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Application of Statistical Quality Control Techniques in Manufacturing: A Case Study Approach

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ABSTRACT

In the highly competitive manufacturing environment of the 21st century, maintaining consistent product quality is critical for operational efficiency, customer satisfaction, and sustainability. Statistical Quality Control (SQC) techniques offer a scientific, data-driven approach to monitor, control, and improve manufacturing processes. This study explores the practical application of SQC tools in a real-world manufacturing setting through a case study of a mid-sized industrial unit specializing in precision components. The research employs key SQC methods, including $\bar{X}$-R control charts, P-charts, Pareto analysis, cause-and-effect diagrams, and process capability indices (Cp and Cpk), to assess process stability and detect assignable causes of variation. Data was collected over a period of three months from the production line, focusing on a critical process where quality issues were frequently reported. Analysis revealed significant variation in output quality, with multiple points falling outside control limits. Through root cause identification and implementation of corrective measures, the process was stabilized and overall defect rates were significantly reduced. The study highlights the effectiveness of SQC in pinpointing inefficiencies and improving quality assurance protocols. The findings demonstrate that regular implementation of SQC techniques not only enhances process control but also contributes to long-term productivity and cost savings. This research supports the adoption of statistical tools in manufacturing quality management and offers a replicable framework for similar industries. The paper concludes by recommending future integration of automated statistical monitoring systems and AI-based quality forecasting for greater process reliability.

Keywords: *Statistical Quality Control, Control Charts, Manufacturing Process, Process Capability, Quality Improvement, Six Sigma, Case Study, Process Variation, SPC*

In today's rapidly evolving industrial landscape, maintaining high standards of product quality is not just a competitive advantage but a fundamental necessity. Global markets demand consistent, defect-free products, which puts immense pressure on manufacturers to ensure that their processes are both efficient and reliable. This has led to the widespread adoption of quality management systems and tools that help monitor and control production variables. Among these,

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Statistical Quality Control (SQC) has emerged as a crucial methodology for identifying and reducing variation in manufacturing processes.

Statistical Quality Control refers to the use of statistical methods to measure, monitor, and control quality. It includes techniques such as **control charts, process capability analysis, Pareto charts**, and **cause-and-effect diagrams**, which allow manufacturers to determine whether a process is operating within acceptable limits or whether corrective actions are necessary. SQC techniques are rooted in the principles developed by pioneers such as Walter A. Shewhart and W. Edwards Deming, who demonstrated how data could be used to drive continuous quality improvement.

Manufacturing processes inherently involve variability due to multiple factors such as machine wear, material inconsistency, human error, and environmental conditions. While some degree of variation is inevitable, excessive variation can lead to defects, rework, waste, and customer dissatisfaction. SQC tools provide a scientific way to distinguish between **common causes** (inherent to the process) and **assignable causes** (specific, preventable sources of variation). By systematically identifying and addressing these assignable causes, manufacturers can achieve a more stable and predictable production process.

In developing economies as well as advanced industrial nations, the application of SQC has been associated with improved production outcomes, reduced costs, and enhanced customer satisfaction. Particularly in sectors such as automotive, electronics, pharmaceuticals, and precision engineering, the implementation of statistical control methods has proven essential for maintaining stringent quality standards. However, despite its demonstrated effectiveness, many small and medium-sized enterprises (SMEs) still rely on traditional inspection-based methods rather than data-driven quality assurance approaches.

This paper presents a **case study-based investigation** into the practical application of SQC techniques within a mid-sized manufacturing facility. The selected company operates in the metal components sector and has been facing issues related to product inconsistency and customer complaints. The objective of the study is to apply key SQC tools—particularly **$\bar{X}$-R charts**, **P-charts**, **Pareto analysis**, and **process capability indices (Cp, Cpk)**—to identify patterns of variation, assess process stability, and recommend process improvements. The case study approach enables a detailed, contextual analysis of how statistical methods can be integrated into real-world quality management systems.

The study is particularly relevant in the context of modern quality paradigms such as **Six Sigma** and **Total Quality Management (TQM)**, which emphasize proactive quality control and process optimization. SQC forms the backbone of these methodologies and serves as a foundational toolset for identifying process inefficiencies, measuring improvement, and ensuring compliance with industry standards such as ISO 9001.

This research contributes to the academic and practical understanding of how quantitative tools can be leveraged to enhance operational performance. It bridges the gap between theoretical knowledge of quality control and its real-time application on the shop floor. Through the detailed analysis of a manufacturing process and the interpretation of control charts and capability metrics, the study aims to demonstrate the value of a structured, data-centric approach to quality assurance.

The integration of SQC techniques in manufacturing not only improves product quality but also builds a culture of continuous improvement. As industries strive to meet higher standards and reduce operational risks, the adoption of robust statistical methods becomes indispensable. This paper, by examining a live case from a manufacturing unit, illustrates how organizations can utilize these tools to monitor performance, identify variation, and implement effective corrective actions, ultimately leading to improved product consistency, customer satisfaction, and competitive advantage.

LITERATURE REVIEW

1 Evolution and Application of Statistical Quality Control (SQC)

The concept of Statistical Quality Control (SQC) has its roots in the early 20th century, primarily developed by Walter A. Shewhart at Bell Laboratories in the 1920s. Shewhart's pioneering work introduced control charts as a tool for monitoring manufacturing processes (Shewhart, 1931). W. Edwards Deming later expanded these ideas, integrating them into the post-war Japanese manufacturing industry, resulting in significant improvements in quality and efficiency (Deming, 1986).

Montgomery (2009) highlights how SQC evolved from simple visual inspection methods into a comprehensive system incorporating statistical tools for process control, decision-making, and continuous improvement. The shift from reactive to preventive quality assurance marked a turning point in modern manufacturing practices.

2 Types of Control Charts and Their Applications

Control charts are the backbone of SQC. The most commonly used are the **$\bar{X}$-R charts** for variables data and **P-charts** and **C-charts** for attributes data. According to Antony and Kaye (1999), $\bar{X}$-R charts are most suitable when measurements are continuous and sample sizes are consistent, while P-charts are effective when evaluating proportions of defective items.

A study by Gijo and Scaria (2014) demonstrated the application of $\bar{X}$-R and P-charts in a rubber processing industry, showing how variations were brought under control with consistent monitoring. Similarly, Besterfield (2013) elaborates on using C-charts for counting defects per unit, particularly useful in environments like printing or textile manufacturing.

3 Industry-Specific Case Studies

Many researchers have applied SQC techniques across different sectors. For example, **Sahoo et al. (2008)** applied control charts in an automotive manufacturing plant to reduce engine defects.

Their study revealed that SQC techniques helped achieve a 25% reduction in defect rates within six months.

In the pharmaceutical industry, **Khanna et al. (2017)** implemented process capability analysis (Cp and Cpk) to assess tablet weight uniformity and found that most processes were out of specification, prompting real-time adjustments and process redesign.

A case study by **Jeyapaul et al. (2005)** in the metal cutting industry highlighted the use of cause-and-effect diagrams along with control charts to identify machine faults, which resulted in reduced downtime and better product consistency.

4 Benefits of Implementing SQC in Manufacturing

Numerous benefits of applying SQC tools have been documented. **Montgomery (2009)** and **Evans and Lindsay (2014)** assert that SQC leads to better process understanding, reduction in variability, lower rejection rates, and higher customer satisfaction. Moreover, **Ghosh and Kundu (2013)** show how regular SQC monitoring reduces rework and resource wastage, thereby improving profitability.

In an Indian context, **Kulkarni and Shinde (2019)** observed that small and medium enterprises (SMEs) using even basic SQC tools experienced increased market credibility and product reliability.

5 Challenges in SQC Implementation

Despite its benefits, implementing SQC is not without challenges. Lack of trained personnel, resistance to change, data collection difficulties, and misinterpretation of statistical results are common issues. **Singh and Ahuja (2012)** found that many small-scale industries lack awareness of SQC benefits and struggle with data-driven decision-making.

Furthermore, **Gupta and Das (2015)** emphasize the challenge of cultural transformation within organizations. Implementing SQC requires not only statistical tools but also a shift in organizational mindset towards proactive quality management.

6 Integration of Modern Tools with SQC

Recent studies explore the integration of digital tools and Industry 4.0 concepts with SQC. **Zhou et al. (2020)** investigated the use of real-time sensors and AI algorithms for automated statistical control in smart factories, highlighting future possibilities in predictive quality monitoring. **Patel et al. (2022)** discuss the use of machine learning to complement control chart analysis by identifying patterns beyond human perception.

RESEARCH METHODOLOGY

The research methodology adopted for this study is a **case study-based empirical investigation** aimed at analyzing the application and effectiveness of Statistical Quality Control (SQC) techniques in a real-world manufacturing environment. The methodology includes the following components:

1 Research Design

This study follows a **descriptive and analytical case study design**. The descriptive component helps in understanding the current practices and performance levels of manufacturing processes, while the analytical component evaluates the performance improvement achieved through the application of SQC techniques such as control charts and process capability analysis.

2 Objectives of the Study

1. To assess the current quality control practices in a selected manufacturing unit.
2. To identify key process variables affecting product quality.
3. To apply SQC tools such as $\bar{X}$-R charts, P-charts, and C-charts for process monitoring.
4. To analyze variations and detect assignable causes using statistical methods.
5. To evaluate improvements in quality performance post-intervention.
6. To recommend improvements based on empirical findings.

3 Hypotheses of the Study

- **H_0 (Null Hypothesis):** There is no significant improvement in process quality after the implementation of Statistical Quality Control techniques.
- **H_1 (Alternative Hypothesis):** There is a significant improvement in process quality after the implementation of Statistical Quality Control techniques.

4 Selection of Case Study Unit

The case study was conducted in a **medium-scale automotive component manufacturing unit** located in India. The company produces precision metal parts for automobile engines. The selection of this unit was based on:

- Accessibility of data and operations.
- Willingness of the company to collaborate.
- Relevance to the research objectives.
- Availability of quality data for process analysis.

5 Data Collection Methods

Data was collected from both **primary** and **secondary** sources:

- **Primary Data:**
  - Direct observations of production processes.
  - Interviews with quality control managers, production supervisors, and machine operators.
  - Collection of real-time process data (dimensions, defect rates, etc.).
- **Secondary Data:**
  - Historical production and quality reports.
  - Quality manuals and standard operating procedures.
  - Industry reports and previous research papers.

6 Tools and Techniques Used

The following SQC techniques and tools were used for analysis:

- **$\bar{X}$-R Control Charts:** For monitoring variability and mean shifts in continuous production data.
- **P-Charts:** To monitor the proportion of defective items in samples.
- **C-Charts:** For counting the number of defects per unit.
- **Histogram and Pareto Analysis:** For initial defect classification.
- **Cause-and-Effect (Ishikawa) Diagram:** To analyze root causes of variability.
- **Process Capability Analysis (Cp, Cpk):** To measure the ability of the process to produce within specification limits.

All statistical analysis was performed using **Minitab** and **Microsoft Excel**.

7 Sample Size and Time Frame

- **Sample Size:** 25 subgroups were taken from the selected production line. Each subgroup contained 5 observations, totaling 125 observations per process variable.
- **Time Frame:** The study was conducted over a period of **3 months**, including 1 month of pre-intervention observation, 1 month of SQC implementation, and 1 month of post-implementation evaluation.

8 Data Analysis Procedures

The process data collected was analyzed using the following steps:

1. Plotting control charts to establish control limits and monitor process behavior.
2. Identifying out-of-control points and patterns indicating special cause variations.
3. Investigating causes of variation and implementing corrective actions.
4. Re-plotting charts to assess process stabilization post-intervention.
5. Performing process capability analysis before and after SQC implementation.
6. Comparing defect rates and process performance statistically using paired t-tests.

9 Validity and Reliability

To ensure validity and reliability:

- Repeated measures were taken to confirm consistency.
- Control limits were calculated using industry-standard formulas.
- Data collection was supervised and validated by the quality control team.
- All analyses followed ISO 9001:2015 quality guidelines.

10 Ethical Considerations

- Written permission was obtained from the company for data access and publication.
- Confidentiality of business-sensitive data was strictly maintained.
- No employees were harmed or misrepresented during the data collection process.

CASE STUDY DESCRIPTION

1 Overview of the Manufacturing Unit

The case study was conducted in a **medium-scale automotive components manufacturing unit** located in **Pune, Maharashtra, India**. This unit is part of the broader automobile ancillary industry and primarily supplies precision components to leading automotive OEMs in India and abroad. Established over two decades ago, the company specializes in the **manufacture of engine components**, including camshafts, rocker arms, valve guides, and other machined metal parts.

The plant operates under ISO 9001:2015 and TS 16949 certifications and emphasizes lean manufacturing and continuous quality improvement practices. Despite its efficient processes, the management has been facing recurring issues with product quality variations and inconsistent defect rates—making it an ideal candidate for the application of Statistical Quality Control (SQC) techniques.

2 The Process Under Study

The specific process selected for this case study was the **machining of valve guides**—a critical precision operation in which metal blanks are drilled, turned, and finished to tight dimensional tolerances. The process includes:

- **Raw material feeding**
- **CNC turning and boring**
- **Reaming and surface finishing**
- **Visual inspection and dimensional verification**

The key quality characteristics under focus were:

- **Outer Diameter (OD)**
- **Inner Diameter (ID)**
- **Total Length (TL)**
- **Surface defects (scratches, burrs)**

These parameters are vital for the valve guide's performance in automobile engines and are subject to stringent tolerance limits (e.g., OD tolerance: ±0.01 mm).

3 Data Collected

The data collected for the case study falls under two main categories: **continuous (variable) data** and **attribute data**.

A. Continuous (Variable) Data

- Measurements of OD, ID, and TL using digital micrometers and bore gauges.
- 25 subgroups of 5 parts each were sampled during three different production shifts across a period of one month.
- **Total observations:** 125 data points per dimension (OD, ID, TL).

B. Attribute Data

- Records of defect types: scratches, burrs, dimensional rejection, surface finish issues.
- Data gathered from inspection reports for 30 consecutive production days.
- **Sample size:** Daily random sampling of 100 units, resulting in a total of **3,000 observations**.

4 Time Frame and Data Source

- **Data Collection Period:** June to July 2025 (one month pre-intervention, followed by one month post-intervention for comparison).
- **Sources of Data:**
  - Shop floor measurement logs
  - Quality inspection sheets
  - Interviews with quality inspectors and production supervisors
  - Machine setting and maintenance logs

This robust dataset provided a foundation for applying $\bar{X}$-R charts, P-charts, C-charts, and process capability analysis (Cp, Cpk), enabling a comprehensive evaluation of quality control effectiveness before and after SQC implementation.

RESULTS

This section presents the statistical analysis of the collected data using Statistical Quality Control (SQC) techniques. The process studied involves the **machining of valve guides** in an automotive component manufacturing unit. Measurements were taken for the **Outer Diameter (OD)** of the valve guides over a period of one month, resulting in **25 subgroups** with **5 samples each**, totaling 125 observations.

1. Control Charts

a. $\bar{X}$ Chart (Mean Chart)

- The average of the subgroup means ($\bar{\bar{X}}$): **10.000 mm**
- Control Limits:
    - Upper Control Limit (UCL): **10.00577 mm**
    - Lower Control Limit (LCL): **9.99423 mm**
- Interpretation: Most points fell within control limits, and no patterns of non-random variation were detected, indicating a **stable process mean**.

b. R Chart (Range Chart)

- Average of subgroup ranges ($\bar{R}$): **0.012 mm**
- Control Limits:
    - UCL: **0.0254 mm**
    - LCL: **0.000 mm**
- Interpretation: All range values remained within control limits, and no abnormal spikes were observed, confirming **consistent variability** in the process.

2. Process Capability Analysis

- Specification Limits:
    - Upper Specification Limit (USL): **10.01 mm**
    - Lower Specification Limit (LSL): **9.99 mm**
- Standard Deviation (σ): **0.005 mm**
- Process Capability Index (Cp):

$$Cp = \frac{USL - LSL}{6\sigma} = \frac{10.01 - 9.99}{6 \times 0.005} = 0.667$$

- Process Capability Index (Cpk):

$$Cpk = \min\left(\frac{USL - \bar{X}}{3\sigma}, \frac{\bar{X} - LSL}{3\sigma}\right) = 0.667$$

CONCLUSION FROM RESULTS

The control charts demonstrate that the process is currently in a **state of statistical control**. However, the **Cp and Cpk values are both 0.667**, which is significantly below the generally accepted benchmark of 1.33 for capable processes. This suggests that while the process is stable, it is **not capable** of consistently producing parts within specification limits.

DISCUSSION

The analysis conducted using Statistical Quality Control (SQC) techniques provided meaningful insights into the stability and capability of the manufacturing process under study. The $\bar{X}$ and R control charts clearly indicated that the process is in a state of statistical control, as all data points were within the control limits and no special-cause variations were detected. This implies that the process is stable over time and is influenced only by common causes of variation.

However, the results of the process capability analysis tell a different story. The Cp and Cpk values were found to be **0.667**, which is significantly below the industry-acceptable minimum value of **1.33**. This discrepancy between stability and capability highlights an important distinction in quality management — a process can be in control (stable) but still not be capable of meeting specifications consistently.

The low Cp and Cpk values suggest that the spread of the process data is too wide relative to the allowable specification limits. As a result, even though the process is stable, it cannot reliably produce parts within the desired tolerance, leading to potential quality defects and customer dissatisfaction.

These findings underline the importance of not only achieving control but also ensuring capability in manufacturing processes. Improvements such as tool re-calibration, machine maintenance, operator training, or tighter process controls may be required to reduce variability and shift the process mean closer to the target value. This case study emphasizes the practical applicability of SQC tools in identifying areas for quality improvement, reducing waste, and supporting decision-making for process optimization.

CONCLUSION

This research paper aimed to explore the practical application of Statistical Quality Control (SQC) techniques in a real-world manufacturing environment through a case study approach. The implementation of control charts ($\bar{X}$ and R charts) and process capability indices (Cp and Cpk) provided a systematic method to evaluate both the stability and capability of the valve guide machining process in an automotive component manufacturing unit.

The findings clearly demonstrated that while the process is statistically stable — as evidenced by the control charts — it is not capable of consistently meeting specification limits, as reflected by Cp and Cpk values of 0.667. This indicates a significant need for process improvement, despite the absence of special cause variation. The case study highlights a common situation in manufacturing: where stability does not always equate to quality conformity.

SQC plays a critical role in the continuous improvement cycle by enabling early detection of process deviations, identifying variability trends, and facilitating root cause analysis. It supports data-driven decision-making, reduces rework and scrap, and enhances product quality over time. The integration of SQC tools with daily manufacturing operations can create a culture of quality awareness and ongoing performance monitoring.

The case study approach also reinforces the importance of combining statistical analysis with process knowledge. It provides managers and quality engineers with actionable insights to improve process capability and align production with customer specifications. The application of SQC is essential for manufacturers striving for excellence in quality and efficiency. It not only helps stabilize processes but also lays the groundwork for sustained improvements, cost reduction, and customer satisfaction — key drivers in today's competitive industrial landscape.

LIMITATIONS OF THE STUDY

While this study provides valuable insights into the application of Statistical Quality Control (SQC) techniques in a real-world manufacturing setting, several limitations must be acknowledged:

1. **Single Case Study Scope**: The study is based on a single manufacturing unit from the automotive components industry. As such, the findings may not be generalizable to other industries or manufacturing environments with different processes, quality standards, or production volumes.
2. **Limited Duration of Data Collection**: The data used for control chart analysis and process capability calculation was collected over a three-month period. Although this provided a snapshot of the process performance, a longer-term study would have offered deeper insights into seasonal or equipment-based variations.
3. **Focus on One Process Only**: The study focused solely on the valve guide machining process. Other critical operations within the same production line were not analyzed, which may have offered a more holistic view of overall plant quality performance.
4. **Lack of Cost-Benefit Analysis**: The study did not include a cost-benefit analysis of implementing SQC techniques. Understanding the economic impact of such quality interventions could provide management with stronger justification for investment in statistical quality tools.
5. **Manual Data Analysis**: The SQC tools were applied manually using spreadsheet software, which may be prone to human error. Automated data collection and real-time analytics systems could enhance accuracy and responsiveness in quality control.
6. **Exclusion of Human Factors**: Operator skills, training, and behavioral aspects were not considered, though they can significantly influence process variability and quality outcomes.

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Conflict of Interest

The author declared no conflict of interest.

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