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Quality Control Improvement Using Statistical Process Control in Manufacturing Industry

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Abstract: Quality improvement remains a critical challenge in manufacturing industries due to increasing product complexity, strict customer requirements, and competitive market conditions. Statistical Process Control (SPC) has been widely recognized as an effective approach for monitoring process stability, reducing variability, and improving product quality. This study aims to analyze the application of SPC as a systematic method to enhance quality control performance in manufacturing operations. A quantitative case-study-based research design was adopted, focusing on production processes where quality deviations frequently occurred. Data were collected through direct observation, historical production records, and defect inspection reports. SPC tools, including control charts, process capability analysis, and Pareto analysis, were employed to identify process variations and root causes of defects. The results demonstrate that SPC implementation significantly improves process stability, reduces defect rates, and enhances process capability indices. Comparative analysis with previous studies confirms that SPC contributes to continuous improvement when supported by structured data analysis and corrective actions. This study concludes that SPC is a practical and reliable quality control approach that supports decision-making and operational excellence in manufacturing industries. The findings provide practical insights for quality engineers and managers seeking to strengthen quality assurance systems.

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INTRODUCTION

Manufacturing industries operate in increasingly competitive environments where product quality, process consistency, and operational efficiency are critical determinants of organizational performance. The demand for high-quality products with minimal defects continues to rise as customers become more sensitive to quality variations and regulatory requirements become more stringent. In this context, quality control systems play a central role in ensuring that manufacturing processes remain stable, capable, and aligned with predefined specifications. Failure to control process variability not only leads to increased defect rates but also results in rework, waste, customer dissatisfaction, and financial losses (Jamadar, 2020; Singh, 2022).

Among various quality management approaches, Statistical Process Control (SPC) has been widely recognized as an effective and systematic method for monitoring, analyzing, and improving manufacturing processes. SPC utilizes statistical techniques, particularly control charts and process capability analysis, to distinguish between common cause variation and special cause variation in production processes. By identifying abnormal process behavior at an early stage, SPC enables timely corrective actions before defects propagate downstream (Solihudin, 2017; Godina et al., 2016).

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Numerous studies have demonstrated that SPC contributes significantly to defect reduction, process stabilization, and continuous quality improvement across diverse manufacturing sectors.

The application of SPC has evolved from its traditional role as a monitoring tool into a comprehensive framework for continuous improvement. Modern manufacturing environments increasingly integrate SPC with other quality improvement methodologies such as Plan–Do–Check–Act cycles, Six Sigma, Just In Time manufacturing, and Total Quality Management. Pérez-Vicente et al. (2024) showed that the integration of SPC with PDCA significantly improved process capability and reduced out-of-specification products in the automotive industry. Similarly, Görmen (2022) emphasized that SPC aligns well with Just In Time principles by preventing defect generation rather than relying on inspection-based quality control.

Empirical evidence from various industrial contexts confirms the effectiveness of SPC in improving manufacturing quality. Case studies in automotive manufacturing report substantial reductions in defect rates and rework costs following the implementation of control charts and capability indices (Gaikwad et al., 2019; Milić et al., 2024). In textile and garment manufacturing, SPC has been shown to enhance fabric quality detection and sewing line stability, leading to improved customer satisfaction and reduced financial losses (Erdinç et al., 2024; Ural & Elmali, 2023). These findings highlight the versatility of SPC as a quality control tool applicable to both discrete and continuous production systems.

Despite its proven benefits, the effectiveness of SPC implementation varies widely across organizations. Several studies indicate that improper chart selection, insufficient operator training, and lack of management commitment often limit the impact of SPC initiatives (Parmar & Deshpande, 2018; Rahman et al., 2015). In small and medium-sized enterprises, in particular, SPC adoption faces challenges related to limited statistical expertise and resource constraints. Rahman et al. (2015) noted that although SPC tools are conceptually simple, their practical application requires structured guidance and organizational support to ensure sustained quality improvement.

Recent research has also expanded SPC applications beyond univariate control charts toward multivariate and advanced statistical approaches. Multivariate control charts, such as Hotelling's T^2, have been successfully applied to monitor multiple quality characteristics simultaneously in complex manufacturing processes (Tiryaki & Aydin, 2022; Mihalcin et al., 2014). Furthermore, Bayesian modeling and process trajectory outlier detection have been introduced to enhance sensitivity and robustness in detecting abnormal process behavior (Date & Yukako, 2020; Pheng et al., 2019). These developments indicate that SPC continues to adapt to the growing complexity of modern manufacturing systems.

In addition to methodological advancements, recent studies emphasize the importance of integrating SPC with digital and data-driven manufacturing environments. Process mining-based SPC approaches enable organizations to analyze large volumes of operational data and identify bottlenecks that affect quality and cycle time performance (Doğan & Hızıroğlu, 2024). Similarly, KPI-based SPC frameworks support real-time monitoring and automated decision-making, particularly in mechatronic and high-precision manufacturing systems (Wohlers et al., 2018). These innovations reinforce the relevance of SPC in the context of Industry 4.0 and smart manufacturing.

However, despite extensive literature on SPC tools and applications, several gaps remain. Many studies focus on specific industries or isolated case studies without providing a comprehensive analysis of SPC implementation outcomes across different manufacturing contexts. Moreover, some investigations emphasize technical aspects of SPC while paying limited attention to practical implementation challenges, such as process variability sources, operator behavior, and organizational readiness (Taher & Alam, 2014; Swetha & Gayatri, 2024). As a result, the transferability of SPC best practices across manufacturing sectors remains limited.

Another limitation identified in the literature is the tendency to evaluate SPC effectiveness using short-term performance indicators without considering long-term process stability. Fuller (2015) and Nechlani (2018) argued that sustainable quality improvement requires continuous monitoring and iterative refinement of control limits based on evolving process conditions. Without such long-term perspectives, SPC initiatives risk becoming routine compliance activities rather than strategic quality improvement mechanisms.

Given these considerations, there is a clear need for a structured and evidence-based examination of SPC implementation in manufacturing industries, focusing on its role in improving quality performance through systematic monitoring and corrective action. This study aims to analyze quality control improvement using Statistical Process Control by synthesizing established SPC techniques and evaluating their contribution to process stability, defect reduction, and operational efficiency. By drawing upon empirical findings from prior studies and applying SPC principles in a manufacturing context, this research seeks to strengthen the understanding of SPC as a practical and replicable quality improvement approach.

The contribution of this study lies in providing a comprehensive analysis of SPC-based quality control improvement that emphasizes practical implementation, performance measurement, and continuous improvement. The findings are expected to offer valuable insights for practitioners seeking to enhance manufacturing quality and for researchers aiming to advance empirical evidence on SPC effectiveness. Ultimately, this study supports the view that Statistical Process Control remains a foundational and adaptable tool for achieving consistent quality performance in manufacturing industries.

RESEARCH METHOD

This study employed a quantitative and descriptive research design to evaluate quality control improvement in a manufacturing process through the application of Statistical Process Control. The research design was selected to systematically observe, measure, and analyze process variation using statistical techniques without altering the original production system. The focus of the study was on assessing process stability, identifying sources of variation, and evaluating process capability based on existing operational data.

Research Setting and Time Frame

The research was conducted in a manufacturing environment that operates under standardized production procedures and quality specifications. The study focused on a single production line to ensure consistency and analytical clarity. Data collection was carried out over a defined observation period during normal operating conditions to capture representative process behavior. No experimental manipulation or process intervention was introduced during the observation period.

Population and Sample

The population of this study consisted of all production outputs generated by the selected manufacturing process within the observation period. The sample included production data related to critical quality characteristics that were routinely measured as part of the company's quality control system. Sampling followed existing inspection procedures and measurement frequencies to maintain consistency with actual operational practices. No additional sampling criteria or measurement variables were introduced.

Data Collection Technique

Primary data were obtained from historical quality inspection records and routine production monitoring documents. The data included measurement results of critical quality characteristics, defect counts, and production quantities. These data were collected directly from the quality control department and verified for completeness and consistency. Secondary data, such as process specifications and standard operating procedures, were used to support the interpretation of SPC results.

Statistical Process Control Tools

Statistical Process Control techniques were applied to analyze process performance and quality stability. Control charts were used to monitor process variation and identify out-of-control conditions. The selection of control chart types was based on the nature of the data, whether variable or attribute, and followed established SPC guidelines. In addition, process capability analysis was conducted using capability indices to evaluate the ability of the process to meet specification limits. All calculations adhered strictly to standard SPC formulas and procedures as documented in the literature.

Data Analysis Procedure

The data analysis process consisted of several sequential steps. First, production data were organized and classified according to measurement periods. Second, control charts were constructed to assess process stability by examining patterns, trends, and points beyond control limits. Third, when out-of-control signals were identified, potential assignable causes were analyzed using existing process documentation and quality records. Fourth, process capability indices were calculated to quantify process performance relative to specification limits. The analysis focused on comparing process conditions before and after quality control improvement efforts, without introducing new improvement interventions.

Validity and Reliability

To ensure data validity, only verified and officially recorded quality data were used in the analysis. Measurement instruments and inspection procedures followed the company's established quality standards. Reliability was maintained by applying consistent SPC methods and analysis procedures throughout the study. Repeated calculations and chart reviews were conducted to minimize analytical errors and ensure result consistency.

Ethical and Operational Considerations

This research utilized operational data solely for academic analysis and quality improvement evaluation. No personal or sensitive employee data were involved. The study did not disrupt production activities or alter existing quality control practices. All findings were interpreted objectively and presented in an aggregated form to maintain confidentiality and operational integrity.

RESULTS AND DISCUSSION

Process Stability Analysis Using Control Charts

The application of Statistical Process Control began with the evaluation of process stability using control charts derived from routine production data. The control charts revealed that the manufacturing process exhibited periods of stable operation interspersed with identifiable out-of-control signals. These signals were characterized by points exceeding control limits and non-random patterns, indicating the presence of assignable causes rather than inherent process variability.

The identification of these signals confirmed that the process was not fully under statistical control during the observation period. This finding aligns with prior studies emphasizing that manufacturing processes often exhibit hidden instability when SPC is not systematically monitored, even if production outputs appear acceptable at a superficial level (Jamadar, 2020; Godina et al., 2016). Table 1 summarizes the control chart evaluation results based on the observed data.

Table 1. Summary of Control Chart Evaluation Results

Evaluation Aspect	Observation Result
Data distribution pattern	Non-random patterns observed
Control limit violations	Detected
Process stability status	Partially unstable
Presence of assignable causes	Identified

The findings support the role of SPC as an early warning system that detects process deviations before they result in significant quality defects (Singh, 2022; Mabokela et al., 2023).

Identification of Process Variations and Quality Issues

Further analysis of the control charts enabled the identification of dominant sources of variation affecting product quality. These variations were associated with operational inconsistencies reflected in inspection records and production logs. The recurring nature of certain out-of-control points suggested systematic issues rather than isolated incidents.

This result is consistent with the literature, which highlights that uncontrolled variation is often linked to factors such as equipment condition, operator practices, and material consistency (Rahman et al., 2015; Parmar & Desai, 2018). The descriptive evaluation confirms that SPC tools are effective in distinguishing between common-cause and special-cause variations without altering the production process.

Process Capability Evaluation

Process capability analysis was conducted to evaluate the ability of the manufacturing process to meet predefined specification limits. The analysis indicated that process performance varied across observation periods, reflecting the influence of previously identified process instability. Table 2 presents the qualitative assessment of process capability outcomes.

Table 2. Process Capability Assessment Overview

Capability Indicator	Assessment Outcome
Compliance with specification limits	Inconsistent
Process centering	Partially shifted
Capability performance trend	Improvement potential identified

These findings are in line with previous studies demonstrating that unstable processes often yield suboptimal capability indices and require stabilization before meaningful improvement can be achieved (Gaikwad et al., 2019; Sunadi et al., 2020).

Impact of SPC Implementation on Quality Control Performance

The systematic application of SPC enhanced the visibility of process behavior and quality performance. Although no new interventions were introduced, the structured monitoring enabled clearer identification of quality risks and operational weaknesses. This outcome reinforces the view that SPC serves not only as a monitoring tool but also as a decision-support mechanism for quality improvement initiatives (Archana & Kumar, 2024; Doğan & Hızıroğlu, 2024).

The findings also confirm that SPC supports continuous improvement by providing objective evidence for corrective actions without relying on assumptions or subjective judgment (Parmar & Deshpande, 2014; Taher & Alam, 2014).

Discussion in Relation to Previous Studies

The results of this study are consistent with existing empirical research demonstrating that SPC effectively improves manufacturing quality by stabilizing processes and reducing variability (Ural & Elmali, 2023; Pérez-Vicente et al., 2024). Similar to findings in automotive and garment manufacturing contexts, SPC enabled early detection of deviations and facilitated structured quality analysis (Erdinç et al., 2024; Milić et al., 2024).

Moreover, the descriptive findings align with systematic reviews highlighting that SPC effectiveness depends on consistent data usage, management commitment, and integration with quality improvement frameworks (Hadiyanto & Sitepu, 2023). This study reinforces SPC's applicability across manufacturing sectors while maintaining methodological simplicity and analytical rigor.

CONCLUSION

This study demonstrates that Statistical Process Control is an effective and systematic approach for improving quality control in manufacturing operations. The application of control charts enabled the identification of process instability and non-random variation patterns that were not easily detectable through conventional inspection methods. These findings confirm that SPC provides a reliable analytical framework for distinguishing between common-cause and assignable-cause variations, which is essential for maintaining consistent product quality.

The process capability evaluation further revealed that quality performance is closely linked to process stability. When the process exhibited instability, compliance with specification limits became inconsistent, highlighting the importance of stabilizing the process before pursuing further quality improvement initiatives. The structured use of SPC tools enhanced process transparency and supported data-driven decision-making without altering the existing production system.

From a practical perspective, the results indicate that SPC can serve as an effective monitoring and diagnostic tool to support continuous quality improvement in manufacturing environments. The findings also reinforce existing literature that emphasizes the role of SPC in reducing quality variability and strengthening operational control. For future research, longitudinal studies focusing on extended observation periods may provide deeper insights into long-term quality performance trends and the sustainability of SPC-based quality control systems.

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