International Journal of Core Engineering & Management
Volume-7, Issue-12, 2024 ISSN No: 2348-9510

EVALUATING THE IMPACT OF QUALITY CONTROL TOOLS ON DEFECT REDUCTION IN THE AUTOMOBILE MANUFACTURING INDUSTRY

Mohammad Faisal
Quality Engineer, Ford Motor Company,Chicago
Mohammadfaisal6016@gmail.com

Abstract

The auto manufacturing industry is one of the largest and most complex industries that can be observed in the global market nowadays. Quality improvement programs must be ongoing, as the demands of the marketplace challenge competitors' abilities to retain customers. The automobile manufacturing industry faces significant challenges related to product quality and defect rates, which can adversely affect customer satisfaction, operational efficiency, and profitability. This study explores the implementation of various Quality Control (QC) tools aimed at reducing defects in the assembly line of an automobile company. Techniques such Flow charts, check sheets, histograms, Pareto diagrams, cause-and-effect diagrams, scatter diagrams, and P-control charts were methodically utilized to detect and analyses, and mitigate defect occurrences. The results indicated a marked reduction in defect frequencies across both the chassis and trim lines, driven by data-driven analysis and targeted corrective actions. By prioritizing critical issues and conducting thorough root cause analysis, the company not only improved product quality but also enhanced operational efficiency and reduced costs associated with rework and warranty claims. This study underscores the essential role of QC tools in fostering a culture of continuous improvement within the automobile manufacturing sector.

Keywords: Quality Control (QC), Defect Reduction, Automobile Manufacturing, Statistical Process Control (SPC) Quality Control 7 Tools.

I. INTRODUCTION

There is a great need for the sector to continue evolving as a result of the increasing competition in the current global market. The increasing needs and expectations of customers have led to a constant hunt for a competitive edge by global company. To be more successful and efficient in the global market, an organization's business processes must prioritize quality. This will boost market share and improve customer loyalty and productivity. To thrive in a highly competitive economy, it is not only essential to minimize waste but also to meet consumer expectations, continuously cut costs, and make improvements [1]. Enhancing the quality of output is a fundamental necessity for any manufacturing system that produces goods or services. As a result, it is a key objective in the industrial sector. The manufacturing sector invests a great deal of time and energy into utilizing a range of control methods and strategies to maintain and improve the quality of their products[2]. In every competitive setting, quality issues impact the entire company. Not only must waste be minimized, but in order to thrive in a fiercely competitive market, constant cost-cutting, customer satisfaction, and continual improvement are also essential. [3][4]. Tools for quality control can be used in the creation, manufacturing, and promotion of products [3]. Delivering products free from flaws is the goal of quality control. The goal of the study is to learn more about the effective use of quality control instruments in business. The relative dependence of quality, productivity, and operating costs [5][6]. Because it directly impacts the quality, costs, and customer satisfaction of products and services, defect reduction is a crucial component of quality improvement. Manufacturing flaws in products provide a significant challenge for all manufacturers [7]. There will always be broken parts, even with careful attention to design, material selection, and product manufacturing [8].

The automobile business currently faces challenges related to product safety, consumer demand for innovative stylistic features, and enhancing vehicle comfort. The automobile manufacturing industry, also known as the automotive industry, is a large and complex sector that involves the design, development, production, and sale of motor vehicles[9]. It also includes the maintenance, repair, and modification of vehicles. In the automobile manufacturing industry, maintaining high-quality standards is crucial for ensuring customer satisfaction and safety[10].

The aim of this study is to investigate the effectiveness of Quality Control (QC) tools in reducing defects within the automobile manufacturing industry, focusing specifically on their application in assembly line processes. By systematically implementing and analyzing various QC methodologies, the research seeks to identify key areas for improvement and establish a framework for enhanced product quality. The motivation behind this study stems from the pressing need for manufacturers to address quality challenges in an increasingly competitive market. High defect rates not only undermine customer satisfaction but also lead to significant financial losses and damage to brand reputation. Thus, this research aims to provide actionable insights that can help organizations implement effective quality management practices, ensuring sustainable growth and operational excellence. The paper contributed as:

- This study establishes a structured framework for implementing Quality Control tools in the automobile manufacturing process, providing a roadmap for other manufacturers aiming to enhance their quality management practices.
- By utilizing statistical analysis and various QC tools, the research offers valuable data-driven insights into defect patterns, enabling manufacturers to prioritize their quality improvement efforts effectively.
- The findings contribute to a deeper understanding of the relationship between specific QC tools and defect reduction, highlighting the most effective strategies for addressing quality issues in assembly lines.
- The study provides practical applications of QC tools, demonstrating their real-world effectiveness in reducing defects, thereby serving as a reference for industry practitioners looking to implement similar strategies.
- This research adds to the existing body of literature on quality management in the manufacturing sector, offering empirical evidence of the benefits of QC tools in enhancing product quality and operational efficiency.

II. QUALITY CONTROL TECHNIQUES ADOPTED IN AUTOMOBILE

Quality control is implemented across all phases of the organisation, but it is particularly critical in production and engineering inside development systems to ensure the quality of services or goods. Quality control is employed to meet client expectations and is essential in the manufacturing sector of firms.[11][12]. Quality Control (QC) is a methodical assessment of several elements that affect product quality. The outcome is contingent upon materials, tools, machinery, labour type, working environment, and other factors. Unlike inspection, quality control activities prioritise the prospective quality of output[13]. Quality control seeks to eliminate flaws at the origin, relying on corrective action protocols and a robust feedback mechanism. Quality control is divided into three primary categories: Off-line quality control, Statistical process control, and Acceptance sampling programs.[14].

- **Off-Line Quality Control:** This area involves activities aimed at improving product quality before production. This they involve the formulation of products and or processes in order to minimize variation and enhance stability. Examples of approaches at this stage include Design of Experiments (DOE) and Quality Function Deployment (QFD).
- **Statistical Process Control (SPC):** SPC is directed at the ongoing observation and management of the production process during its function. It compiles statistical techniques to be able to examine and control fluctuation within the development process. SPC tools, for example, control charts help in controlling the process behavior and immediate action can be taken if process deviates from the standard.
- **Acceptance Sampling Plans:** Acceptance sampling is used to evaluate the quality of a batch or lot of products. The process entails examining a random sample from the lot to determine whether to accept or reject the entire batch. Acceptance sampling is particularly useful when testing every unit is impractical or destructive.

Benefits of implementing quality control tools:

- Facilitates the management of reject rates and rework.
- Advantages of minimizing manufacturing expenses.
- Decrease in consumer complaints.
- Enhancement of the procedure.
- Facilitates the identification of the underlying issue.

2.1 Core Quality Techniques Adopted by Various Industries

1. APQP (Advance Product Quality Planning)

Advanced Product Quality Planning (APQP) is a systematic approach designed to ensure customer satisfaction with new processes and products. APQP has existed in various techniques and forms for several decades. Initially termed Advanced Quality Planning (AQP), APQP is utilized by several automotive manufacturers to guarantee quality and performance [15].

2. **PPAP (Production Part Approval Process)**

In the aerospace and automotive sectors, PPAP is a standard procedure that facilitates communication and assistance between suppliers and manufacturers on production designs and procedures. To comprehend the requirements of suppliers and manufacturers, the Production Part Approval Process (PPAP) ensures that manufacturing processes for automotive components are consistent at specified production rates. The entire PPAP procedure is delineated in the PPAP manual published by the Automotive Industry Action Group (AIAG)[16].

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Volume-7, Issue-12, 2024 ISSN No: 2348-9510

3. FMEA (Failures Modes and Effects Analysis)

Failure Mode and Effects Analysis (FMEA) is a development tool used in the process, product, and service development life cycles. When the product is completed, the FMEA is used for troubleshooting. Error modes are assessed for incidence, severity, and detection in the conventional FMEA procedure. The risk priority number (RPN) is derived by multiplying these values. FMEA is a reliability technique that determines the frequency, modes of failure, and potential causes of a certain product or system.[17].

4. SPC (STATISTICAL PROCESS CONTROLS)

In the corporate sector, quality is seen as a crucial attribute for both competition and survival. As a result, SP is used by many businesses to achieve high product quality. One crucial component of TQM that is still valued highly is SPC. To keep control status, SPC monitors and evaluates using statistically based techniques. Numerous articles discuss how SPC is used in different sectors. SPC improves the quality of the mountainous work in industries[18].

III. INTEGRATION OF QUALITY TOOLS IN MAINTENANCE: AN EXAMPLE

Take into consideration a facility with two machines (A&B). Machine A has had more downtime in the past few months. The maintenance department made an effort to identify the cause and manage the current issue
[19]. Data is first gathered from both devices. We're keeping track of the amount and duration of outage. After building the histogram for each machine, it is compared. A noticeable slope to the right of the histogram is seen upon examination of machine A's histogram. The group made an effort to determine what was causing this. The team determined that the following factors may be contributing to the excessive downtime: the new operator's behaviours, the frequency of preventative maintenance like lubrication, the quality of replacement parts, and process-related issues such excessive vibration. The Pareto diagram revealed the underlying reasons for downtime. The frequency of lubrication and vibration levels were the primary factors. The figure 1 shows the seven quality control tools.

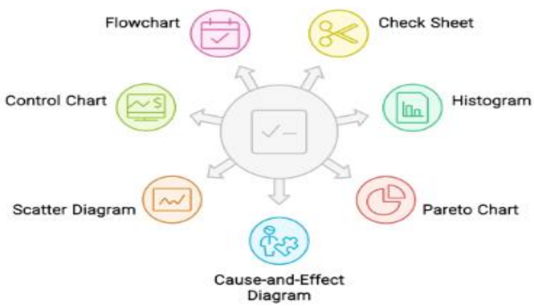

Figure 1: Seven Quality control Tools

A scatter gram was used to look at the relationship between vibration, lubrication frequency, and downtime. There was shown to be a significant relationship between vibration and downtime. It emphasizes how the machine's improper settings were maintained by the new operator, which causes a significant amount of vibration in the machinery. The equipment was operated and maintained with the help of the checklist. A control card was designed and installed to manage the machines' downtime. The aforementioned illustration shows that in order to achieve SPC's goals in terms of maintenance technology, quality tools must be integrated [20]. Data collection, checklist, histogram, cause and effect diagram, checklist, data set, Pareto chart, scatter plot, checklist, and lastly control charts are the instruments used in the example above.

3.1 MSA (Measurement System Analysis)

A fundamental study known as Measurement System Analysis (MSA) identifies the sources of discrepancy that support the measurement system. According to its definition, MSA is a quantitative and investigative technique for determining how variations in the measuring process represent overall process variability. Depending on the kind of data gathered via the measurement system, there are two primary forms of analysis for measurement systems[21][22]. Measurement systems for continuous and attribute data are analyzed using methodologies for measurement system analysis. It is important to highlight the components of the measuring system that increase its capacity and have an impact on the variation in the findings. Quantifying the accuracy of the measuring system allows for the characterization of its potential. The degree of connection between the measured and real magnitude values is known as accuracy. Three mechanisms contribute to the measurement system's accuracy: bias, linearity, and stability. This measurement system's accuracy is made up of two parts: repeatability and reproducibility[23]. An explicit kind of measurement system analysis that establishes the measurement system's accuracy is called a gauge R & R research (GR & R).

- GR&R analysis - crossing - two methods: mean averages and ranges technique and ANOVA method.
- GR&R analysis - The ANOVA approach is used for nested examination.

3.2 Six-Sigma

Six Sigma assists in managing competitiveness, which has markedly intensified in the contemporary company landscape. To surpass the competition, superior quality items must be provided to clients at reasonable prices. Six Sigma consistently retains its preeminent status relative to other quality methodologies due to its adaptability and practicality in meeting corporate requirements. The significance of six sigma has escalated swiftly, and its implementation in business is pervasive[24].

IV. DEFECT REDUCTION IN THE MANUFACTURING INDUSTRY ASPECT OF QUALITY IMPROVEMENT

Defect reduction is an important aspect of quality improvement in the manufacturing sector, as it has a direct bearing on customer happiness, operational effectiveness, and product quality. The process of locating, evaluating, and reducing or removing flaws in a system, process, or product is known as defect reduction. Defects are typically defined as deviations or flaws that cause the product or system to perform below its intended or expected level of quality[25][26]. These problems may occur owing to several circumstances, including design flaws, manufacturing mistakes, software issues, or insufficient procedures. Defect reduction may be accomplished using several strategies, such as statistical process control, root cause analysis, and process improvement methodologies. This section will examine diverse methodologies employed by prior researchers to mitigate flaws, including an array of instruments and procedures utilised in the manufacturing sector. Rejected products have a significant impact on the manufacturing industry, both financially and operationally. Here are some of the main impacts that can occur[27]:

- **Additional costs:** Rejecting products results in additional costs for the manufacturing industry. Defects and quality problems can cause significant costs for manufacturers and increase external failure costs. These costs include wasted raw materials, time and labor used to manufacture substandard products, and costs to repair or replace rejected products. The higher the reject rate, the greater the costs incurred.
- **Decreased productivity:** Reject products disrupt production flow and reduce efficiency and productivity. Whenever products need to be recalled and resent through the production line, the time taken is much longer, thus lowering the overall production rate. Moreover, issues resulting from the reject trend also lead to production delays that exchange completion time and stock quality.
- **Decreased reputation and customer trust**: These products can in the process bring a company a bad reputation and customers will have low trust in the firm's goods. Low quality products may as well lead to customer dissatisfaction and does destabilize the brand image in the market. Customers may shift and look for other alternatives with competitors, with better quality products to buy from.
- **Market loss and business opportunities**: Returned products are also another form of costs that leads to market losses of the company. Thus, if products fail to meet the customers need, or if they do not conform to market standards, the firm could lose market share or possibly business.
- **Low quality and reclamation**: Several rejections can point to a system failure, for example a production system failure or substandard raw materials or failure in the quality assurance system. This result can make a company reputate as a low-quality producer and thus limit sustainable growth in the future.

Consequently, the manufacturing industry needs to minimize the level of rejection of products by providing quality management practices, production checks, employee training, and analysis of the production line. In the case of manufacturing industries, high rejected products tend to pull down operational efficiency, reputation and customer satisfaction, which are undesirable for the company in the long run since they lead to high turnover, loss of credibility and customers respectively.

V. CASE STUDY ON QC TOOLS TO REDUCE DEFECTS IN AN AUTOMOBILE MANUFACTURING INDUSTRY

This paper focuses on the application of techniques that can help in the control of poor quality in an assembly line of an automobile company. The emphasis is made on the analysis of chassis and trim lines to determine the presence of critical defects inherent in products at the production stage. The purpose of the research was to establish the control of the defects detected in the assembly line by the systematic application of QC tools. Observations of the assembly process were done often to determine which processes were most likely to produce defects. More specifically, the chassis line, with such parts as wheels, engine section, fuel wiring, battery wiring, etc., and trim line, which embraces such elements as shade, seats, dashboard, etc., were identified for the further analysis.

5.1 Materials and Methods

A significant lot of attention was paid to the situation in the assembly line in order to determine the frequency of defects. VID was able to determine the defects through repetitive inspections at both the chassis and trim lines [28].

1. **Data Collection Tools**

Data collection was done systematically using various QC tools;

- **Flow Charts (QC Tool-1):** Used to map the assembly line processes and visually represent the defect occurrences.
- **Check Sheets (QC Tool-2):** Data on defects were collected through check sheets, which enabled a systematic and straightforward way to track the occurrences of different defects. Data collection lasted four months, from November 2015 to February 2016.
- **Histograms (QC Tool-3):** Used to visualize the variation in defect frequency over the four-month period, providing insights into process capabilities. It was observed that defect rates were high initially due to the absence of proper quality control.
- **Pareto Diagrams (QC Tool-4):** Pareto diagrams were utilized to prioritize defects based on their frequency, highlighting that a significant number of defects occurred in November and December.
- **Cause and Effect Diagram (QC Tool-5):** Employed to determine root causes of defects, especially during the high-defect months of November and December.
- **Scatter Diagram (QC Tool-6):** Used to evaluate the relationship between defect frequency and time, revealing a negative correlation—indicating an overall reduction in defects over time.
- **P-Control Chart (QC Tool-7):** Applied to monitor whether the measurement process was statistically in control, noting significant defect reduction in weeks 7 and 9 for chassis and trim lines respectively.

5.2 Results and Analysis

In the results section of the case study, the chassis and trim lines were analyzed separately to evaluate the effectiveness of the quality control (QC) tools in reducing defects. Below is a detailed discussion of the results for both lines[29]:

- **Chassis Line:** A decrease in defect frequency was observed after applying QC tools. Notably, a reduction in engine hood damage and compressor pipe rusted issues was recorded after implementing root cause analysis.
- **Trim Line:** Similar improvements were observed, with a reduction in door sealing and footstep assembly-related defects. The Pareto diagrams highlighted that the defects were significantly reduced in the months after QC tool application (January and February).
- **Defect Reduction:** Application of QC tools yielded significant results involving the lines with enhanced designs of both the chassis and trim, with histograms and Pareto charts. As explained in Figure 2 & 3 the reduction of defects were shown in detail to endorse the measures of quality control.

International Journal of Core Engineering & Management
Volume-7, Issue-12, 2024 ISSN No: 2348-9510

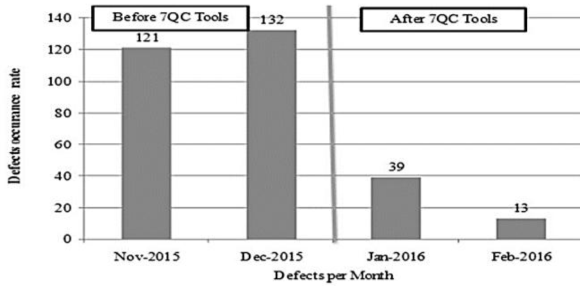

Figure 2: Reduction in defects in chassis line

The performance comparison of the defect rates of the chassis line before and after adopting the above QC tools is shown in Figure 2. This sort of presentation obviously shows that there has been a reduction in the number of defects we had and thus fully supports the conclusion that the systematic use of the QC tools time made a positive impact on the quality of the products.

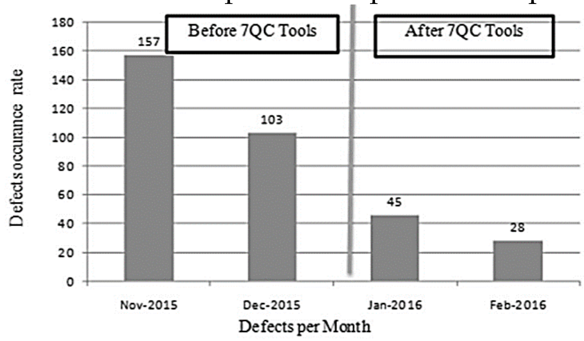

Figure 3: Reduction of defects in trim line

Figure 3 give an insight of the relative level of defect registration on the trim line before and after the socialization of QS tools. This figure shares a perfect indication of how the number of defects has been reduced due to the improvement of the quality. Subsequently, the above case study holds an overview of a breakthrough in the structured approach to the quality control processes of manufacture. The successful implementation of the 7 QC tools enable the company to claim a low level of defects in the production of both the chassis and trim lines. The mentioned tools offered uncomplicated understanding of the defects' occurrences, provided possibility of choosing the most significant problems, and helped to define root causes. Finally, the case study shown clearly illustrates that monitoring must be continuous, the analyses of the data should be performed systematically, and various tools of QC should be applied to enhance the product quality and minimize manufacturing defects.

VI. IMPACT OF QUALITY CONTROL (QC) TOOLS ON DEFECT REDUCTION

The impact of Quality Control (QC) tools on defect reduction in the automobile manufacturing industry includes:

- **Identification of Defects:** Use of flow charts, check sheets and histogram enlighten the defects mapped out in production systematically.
- **Prioritization of Issues**: To the specific aim, Pareto diagrams were employed to identify and rank the most common defects, on which corrective action could then focus.

- **Root Cause Analysis:** By using cause-and-effect diagrams it was easy to determine what really was causing the defects such as incorrect setting of machines or lack of maintenance.
- **Correlation Analysis:** Inspector charts used to predict the correlation between other factors ant the cause of defects like vibration levels which lead to machine downtime.
- **Statistical Control:** P-control charts were used to observe the production process and determine whether or not it was statistically in control, and where specific defect rates were lower.
- **Defect Reduction:** The use of QC tools eliminated the following defects in the chassis and trim lines among them; engine hood damage, compressor pipe rusting, door sealing and footstep assembly.
- **Cost Reduction:** Thus, the reduction of the overall number of defects minimised costs amounting to rework, delivered products or services, and warranty claims.
- **Enhanced Product Quality**: Keeping keen track of QC instruments or constant deployment of these instruments was instrumental to enhanced quality of products hence increased appreciation among customers.
- **Operational Efficiency:** A decline in the number of defects together with improvements in the various processes employed was also beneficial to the operations efficiency and productivity.
- **Data-Driven Decision Making**: The use of QC tools provided a data-driven basis for decision-making, enabling more informed and effective quality management strategies.

VII. LITERATURE REVIEW

This section provides the existing works on quality control tools on defect reduction in the various manufacturing industry with various tools and techniques. Also, table 1 provide the summary of these related work with various key factors.

Montalbo et al. (2023), used a Pareto Chart to find that flaws are associated with bridging, rounding, holes, and narrow walls. The researchers found that thermoforming machine materials are too fragile Using the Why-Why analysis and Fishbone diagram. Accordingly, the researchers suggested designing and developing an impact tester to reduce defects. The prototype would visually assess polypropylene material quality after impact and regulate the bulk production of faulty sheets from the extrusion process. The sheets are tested on this prototype before mass manufacturing to improve the company's reputation and performance[30].

Salmi (2020), The team was able to address a real nonconformity, enhance the general quality of reporting, and establish a useful feedback loop between field technicians and operations management by putting the quality control method into practice. The quantity of non-conformities discovered, the time spent on quality control duties, the time spent fixing non-conformities, and the resources used on auditing were used to gauge the outcomes. Data, the subjective experiences of stakeholders, and comments gathered during the study cycles served as the basis for the assessment. [31]

Ribah and Singh (2023), study uses the RII approach to determine the relative relevance of quality elements in construction and the influence of assurance and quality control on construction projects. At the beginning of this research, a questionnaire with 37 criteria divided into five groups was produced. In the research region, 153 professional and skilled workers from various building sites owned by various construction businesses were given questionnaires. A total of 136 were obtained back. The data was analyzed using SPSS, and the relative relevance of various components was ascertained using the RII approach. Many aspects were considered and recommendations were made. Kebbi State Nigeria construction sites are the case study. Statistics were used to measure and analyze the data statistically assessed[32].
I. Memon et al. (2019), Many manufacturers and service companies aim for zero faults. For defect reduction and productivity improvement, statistical methods are applied. After QC tools were implemented, chassis line faults dropped 90% (from 132 to 13). The trim line failure rate dropped 80% from 157 to 28. The manufacturer employed just a few of the seven quality control instruments in their assembly procedure. It may be necessary for the organization to adopt all seven QC tools in every department [28].

Yan (2022), work uses SVM to detect noncontact car cylinder block defects. Deformation is easy in car cylinder block walls with thin holes and complex structures. Simulation and experiment analyses clamping and milling deformation during vehicle engine cylinder block top surface machining. To solve the problem, control the milling deformation profile error measure. Laser-nonultrasonic contact can function on non-planar objects. Only works on planes and cylinders. Automotive and other industries use laser nonultrasonic touch technologies to discover faults in curved products with free-form surfaces [33].

Chazhoor et al. (2023), lack of the work addresses defect data and prolonged model training durations. The Northeastern University (NEU) steel dataset served as a benchmark for five advanced object identification models: Faster R-CNN, Deformable DETR, Double Head R-CNN, RetinaNet, and Deformation Convolutional Network. The deformable convolutional network achieved a peak accuracy of 77.28% on the NEU dataset during fivefold cross-validation. Alternative models performed well with 70–75% accuracy. The findings lay groundwork for steel flaw detection research and have major practical ramifications. [34].

Chen et al. (2023), review provides information on the current state of affairs and future prospects for additive manufacturing in the automobile sector. A variety of additive manufacturing (AM) processes are covered, with special attention to their materials, mechanisms, and applications in the automobile industry. These processes include Selective Laser Sintering (SLS), Stereo lithography (SLA), Binder Jetting (BJ), Fused Filament Fabrication (FFF), and Selective Laser Melting (SLM). Furthermore, the potential for using additive manufacturing (AM) in the automotive sector is discussed, emphasizing the advantages of AM lightweight and material savings, AM design flexibility and customization, AM rapid prototyping, and AM quick product development, with an emphasis on electric vehicles (EVs). By assessing AM's present state and potential for the future, stakeholders will be better equipped to handle related problems and properly use AM to shape how automotive design and production will advance in the future.[35].

International Journal of Core Engineering & Management
Volume-7, Issue-12, 2024 ISSN No: 2348-9510

Table 1: Summary of related work for QC with defect reduction in various manufacturing industries.

Study	Objective	Methodology	Key Findings	Applications
Montalbo et al. (2023) [30]	Identify defects in thermoforming machine materials	Pareto Chart, Fishbone Diagram, Why-Why Analysis	High defect rate due to lack of QC equipment; proposed impact tester to improve quality	Thermoforming process in automotive
Salmi (2020) [31]	Improve overall quality control in manufacturing operations	Data assessment, stakeholder feedback	Non-conformities reduced, improved reporting quality; permanent QC process adopted	Manufacturing quality management
Ribah and Singh (2023) [32]	Assess quality elements in construction projects	RII approach, questionnaire, SPSS analysis	Identified key quality factors; recommendations made based on data analysis	Construction quality assurance
I. Memon et al. (2019) [28]	Reduce defects in assembly lines	Application of classic QC tools	Significant defect reduction: chassis line faults dropped by 90%	Automotive assembly line processes
Yan (2022) [33]	Detect defects in automotive components using SVM	Simulation, machine vision techniques	Improved detection efficiency for cylinder block defects	Automotive noncontact fault detection
Chazhoor et al. (2023) [34]	Automate flaw detection in steel products	Benchmarking object detection models	Deformable convolutional network achieved highest accuracy	Steel industry flaw detection
Chen et al. (2023) [35]	Explore applications of additive manufacturing in automotive	Review of AM techniques and case studies	Highlighted advantages of AM: material efficiency, rapid prototyping	Automotive design and production

From this table 1 it becomes clear on the comparative studies with outlining the contribution of the studies in the subject area of quality control with a special reference to the detection of defects in various industry types especially in automotive industry.

VIII. CONCLUSION AND FUTURE WORK

This work has well demonstrated that quality control tools do apply and are effective in minimizing on defects and improving the quality of products in the automobile production line. The conclusion that can be made with the help of the present study procide evidence of the efficiency of Quality Control tools in decreasing the number of defects in the automobile manufacturing industry. The adoption of QC tools in chassis and trim line production through identification and prioritization of defect, plus root cause analysis practically reduced the number of defects recorded. Due to the techniques of the SPC, the production was controlled and the processes did not de-deviate from their optimal performance thus enhancing the quality of the products that were being produced and therefore customer satisfaction. Impressive too was the decreased number of defects, which in turn led to decreased costs in terms of reworking and warranty issues thus increasing the company's competitive edge. In addition, this study shows that using QC tools create a foundation for long-term of having structured procedure to control quality in manufacturing operations. Indeed, this research forms a one-stop-shop to manufacturers who want to adopt efficient strategies in quality management to transform their organizations' challenging operating landscapes.

Interactivity In the future, enriching a set of QC tools with things like machine learning or artificial intelligence can enhance a quality management system. Moreover, the advancing of the material selection processes and the incorporation of other ways to make quality control measures more sustainable will be inescapable in order to align manufacturing objectives with social and ecological impacts. Future work might analyze possibilities to extend the diagnostic and non-damaging techniques, especially with relation to Industry 4.0 and smart manufacturing.

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