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Integrated framework based on importance performance analysis and fault tree analysis for defect reduction in garment manufacturing

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ABSTRACT

Quality improvement is essential for enhancing the competitiveness of export-oriented garment manufacturers. However, production defects during cutting, sewing, and finishing continue to increase rework, material waste, production costs, and delivery delays, indicating weaknesses in existing quality management practices. This study aimed to develop an integrated quality improvement framework by identifying priority production quality attributes and diagnosing the root causes of manufacturing defects at PT Anggun Kreasi Garment. A descriptive quantitative case study was conducted involving **30 respondents** selected through purposive and proportional stratified random sampling. Data were collected using a validated questionnaire (Cronbach's Alpha = 0.969 for importance and 0.962 for performance), supported by observations, interviews, and company quality records. Customer Satisfaction Index (CSI), Importance–Performance Analysis (IPA), and Fault Tree Analysis (FTA) were applied sequentially to evaluate production quality, identify priority attributes in Quadrant I, and determine the underlying causes of defects. The analysis identified 22 priority quality attributes across the cutting, sewing, and finishing departments. The dominant root causes were associated with machine reliability, work methods, human factors, material management, workplace conditions, and quality control practices. The proposed integrated IPA–FTA framework supports evidence-based quality improvement by linking performance evaluation with root-cause analysis, enabling more focused and effective decision-making for continuous quality improvement in garment manufacturing.

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Introduction

The garment manufacturing industry plays a strategic role in the global economy by generating employment opportunities, supporting export activities, and strengthening industrial supply chains. In Indonesia, this sector has become one of the major contributors to manufacturing exports while facing increasingly intense competition in international markets (Dartanto, 2018; Rukmana et al., 2024). To remain competitive, garment manufacturers are required to deliver products with consistent quality, short production lead times, and high operational efficiency (Alves et al., 2022; Niinimäki et al., 2020). However, garment production involves multiple interdependent processes including cutting, sewing, assembly, and finishing in which defects may occur at different stages and propagate throughout subsequent operations. Previous studies have shown that production defects such as skipped stitches, broken stitches, uneven seams, dimensional inaccuracies, and finishing imperfections not only decrease conformance to quality standards but also increase customer complaints, product returns, and production costs, thereby affecting organizational competitiveness (Khan & Mubarik, 2021). Consequently, improving production quality has become a strategic priority for garment manufacturers operating in highly competitive global markets.

Beyond operational performance, manufacturing defects have increasingly been recognized as a sustainability issue because every defective product represents unnecessary consumption of fabric, thread, energy, water, and labor resources (Gardas & Raut, 2019; Srivastava et al., 2026). Such inefficiencies contradict the principles of sustainable manufacturing and the circular economy, which emphasize resource efficiency, waste minimization, and continuous process improvement throughout the product life cycle (Jia et al., 2020). Nevertheless, the relationship between quality management and sustainable manufacturing remains insufficiently articulated in existing studies. While sustainable manufacturing research primarily focuses on environmental performance and resource efficiency, quality management research tends to emphasize operational control and defect reduction. As a result, the mechanisms through which systematic quality improvement contributes simultaneously to operational excellence and manufacturing sustainability remain underexplored (Karasan & Erdogan, 2021). This conceptual separation indicates the need for analytical approaches capable of linking production quality improvement with broader sustainability objectives.

Despite continuous implementation of quality control systems, many garment manufacturers continue to experience high defect rates because conventional inspection practices primarily identify defects after production rather than preventing them through systematic process evaluation. Preliminary observations at PT Anggun Kreasi Garment, an export-oriented manufacturer producing apparel for internationally recognized brands, revealed that the average First Pass Yield (FPY) during January–June 2025 reached only 85%, indicating an overall defect rate of 15%. The sewing process contributed the highest proportion of defects (45%), followed by cutting (35%) and finishing (20%). Dominant defects included skipped stitches, uneven stitches, frayed edges, dimensional variation, untreated stains, and poor pressing quality. These quality problems generated substantial rework, material waste, production delays, and reduced labor productivity, demonstrating that existing inspection-based quality control has not adequately supported systematic defect prevention or continuous process improvement.

Previous studies have applied individual analytical methods to improve manufacturing quality. Importance–Performance Analysis (IPA) has been widely used to identify priority quality attributes based on stakeholder perceptions, whereas Fault Tree Analysis (FTA) has been employed to investigate the root causes of operational failures (Liu et al., 2020; Martinez et al., 2023). Although these approaches have proven useful independently, most studies employ them as separate analytical techniques, resulting in fragmented decision-making processes in which improvement priorities and root-cause diagnosis are conducted independently. Furthermore, recent studies on garment manufacturing have largely focused either on defect identification or failure analysis without establishing an explicit analytical linkage between critical quality attributes and the operational factors responsible for their performance gaps (Agrawal et al., 2021; Zhang & Wang, 2023). Consequently, existing research provides limited guidance for developing integrated quality improvement strategies that simultaneously prioritize operational issues and identify their underlying causes.

Method

Research Design

This study employed a descriptive quantitative case study to evaluate production quality performance and identify the root causes of manufacturing defects at PT Anggun Kreasi Garment, Indonesia. A case study design was selected because it enables an in-depth investigation of quality management practices within an actual production environment while preserving the operational characteristics of the organization. The quantitative approach was adopted to measure employees' perceptions of production quality attributes systematically and to prioritize improvement opportunities using structured analytical techniques. The unit of analysis comprised production quality attributes across the cutting, sewing, and finishing departments, which were identified through the company's internal production quality reports as contributing approximately 85% of total production defects during the observation period (January–June 2025). The study focused exclusively on production quality improvement and excluded product design, marketing, and distribution activities.

Research Participants

The participants consisted of personnel directly involved in garment production and quality management, including production managers, production supervisors, quality control (QC) inspectors, and senior operators. Senior operators were defined as production employees with a minimum of two years of continuous experience who were responsible for supervising operational activities and providing technical guidance to production teams. These participants were selected because they possessed comprehensive knowledge of production processes, operational constraints, and quality-related issues. Participation was voluntary, informed consent was obtained from all respondents, and all collected information was treated confidentially.

Population and Sampling

The target population comprised all employees involved in garment production at PT Anggun Kreasi Garment. The accessible population consisted of 150 employees directly engaged in production quality activities across the cutting, sewing, and finishing departments.

The minimum sample size was determined using the Slovin formula with a 5% margin of error, resulting in a sample of 30 respondents. A two-stage sampling procedure was adopted. First, purposive sampling was applied to establish respondent eligibility. Eligible participants were required to (1) have at least two years of work experience; (2) be directly involved in production or quality control activities; and (3) possess sufficient knowledge of production quality issues. Second, proportional stratified random sampling was conducted to ensure representative participation from each occupational group. The final sample consisted of 3 production managers, 10 production supervisors, 9 quality control inspectors, and 8 senior operators, reflecting the proportional composition of quality-related personnel within the company. This sequential procedure ensured that all respondents possessed relevant expertise while maintaining balanced representation across key production functions.

Research Variables and Instruments

The study examined production quality attributes and operational factors contributing to manufacturing defects. Production quality performance was evaluated through two measurement dimensions, namely importance and performance, while defect-causing factors identified through Fault Tree Analysis constituted the analytical basis for root-cause investigation. Primary data were collected using a structured questionnaire developed based on the principles of Importance Performance Analysis (IPA). The questionnaire consisted of 25 production quality attributes evaluated using two dimensions: importance and performance. All questionnaire items were measured using a five-point Likert scale, ranging from 1 ("strongly disagree/very low") to 5 ("strongly agree/very high").

Prior to the main analysis, the instrument was evaluated for validity and reliability. Item validity was assessed using Corrected Item Total Correlation, with all indicators exceeding the minimum acceptable criterion. Instrument reliability was assessed using Cronbach's Alpha, yielding coefficients of 0.969 for the importance dimension and 0.962 for the performance dimension, indicating excellent internal consistency. These results confirmed that the questionnaire was suitable for subsequent analyses using Customer Satisfaction Index (CSI), Importance Performance Analysis (IPA), and Fault Tree Analysis (FTA). Field observations, company production reports, and semi-structured interviews were employed to triangulate and verify questionnaire findings.

Data Collection

Data were collected through four complementary techniques: 1) structured questionnaires were administered to evaluate respondents' perceptions of the importance and performance of production quality attributes; 2) direct observations were conducted throughout the cutting, sewing, finishing, and packing processes to identify defect-prone production activities; 3) semi-structured interviews were conducted with production supervisors, Quality Assurance (QA), Quality Control (QC), and Production Planning and Inventory Control (PPIC) personnel to obtain qualitative explanations regarding operational problems and improvement opportunities; and 4) internal quality reports, production records, and relevant literature were reviewed to verify defect patterns and support the interpretation of analytical findings. The integration of these four techniques enhanced data triangulation and strengthened the credibility of the study.

Data Analysis

The analytical framework integrated Customer Satisfaction Index (CSI), Importance–Performance Analysis (IPA), and Fault Tree Analysis (FTA) to develop an integrated quality improvement framework.

First, the Customer Satisfaction Index (CSI) was calculated to evaluate the overall level of production quality satisfaction, resulting values were interpreted according to established customer satisfaction categories. The CSI value was obtained using:

$$CSI = \frac{\text{Weighted Total (Perception)}}{\text{Weighted Total (Expectation)}} \times 100$$

Second, Importance–Performance Analysis (IPA) was employed to compare the importance and performance scores of each production quality attribute. The conformity level was calculated using:

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$$TK_i = \frac{X_i}{Y_i} \times 100\%$$

where X_i represents the performance score and Y_i represents the importance score. The calculated scores were subsequently plotted on the IPA Cartesian matrix to determine priority improvement attributes.

Third, Fault Tree Analysis (FTA) was applied to investigate the root causes of priority production defects identified through IPA. Following the top-down procedure recommended in IEC 61025 and the NASA Fault Tree Handbook, the analysis defined the top event, constructed the fault tree, identified intermediate and basic events, and determined the dominant operational factors contributing to production failures.

Finally, the findings from CSI, IPA, and FTA were integrated to formulate evidence-based quality improvement strategies. The proposed strategies were subsequently validated through focus group discussions involving representatives from the QC, QA, PPIC, and production departments to ensure their practical relevance and feasibility.

Research Framework

The research was conducted in four sequential stages. The first stage involved preliminary observations and a literature review to identify production quality problems and formulate the research objectives. The second stage consisted of data collection through questionnaires, observations, interviews, and company documentation. The third stage involved data analysis using the Customer Satisfaction Index (CSI), Importance–Performance Analysis (IPA), and Fault Tree Analysis (FTA) to evaluate production quality, identify priority improvement attributes, and determine the root causes of production defects. Finally, the analytical findings were integrated to formulate quality improvement strategies, which were validated through expert discussions before drawing conclusions and developing managerial recommendations.

Results and Discussions

Instrument Validity and Reliability

Prior to the main analysis, the questionnaire was evaluated to ensure that all measurement items were valid and internally consistent. The instrument consisted of 25 production quality attributes assessed using the two dimensions of importance and performance, following the analytical framework of Importance–Performance Analysis (IPA).

Item validity was examined using the Corrected Item–Total Correlation (Pearson Product–Moment correlation) based on responses from 30 participants. The calculated correlation coefficients ranged from 0.461 to 0.835, exceeding the critical value ($r = 0.361$, $\alpha = 0.05$). These results indicate that all questionnaire items satisfied the required validity criterion and were therefore retained for subsequent analyses.

The internal consistency of the questionnaire was evaluated using Cronbach's Alpha. As shown in Table 1, the importance dimension achieved a Cronbach's Alpha coefficient of 0.969, whereas the performance dimension obtained 0.962. Both coefficients exceeded the commonly accepted minimum reliability threshold of 0.70 (Hair et al., 2019), indicating that the questionnaire demonstrated satisfactory internal consistency for evaluating production quality attributes.

Table 1. Instrument Reliability Results

Variable	Number of Items	Cronbach's Alpha
Importance	25	0.969
Performance	25	0.962

Customer Satisfaction Index (CSI)

The Customer Satisfaction Index (CSI) was calculated to evaluate respondents' overall perceptions of production quality performance. The calculation incorporated the Mean Importance Score (MIS), Mean Satisfaction Score (MSS), Weight Factor (WF), and Weight Score (WS) for each production quality attribute.

Table 2. Summary of Customer Satisfaction Index Results

Indicator	Value
Total MIS	105.34
Weighted Total	279.68
CSI	55.94%

The analysis produced a **Customer Satisfaction Index of 55.94%**, indicating that the current production quality performance has not yet fully met respondents' expectations. The Mean Importance Scores ranged from 3.93 to 4.43, suggesting that respondents regarded nearly all production quality attributes as highly important. The highest importance scores were observed for Item 1 (pattern and marker accuracy) and Item 6 (dimensional tolerance compliance), both achieving a mean score of 4.43.

By comparison, the Mean Satisfaction Scores ranged from 2.42 to 3.25, indicating relatively lower perceptions of actual production performance. The lowest satisfaction scores were recorded for Item 10 and Item 20, each obtaining an average score of 2.42. The discrepancy between importance and satisfaction scores demonstrates the existence of performance gaps across several production quality attributes. These findings provide the basis for the subsequent Importance–Performance Analysis (IPA).

Importance–Performance Analysis (IPA)

Following the CSI analysis, Importance–Performance Analysis (IPA) was performed to identify production quality attributes requiring priority improvement. The average importance and performance scores were mapped onto Cartesian matrices for the cutting, sewing, and finishing departments, as presented in Figures 1–3.

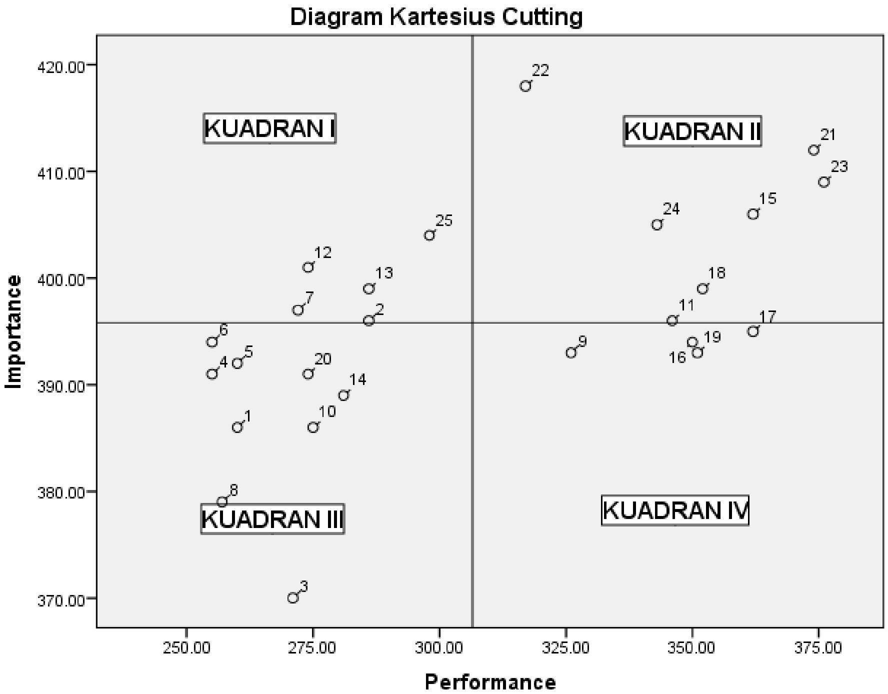

Figure 1. Importance–Performance Analysis (IPA) Cartesian diagram for the cutting department.

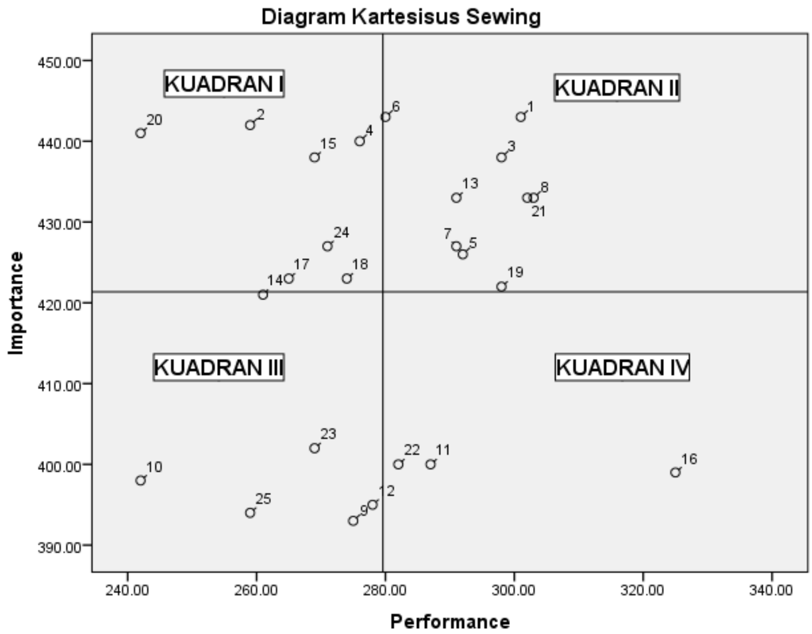

Figure 2. Importance–Performance Analysis (IPA) Cartesian diagram for the sewing department.

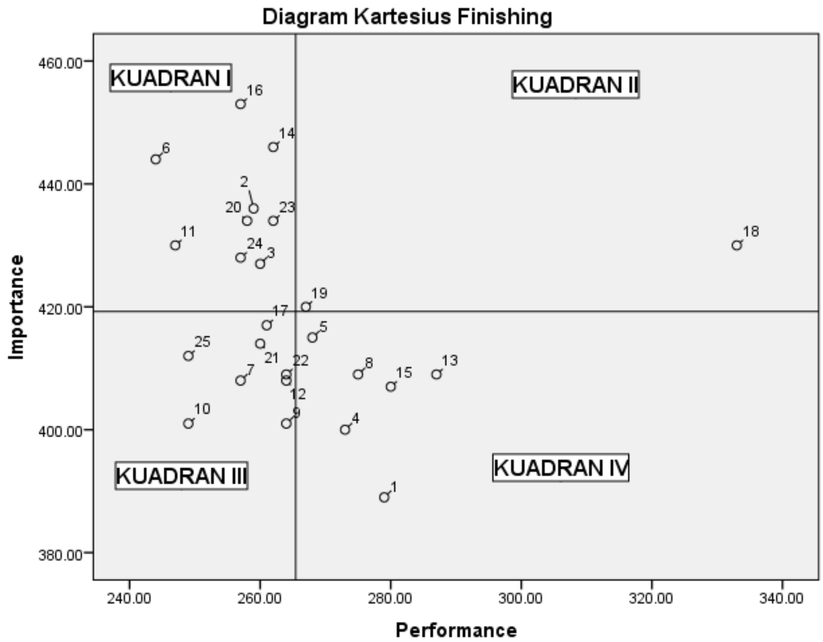

Figure 3. Importance–Performance Analysis (IPA) Cartesian diagram for the finishing department.

The IPA results classified all evaluated production quality attributes into four quadrants according to their relative importance and performance levels.

Quadrant I (Concentrate Here) contained five priority attributes, namely Items 2, 7, 12, 13, and 25. These attributes exhibited above-average importance but below-average performance, indicating that they represented the most critical operational issues requiring immediate managerial attention. The identified priorities were associated with machine condition, cutting consistency, defect identification procedures, counter-sample utilization, and workplace ergonomics.

Quadrant II (Keep Up the Good Work) included attributes characterized by both high importance and high performance, indicating that these production activities should be maintained to preserve current quality standards.

Quadrant III (Low Priority) consisted of attributes with relatively low importance and low performance. Although these attributes were not considered immediate priorities, continuous monitoring remained necessary.

Quadrant IV (Possible Overkill) comprised attributes demonstrating relatively high performance despite comparatively lower importance, suggesting that organizational resources allocated to these activities may exceed operational priorities. Overall, the IPA findings indicate that quality improvement initiatives should primarily focus on the attributes located in Quadrant I because they contribute most substantially to the observed performance gaps.

Fault Tree Analysis (FTA)

The priority production quality attributes identified through IPA were subsequently analyzed using Fault Tree Analysis (FTA) to determine the root causes of operational deficiencies.

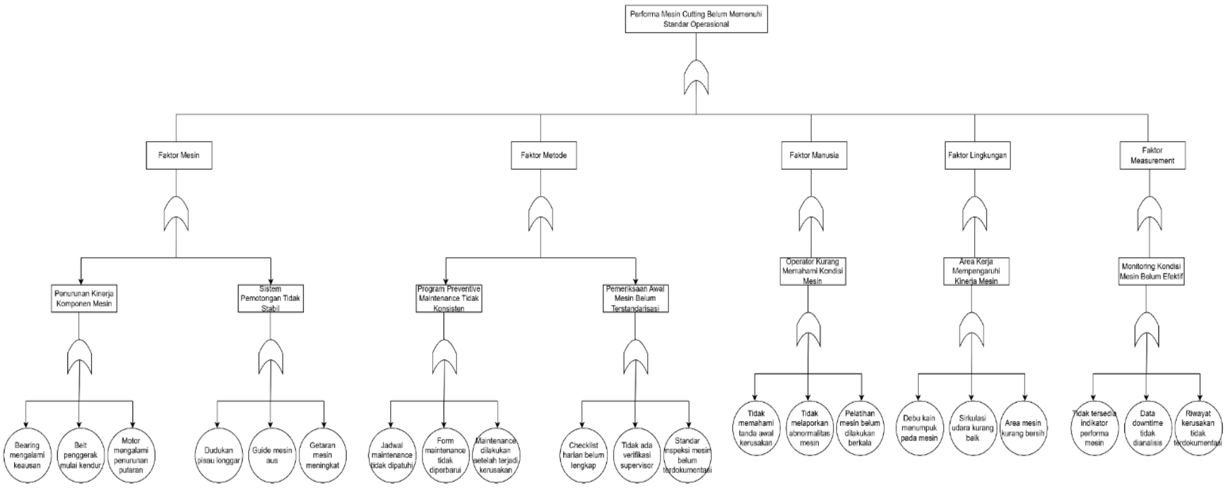

Figure 4. Representative Fault Tree Analysis for Item 2.

Figure 4 presents a representative FTA model for Item 2. The same analytical procedure was subsequently applied to all priority attributes identified in Quadrant I to identify their underlying operational causes. The FTA results indicate that production quality deficiencies originated from the interaction of multiple operational factors rather than a single isolated cause. Across all priority attributes, five major categories of root causes were consistently identified, namely human factors, machine factors, method factors, material factors, and environmental factors.

For example, the analysis of Item 2 showed that unstable cutting machine performance primarily resulted from inconsistent preventive maintenance, inadequate monitoring of blade sharpness, and the absence of standardized daily inspection procedures. Similar patterns were observed for the remaining priority attributes, where deficiencies in process standardization, inspection systems, operator competency, and workplace ergonomics contributed directly to production quality problems.

Table 3. Priority Technical Issues Identified from the Integrated IPA–FTA Analysis

Production Stage	Priority Attributes (IPA Quadrant I)	Main Root Causes (FTA)	Main Technical Priorities
Cutting	Machine condition, panel uniformity, defect identification, counter sample, ergonomics	Machine maintenance, inspection inconsistency, workstation design	Preventive maintenance, standardized inspection, ergonomic workstation
Sewing	Needle/thread selection, equipment readiness, skip stitch, SOP compliance	Machine setting, operator competency, inspection	Machine standardization, operator training, inline inspection
Finishing	Chemical control, washing parameters, pressing, inventory, waste management	Monitoring system, equipment maintenance, inventory accuracy	Process monitoring, preventive maintenance, inventory management

The integrated IPA–FTA analysis demonstrates that production quality improvement should prioritize operational issues with both high strategic importance and identifiable root causes. These findings provide an evidence-based foundation for developing targeted quality improvement strategies across the cutting, sewing, and finishing departments.

The findings demonstrate that the overall production quality performance at PT Anggun Kreasi Garment has not yet fully met employee expectations, as reflected by the Customer Satisfaction Index (CSI) of 55.94%. This result indicates the existence of substantial performance gaps across several production quality attributes and suggests that quality improvement should extend beyond end-product inspection toward a more systematic evaluation of production processes. Previous studies have similarly emphasized that manufacturing competitiveness depends not only on product conformity but also on the organization's ability to continuously improve production processes and operational consistency (Chen et al., 2020; Hader et al., 2022). Therefore, the CSI findings provide empirical evidence that current production practices still require significant operational improvement to achieve higher manufacturing quality.

The Importance Performance Analysis (IPA) further revealed that production quality attributes were unevenly distributed across the four Cartesian quadrants, indicating differences in managerial priorities among production activities. Attributes classified in Quadrant I represent operational aspects that combine high importance with relatively low performance and therefore require immediate corrective action. Similar observations have been reported by Gupta and Sharma (2022), who found that apparel manufacturers frequently experience inconsistent implementation of quality management systems despite having established operational standards. Likewise, (Berhe et al., 2023) argued that quality improvement initiatives become more effective when organizations prioritize operational attributes that exert the greatest influence on overall production performance instead of distributing resources equally across all production activities. In the present study, priority issues consistently involved machine condition, production consistency, inspection procedures, operator compliance with standard operating procedures, and workplace ergonomics, indicating that process reliability remains the principal challenge throughout garment production.

The identification of similar priority attributes across the cutting, sewing, and finishing departments also suggests that production quality problems are systemic rather than isolated within individual workstations. Although each department performs different operational functions, recurring deficiencies in equipment reliability, inspection consistency, operator competency, documentation accuracy, and production monitoring indicate weaknesses that extend across the entire production system. Comparable findings were reported by (F. He et al., 2026; Junqueira et al., 2021), who demonstrated that organizational quality performance depends on the consistency of process implementation throughout production rather than improvements confined to individual departments. (Atikasari & Yun, 2025; Martinez et al., 2023) similarly emphasized that manufacturing quality should be managed through integrated operational systems capable of identifying critical production weaknesses before defects propagate to subsequent production stages.

While IPA effectively identifies operational priorities, it does not explain why these deficiencies occur. For this reason, Fault Tree Analysis (FTA) was employed to investigate the underlying causes associated with each priority attribute. The FTA results showed that production defects originated from the interaction of multiple operational factors, including human, machine, method, material, and environmental factors. These findings are consistent with previous studies demonstrating that production failures rarely result from a single operational error but instead emerge through complex interactions among organizational, technical, and human factors (Oakland, 2014)(Dal Forno et al., 2025). Preventive machine maintenance, standardized operating procedures, inspection consistency, operator competency, and systematic production monitoring emerged as the dominant factors influencing production quality within the investigated garment manufacturing environment.

The integration of IPA and FTA provides a more comprehensive analytical perspective than applying either method independently. Previous studies generally employed IPA to prioritize customer or operational requirements or used FTA solely to diagnose production failures (Liza et al., 2021; Mecheri et al., 2025). However, relatively few studies have established an explicit analytical linkage between performance prioritization and root-cause investigation within a unified quality management framework for garment manufacturing. In this study, IPA identified the operational attributes requiring immediate managerial attention, whereas FTA explained the mechanisms responsible for the observed performance deficiencies. Consequently, the proposed framework enables improvement priorities to be determined not only according to perceived importance but also according to the operational factors responsible for quality failures. This sequential analytical process strengthens managerial decision-making because corrective actions can be directed toward the most influential operational causes rather than addressing production problems in a fragmented manner.

From a theoretical perspective, this study contributes to quality management literature by demonstrating the complementary roles of Importance–Performance Analysis and Fault Tree Analysis in manufacturing quality evaluation. Rather than treating production performance assessment and root-cause diagnosis as separate analytical activities, the proposed framework establishes a systematic relationship between operational performance gaps and their underlying causes. This contribution extends previous discussions on integrated quality management systems (Naseem et al., 2025) by providing an evidence-based approach for linking performance evaluation with operational failure analysis within garment manufacturing. The study therefore contributes methodologically by illustrating how two established analytical techniques can be combined into a structured decision-support framework for continuous quality improvement.

The findings also have important managerial implications. Since quality deficiencies were consistently associated with machine reliability, process standardization, inspection effectiveness, operator competency, and workplace management, quality improvement initiatives should prioritize preventive actions rather than corrective inspection after production has been completed. This recommendation aligns with contemporary quality management principles, which emphasize prevention, process stabilization, and continuous improvement as more effective approaches than relying solely on defect detection (Lingkon et al., 2024). Furthermore, the results support the broader manufacturing literature indicating that improved process control contributes not only to operational efficiency but also to more effective utilization of production resources by reducing unnecessary rework, material waste, and production delays (J. He et al., 2022).

Despite these contributions, several limitations should be acknowledged. This study was conducted as a single-company case study, which may limit the generalizability of the findings to other garment manufacturers with different production systems, organizational structures, or quality management practices. In addition, the evaluation of production quality relied primarily on employee perceptions measured through the IPA questionnaire, although these perceptions were supported by field observations, company quality reports, and root-cause analysis using FTA. Future studies are encouraged to validate the proposed framework across multiple garment manufacturing companies and incorporate objective production performance indicators, such as defect rates, process capability indices, or machine performance data, to strengthen external validity and broaden the applicability of the proposed integrated quality management framework.

Conclusions

This study demonstrates that improving production quality in garment manufacturing requires not only identifying operational performance gaps but also understanding the underlying causes of those deficiencies. By integrating Importance–Performance Analysis (IPA) and Fault Tree Analysis (FTA), the proposed framework systematically links the prioritization of critical production quality attributes with root-cause diagnosis, enabling quality improvement initiatives to be directed toward the operational factors that have the greatest influence on production performance. This integrated approach extends conventional quality evaluation by combining performance assessment with causal analysis within a single decision-support framework, thereby providing a more structured basis for continuous quality improvement in garment manufacturing. From a theoretical perspective, the study contributes to quality management literature by illustrating how IPA and FTA can be integrated to strengthen evidence-based decision-making beyond the independent application of each method. Rather than using IPA solely to identify priority attributes or FTA solely to investigate production failures, the proposed framework establishes a systematic relationship between operational performance evaluation and root-cause analysis. From a practical perspective, the findings highlight the importance of preventive maintenance, process standardization, inspection consistency, operator competency development, production monitoring, and workplace management as key priorities for improving production quality and operational effectiveness within garment manufacturing environments.

Several limitations should be acknowledged. This research was conducted in a single garment manufacturing company using a cross-sectional design, which may limit the generalizability of the findings to organizations with different production systems or managerial practices. In addition, the evaluation of production quality relied primarily on employee perceptions obtained through structured questionnaires, although these were supported by field observations, company quality records, and Fault Tree Analysis. Future research is encouraged to validate the proposed integrated IPA–FTA framework across multiple manufacturing companies, incorporate objective production performance indicators such as defect rates and process capability measures, and examine its applicability in different manufacturing sectors to strengthen the external validity and practical applicability of the framework.

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