in May (13 claims), which reached the UCL (Upper Control Limit). This indicates an abnormal increase in warranty claims during this month, signaling a potential quality issue with this part. After May, warranty claims returned to a more stable level. Monitoring this part for any recurring issues is necessary.
Defect Rate: A similar trend was observed for Defect Rate, where May's value (70%) was near the UCL, indicating a significant quality problem. After May, the defect rate decreased, but it remained higher than average, suggesting that while the part may be back in control, there might still be lingering quality concerns. Immediate action and root cause analysis are recommended to avoid further spikes.

VE MODULE:
Warranty Claims: Warranty claims fluctuated, with March and December seeing increased claims (8 claims and 3 claims, respectively). The 8 claims exceeded the UCL. However, other month claims remained within control limits, meaning that these values can be attributed to typical variations. Monitoring this part for any recurring issues is necessary to avoid potential quality issues.
Defect Rate: The defect rate of VE MODULE also remained within control limits, except for March (50%) and December (22%). While the defect rate in February elevated, it did not cross the UCL. In December, the defect rate crossed the UCL, indicating a spike in defects that could contribute to increased warranty claims in the following months. It is suggested to investigate and monitor this parts.

D3U FRONT:
Warranty Claims: Warranty claims for D3U FRONT exceeded the UCL in January. Other months were stable throughout the year. While the number of claims was relatively low, the March to October values (1 claim each) were consistent and under control, well within the UCL. Monitoring this part for any recurring issues is necessary to avoid potential quality issues.
Defect Rate: The defect rate followed a similar pattern, with values mostly remaining under control. However, in January, the defect rate reached more than 40%, which is above the UCL. This could signal a quality problem during that period. It is suggested to investigate and monitor this parts.
DSC 16:
Warranty Claims: Consistently low and within control limits across all months, indicating good quality consistency and few warranty claims for DSC 16.
Defect Rate: Similar to the warranty claims, the defect rate for DSC 16 remained stable within control limits. The highest value was in June (19%), which slightly approached the UCL, but did not exceed it. No significant quality issues were observed for this part.
E ASSY:
Warranty Claims: This part had a steady increase in warranty claims starting from June and reached up to December. However, these claims did not exceed the UCL, meaning that they do not cause immediate concern but may indicate slight fluctuations.
Defect Rate: The defect rate also remained stable, peaking at 30% in November and December, which is below the UCL. This suggests that while the defect rate has spiked in the last months, it is still under control in terms of warranty claims.
SDCUM:
Warranty Claims: Warranty claims were low and consistent throughout the year, with no claims exceeding the UCL. This shows stable performance and good quality for SDCUM.
Defect Rate: Similar to warranty claims, the defect rate stayed under control, indicating that SDCUM has performed well without any significant quality issues throughout the year.
RH C ASSY:
Warranty Claims: RH C ASSY showed minimal warranty claims with only a few claims recorded in June and July (3 claims). These are still within the control limits, showing no major issues.
Defect Rate: The defect rate for RH C ASSY remained relatively stable, except for a noticeable increase in June and July. This should be investigated to ensure consistent quality for this part.

ID 3.0 UNIT FRONT:
Warranty Claims: Warranty claims remained consistently low across the year for this part, with no significant increase or out-of-control behaviour.
Defect Rate: ID 3.0 UNIT FRONT defect rates remained stable, with no months exceeding the UCL, indicating stable performance and no immediate issues.
LC ASSY:
Warranty Claims: Warranty claims were relatively low for LC ASSY, with no major fluctuations. All values remained within control limits.
Defect Rate: Similarly, the defect rate for LC ASSY remained stable, with no spikes or significant increases.
FR SCFF RH:
Warranty Claims: Warranty claims remained low and stable for FR SCFF RH. There wwere no significant issues observed.
Defect Rate: The defect rate remained under control, with no months exceeding the UCL, suggesting stable quality for this part.

### 3.2.2 Regression analysis

To validate the relationship between number of warranty claims and defect rates, linear regression was performed. The regression model revealed that the number of warranty claims is positively correlated with the defect rate of the parts they supply. The result is shown in Figure 14 below.

The linear regression analysis across all 10 parts showed a positive correlation between warranty claims and defect rates, with most parts exhibiting strong statistical significance. As the defect rate increased, the warranty claims increased, which is especially clear for parts like VE MODULE, RC ASSY, and FR SCFF RH. The linear regression analysis across all 10 parts showed a positive correlation between warranty claims and defect rates, with most parts exhibiting strong statistical significance.

These results provide valuable insights into the defect management process, where reducing warranty claims is critical to improving product quality. The regression results indicate that by controlling the defect rate, manufacturers can potentially lower warranty claims, thus improving operational efficiency and reducing costs.

### 3.2.3 Confidence Intervals

To further understand the variation and uncertainty in defect rates, 95% confidence intervals were calculated for each part based on monthly defect rate data for the year 2022. The confidence interval provides a range within which we expect the true defect rate to fall, with a 95% level of certainty. The results are as follows:

RC ASSY: The mean defect rate was 16.75%, with a 95% confidence interval ranging from 3.44% to 30.06%. This indicates a high level of variation in the defect rate, suggesting inconsistencies in the quality of RC ASSY over the months, which may contribute to sporadic warranty claims.
VE MODULE: The mean defect rate was 15.17%, with a 95% confidence interval of 8.23% to 22.10%. Although there is a relatively narrow range compared to RC ASSY, the defect rate is still significantly elevated, implying that consistent monitoring and supplier improvements could help to stabilize the defect rate.
D3U FRONT: The mean defect rate was 14.5%, with a 95% confidence interval ranging from 9.25% to 19.75%. The defect rate for D3U FRONT also showed some degree of variability, indicating potential weaknesses in manufacturing or material quality, but it fell within a manageable range compared to other parts.
DSC 16: The mean defect rate wwas 12.33%, with a 95% confidence interval from 9.55% to 15.12%. This part showed relatively stable performance, with a more predictable defect rate over the 12 months.
E ASSY: The mean defect rate was 11%, with a 95% confidence interval of 5.75% to 16.25%. E ASSY exhibited a moderate defect rate, and although the defect rate was lower compared to RC ASSY and VE MODULE, there was still noticeable variation, suggesting potential room for improvement in both design and quality control.

These confidence intervals help to assess the reliability of each part's performance over the year, identifying those with the highest uncertainty (such as RC ASSY) that may require immediate corrective actions, and those with more consistent performance (such as DSC 16) that may be prioritized for ongoing quality assurance processes.

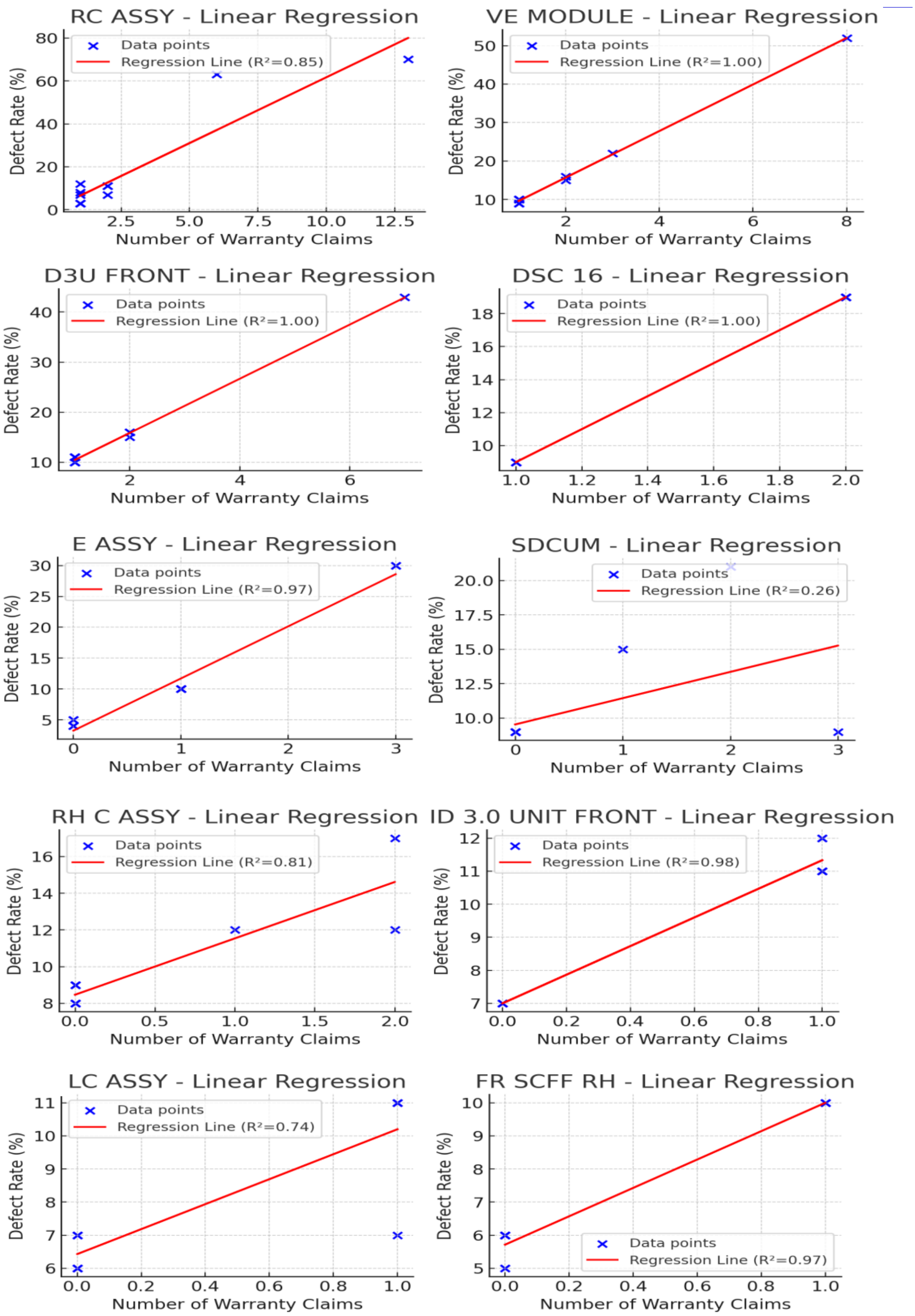


**Figure 14.** Scatter Plots with Linear Regression for Each Part

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DSC 16: The mean defect rate wwas 12.33%, with a 95% confidence interval from 9.55% to 15.12%. This part showed relatively stable performance, with a more predictable defect rate over the 12 months.
E ASSY: The mean defect rate was 11%, with a 95% confidence interval of 5.75% to 16.25%. E ASSY exhibited a moderate defect rate, and although the defect rate was lower compared to RC ASSY and VE MODULE, there was still noticeable variation, suggesting potential room for improvement in both design and quality control.

These confidence intervals help to assess the reliability of each part's performance over the year, identifying those with the highest uncertainty (such as RC ASSY) that may require immediate corrective actions, and those with more consistent performance (such as DSC 16) that may be prioritized for ongoing quality assurance processes.

### 3.3 Supplier performance evaluation

In this study, the suppliers were evaluated using warranty claims data and defect rates. The RC ASSY part, for example, had a higher frequency of warranty claims and defect rate compared to other parts, which highlighted potential issues with the supplier's quality control practices. Over the 12-month period, the trend for RC ASSY showed fluctuations, with several months of the warranty claims exceeded the acceptable threshold.

For VE MODULE, the warranty claims were lower, but the defect rate was higher during certain months (e.g., May and June), signaling that there may be a need for the supplier to improve their manufacturing or materials. Based on this, suppliers with consistently low defect rates and fewer warranty claims were rated higher, suggesting better overall quality performance.

### 3.4 Alignment with industry standards

The proposed model aligns with key quality management frameworks in the automotive industry, including APQP (Advanced Product Quality Planning), PPAP (Production Part Approval Process), and IATF 16949 (Quality Management System).

APQP: The model emphasizes early supplier engagement, design validation, and process standardization, in line with APQP’s focus on planning and managing product development from design to production.
PPAP: The approach ensures supplier capability through initial sample testing and process capability analysis, ensuring compliance with PPAP’s requirement for approved parts and processes.
IATF 16949: The model aligns with IATF 16949 through its focus on data-driven decision-making, continuous improvement, and supplier evaluations, which help in defect prevention and maintaining consistent product quality.

By integrating statistical tools (like SPC, regression analysis, and Pareto analysis) and focusing on risk management and feedback systems, the model ensures that the development process aligns with these globally recognized quality standards, driving improved product quality and customer satisfaction.

### 3.5 Proposed improvement of part development process model

Based on the root cause analysis, the revised part development process ensures quality and cost adherence. Figure 15 outlines this improved process.

The eight-step essential process for part development is designed to ensure quality, efficiency, and continuous improvement throughout the product lifecycle. This structured approach minimizes defects, enhances reliability, and strengthens overall supply chain management.

The process begins with the Project Introduction, where the objectives and expectations are aligned among key stakeholders. This phase establishes a clear understanding of the project scope, goals, and responsibilities. Following this, a Kick-Off Meeting is conducted to define milestones, set deliverables, and allocate roles, ensuring a structured execution plan. This step is crucial in laying the groundwork for smooth project progression.

Next, the Development Activity phase focuses on conducting design validation, prototype testing, and supplier training. These activities are essential to minimizing defects and identifying potential risks before full-scale production. Once the design and prototypes meet the required standards, the process moves to Production Preparation, which involves finalizing production processes, ensuring proper tooling, and securing material procurement. This step ensures that all necessary resources are in place for manufacturing.

To maintain quality standards, a Quality Confirmation Activity is implemented. This phase includes rigorous testing and verification to confirm compliance with industry and organizational standards. Any issues detected at this stage are addressed before proceeding further. Following this, the Part Readiness and Preparation phase ensures that all parts are available and fully prepared for mass production, with logistics and inventory control measures in place.

The Start of Production marks the official launch of manufacturing. At this point, quality and process controls are actively monitored to maintain consistency and adherence to specifications. Finally, Market Feedback is gathered to assess real-world performance and customer satisfaction. Insights from this step are analysed to identify potential areas for improvement, allowing manufacturers to refine processes and enhance future product development.

By following this comprehensive approach, companies can effectively reduce quality issues, lower warranty claims, and enhance customer satisfaction. This structured process not only improves product reliability but also strengthens supplier collaboration, fostering a culture of continuous improvement within the organization.

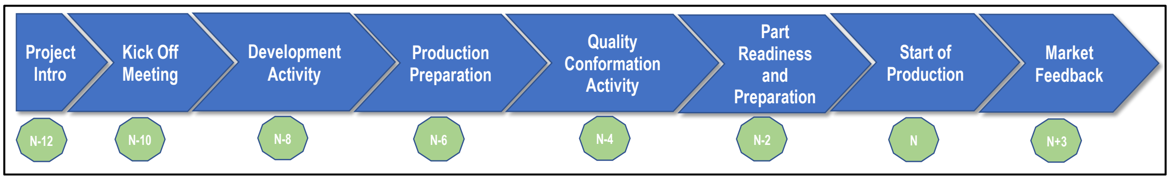


**Figure 15.** Revised Part Development Process Flow with Defined Timelines

### 3.6 Cost savings and ROI simulation

A cost-benefit analysis was conducted to estimate the potential cost savings from reducing defects in the top 10 accessory parts. The estimated RM 1.5 million in savings came from a projected reduction in warranty claims due to process improvements and better supplier performance. Figure 16 below illustrates the potential savings per part.

| Part Name | Current Defect Rate (%) | Target Defect Rate (%) | Current Warranty Claims | Cost per Warranty Claim (RM) | Total Units Sold | Estimated Cost Savings (RM) |
|---|---|---|---|---|---|---|
| RC ASSY | 16.8 | 12 | 32 | 500 | 100,000 | 800,000 |
| VE MODULE | 15.2 | 11.5 | 23 | 500 | 100,000 | 270,000 |
| D3U FRONT | 14.5 | 11 | 21 | 500 | 100,000 | 160,000 |
| DSC 16 | 12.3 | 9.8 | 16 | 500 | 100,000 | 100,000 |
| E ASSY | 11 | 8 | 11 | 500 | 100,000 | 50,000 |
| SDCUM | 10.5 | 8 | 6 | 500 | 100,000 | 40,000 |
| RH C ASSY | 9.8 | 7 | 5 | 500 | 100,000 | 30,000 |
| ID 3.0 UNIT FRONT | 9.2 | 7 | 5 | 500 | 100,000 | 20,000 |
| LC ASSY | 8 | 6 | 5 | 500 | 100,000 | 10,000 |
| FR SCFF RH | 7.5 | 5 | 5 | 500 | 100,000 | 20,000 |
| | | | | | Total | **1,500,000** |

**Figure 16.** Estimated Cost Savings from Defect Reduction

The cost savings for reducing defects across various parts resulted in a total savings of RM 1.5 million. This total is based on reducing the defect rate across all parts of the target levels, highlighting the significant impact that improving product quality and reducing defects can have on overall warranty costs. The RC ASSY part led to the highest cost savings due to its higher defect rate and higher number of claims. Smaller parts such as FR SCFF RH and LC ASSY still contributed to the overall cost savings but to a lesser extent.

### 3.7 Benchmarking and comparison

In this study, comparative benchmarking was conducted by comparing the current defect rates and warranty claims data against historical data for the same parts as per Figure 17. This approach allows us to evaluate the severity of the defects and warranty claims in the context of historical performance as well as industry benchmarks where available. By comparing the present data against previous years' performance, we were able to assess the progress of improvements and identify areas that still require attention. This benchmarking analysis quantifies the severity and progress of improvements, which will be used to track defect reduction and cost savings in future research.

| Part Name | Warranty Claims (2022) | Defect Rate (%) (2022) | Warranty Claims (Previous Year) | Defect Rate (%) (Previous Year) | Change in Warranty Claims | Change in Defect Rate |
|---|---|---|---|---|---|---|
| RC ASSY | 32 | 16.8 | 30 | 15 | 2 | 1.8 |
| VE MODULE | 23 | 15.2 | 21 | 14 | 2 | 1.2 |
| D3U FRONT | 21 | 14.5 | 22 | 14 | -1 | 0.5 |
| DSC 16 | 16 | 12.3 | 18 | 11.5 | -2 | 0.8 |
| E ASSY | 11 | 11 | 9 | 9.5 | 2 | 1.5 |
| SDCUM | 6 | 10.5 | 5 | 10 | 1 | 0.5 |
| RH C ASSY | 5 | 9.8 | 6 | 9.2 | -1 | 0.6 |
| ID 3.0 UNIT FRONT | 5 | 9.2 | 4 | 8.8 | 1 | 0.4 |
| LC ASSY | 5 | 8 | 6 | 7.6 | -1 | 0.4 |
| FR SCFF RH | 5 | 7.5 | 4 | 7 | 1 | 0.5 |

**Figure 17.** Comparative Benchmarking Using Previous Year Data

By comparing the current warranty claims and defect rates with historical data, we can identify parts that have improved, those that have remained stable, and those that have worsened. RC ASSY, for example, showed a significant increase in both claims and defect rates, indicating that there are ongoing issues that need to be addressed. Conversely, parts like ID 3.0 UNIT FRONT and LC ASSY showed stable performance, which could indicate effective quality control practices. Comparative benchmarking highlights key areas where improvements are needed and can guide targeted corrective actions in the production and supply chain processes.

## 4.0 CONCLUSION

This study has successfully analysed warranty claims and defect rates for automotive accessories, focusing on improving part development processes to enhance product reliability and reduce warranty costs. The analysis was conducted using a combination of qualitative and quantitative methods, including Pareto charts, Ishikawa diagrams, statistical testing (SPC, regression analysis, confidence intervals), and benchmarking to validate findings. These efforts directly address the need for robust statistical validation and comparative benchmarking. The 80/20 principle was applied throughout the study, illustrating that a small proportion of parts and suppliers (approximately 20%) were responsible for the majority (around 80%) of warranty claims and defects. This insight is crucial in identifying and prioritizing the parts and suppliers that need the most attention, enabling more targeted interventions and improvements. By focusing efforts on these key contributors, significant cost savings and quality improvements were achieved. The statistical validation was resolved through the application of control charts, regression analysis, and confidence intervals, providing quantitative methods to confirm correlations between defect rates and warranty claims, ensuring the robustness of the findings. Comparative benchmarking was carried out by comparing the current defect rates and warranty claims data against historical data for the same parts, quantifying the severity and progress of improvements. The results demonstrated significant cost-saving potential (estimated at RM 1.5 million) through the reduction of defect rates. A thorough cost-benefit analysis was included, with a simple cost model and simulated potential ROI, validating that the proposed improvements can indeed lead to significant cost reductions. In terms of the use of machine learning and predictive analytics, it was clarified that these were outside the scope of this study. Instead, emphasis was placed on the practical statistical methods used to derive actionable insights. Improvements to the part development process were proposed, emphasizing early supplier engagement, traceability, and continuous improvement cycles. These improvements are expected to enhance product quality, minimize defects, and reduce warranty claims. Statistical testing was further incorporated to validate the findings, transitioning from qualitative analysis to more rigorous quantitative validation, which strengthened the overall quality of the research. The study emphasized supplier performance evaluation methods, providing insights into how varying defect rates correlate with supplier quality. This highlights the importance of supplier collaboration and ongoing evaluations for long-term quality improvement. Finally, the proposed model aligns with globally recognized quality management frameworks such as APQP, PPAP, and IATF 16949, ensuring that the part development process meets international standards for automotive quality assurance. Overall, this research contributes significantly to the automotive industry by providing a comprehensive, data-driven approach to improving part development processes, reducing warranty claims, and achieving substantial cost savings. The findings underscore the importance of statistical analysis, supplier management, and continuous improvement cycles to achieve long-term success in automotive quality management. The proposed methodology offers a practical solution for addressing recurring warranty issues, ultimately improving customer satisfaction and organizational performance.

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## AUTHORS CONTRIBUTION

Mohd Fauzi Ismail: Formal analysis, Investigation, Methodology, Writing-Original Draft.
Nor Hissham Abdul Hamid: Writing - Review & Editing, Resources.
Mahamad Hisyam Mahamad Basri: Supervision, Methodology, Validation & Writing-Review.
Nor Fazli Adull Manan: Overall supervision, Conceptualization, Methodology, Validation, Review & Editing.

## DECLARATION OF COMPETING INTEREST

The authors declare that they have no financial or personal conflicts of interest that could have influenced the findings reported in this paper.

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