ISSN: 2771-4357

Research Article

Journal of Textile Engineering and Fashion Technology

Impact of Total Quality Management on Process Performance in Apparel Manufacturing: Evidence from a Comparative Case Study in Bangladesh

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Submitted: 2026, Jul 17 **Accepted:** 2026, Aug 20; **Published:** 2026, Aug 31

Citation: Chowdhury, N. U. H., Sayed, M. S., Rahman, S. (2026). Impact of Total Quality Management on Process Performance in Apparel Manufacturing: Evidence from a Comparative Case Study in Bangladesh. *J Textile Eng & Fash Tech, 8*(1), 01-19.

Abstract
Total Quality Management (TQM) has become a foundational management philosophy for industries that operate in conditions of high competition, evolving buyer expectations, and complex global supply chain systems. Within the textile and apparel sector, the demand for flawless product quality, operational efficiency, and international compliance standards has positioned TQM as a strategic necessity rather than an optional tool. This paper examines the theoretical foundations of TQM, its core principles, and its application across the textile and apparel value chain. Additionally, the study explores the integration of sustainability, discusses modern compliance frameworks such as ISO 9001, ISO 14001, ISO 45001, ISO/IEC 17025, and AQL (ISO 2859), and highlights the transformative role of digitalization and Industry 4.0 tools in strengthening TQM. Challenges associated with implementation in developing countries, including Bangladesh, are reviewed alongside practical recommendations. The paper concludes by emphasizing that TQM remains an indispensable framework for ensuring competitiveness, compliance, and long-term sustainability in the apparel sector.

Keywords: Total Quality Management (TQM), Apparel Manufacturing, Process Performance, Lean Manufacturing, Six Sigma (DMAIC), Statistical Process Control (SPC), AQL (ISO 2859-1), ISO 9001, ISO/IEC 17025, Industry 4.0, Sustainability, ESG Compliance, DHU Reduction, RFT Improvement, Bangladesh RMG Industry

1. Introduction

The textile and apparel industry occupies a uniquely complex position in the global manufacturing landscape. It brings together diverse raw materials, labor-intensive processes, and fast-changing fashion cycles while operating under continuous cost pressure and increasingly demanding compliance expectations. Countries such as Bangladesh, Vietnam, India, China, and Turkey have built large segments of their economies around apparel manufacturing, yet the growing expectations of international buyers— ranging from product quality to social responsibility—have reshaped how factories approach daily operations. In this environment, product quality is no longer viewed as a final checkpoint but as a strategic requirement woven into every stage of production. A small variation in yarn count, shade matching, shrinkage behavior, or seam strength can quickly escalate into shipment delays, rework, financial penalties, and long-term reputational damage. Traditional inspection-centered quality control systems, which identify defects only after production is completed, often fail to prevent these losses. They detect problems but do little to eliminate their underlying causes.

Total Quality Management (TQM) emerged as a response to these limitations. Developed through the contributions of quality thinkers such as Deming, Juran, and Ishikawa, TQM shifted the focus from reactive inspection to preventive, process-oriented, organization-wide quality management. Its emphasis on continuous improvement, employee involvement, leadership commitment, and a strong customer focus has made it one of the most widely adopted management philosophies across global manufacturing sectors. In the textile and apparel industry, TQM is particularly relevant because of the sector's inherent variability and the need for consistent process discipline. As buyers impose tighter measurement tolerances, stricter colorfastness requirements, and higher environmental and chemical compliance standards, manufacturers increasingly rely on structured systems such as ISO 9001, ISO 14001, ISO 45001, and ISO/IEC 17025 to maintain credibility. These frameworks, combined with TQM principles, help factories build predictable processes, improve efficiency, and reduce risks associated with nonconformity.

Recent years have also seen a growing intersection between TQM and digital transformation. The introduction of real-time quality monitoring, automated sewing and cutting technologies, cloud-based laboratory data systems, and AI-assisted defect detection has expanded what quality management can achieve. For manufacturers competing in a global market defined by speed, transparency, and environmental responsibility, the integration of TQM with Industry 4.0 tools offers a pathway not only to improved quality but to sustainable, long-term competitiveness. This paper explores the conceptual foundations of TQM and examines how these principles translate into practical applications across the textile and apparel production chain. It also discusses the growing importance of sustainability and digitalization, highlighting how modern apparel factories are using TQM to strengthen compliance, efficiency, and operational resilience in a rapidly evolving global industry.

2. Theoretical Foundations of TQM

2.1. Definition and Evolution

TQM evolved from the work of quality pioneers such as Deming (1986), Juran (2016), and Ishikawa (1985) [1-3]. Their foundational principles—customer satisfaction, process control, employee involvement, and continuous improvement—form the backbone of TQM today. Deming emphasized statistical methods and systems thinking, Juran highlighted quality planning and cost of poor quality, and Ishikawa promoted the use of quality circles and cause-and-effect analysis. Over time, global industries such as automotive, electronics, and textiles adopted these principles to improve competitiveness.

2.2. Key Principles of Total Quality Management (TQM)

The successful implementation of Total Quality Management (TQM) depends on several core principles that guide organizational behavior, decision-making, and process control. These principles are universal across industries but take on particular significance in the textile and apparel sector due to the industry's process complexity, quality sensitivity, and buyer-driven compliance expectations. The following subsections discuss the major principles that underpin TQM, along with their relevance to textile and apparel manufacturing.

2.2.1. Customer Focus

Customer focus is the foundational principle of TQM. Customers—both external buyers and internal departments—define the expectations and quality standards that the organization must meet to remain competitive. In the apparel industry, customer expectations are highly technical and often documented in buyer manuals, technical sheets, and compliance guidelines. These include GSM requirements, allowable shrinkage limits, seam strength values, colorfastness grades, measurement tolerances, fabric appearance, AQL sampling levels, and sustainability expectations regarding chemical safety and environmental performance [4]. A TQM-focused organization actively collects, analyzes, and interprets customer feedback and translates it into measurable process controls. This may involve developing Standard Operating Procedures (SOPs), Work Instructions (WIs), critical quality checkpoints, and material specifications that reflect customer needs. According to ISO 9001:2015, customer satisfaction must be continuously monitored and incorporated into the quality management system as a performance indicator [5]. In the apparel sector, maintaining customer focus ensures that manufacturers consistently deliver products that meet brand expectations, regulatory requirements, and market demands.

2.2.2. Leadership Commitment

Leadership commitment is essential for promoting a culture of quality throughout the organization. Top management plays a pivotal role in establishing the company's long-term quality vision, defining strategic objectives, allocating necessary resources, and promoting employee engagement. Without leadership support, TQM initiatives often fail due to lack of coordination, inconsistent implementation, or inadequate resource allocation. Leadership commitment is particularly important in developing countries where apparel factories frequently struggle with limited training budgets, resistance to organizational change, and insufficient documentation systems [6]. According to ISO 9001:2015, leadership must demonstrate its commitment by integrating the QMS into the organization's core processes, promoting risk-based thinking, and ensuring effective communication at all levels [5]. Strong leadership also creates an environment that encourages transparency, accountability, and a proactive approach to quality improvement. In an industry where customers expect high compliance performance, leadership commitment ensures that the organization invests in certified systems such as ISO 9001, ISO 14001, ISO 45001, and ISO/IEC 17025 and maintains a continuous improvement culture [7-9].

2.2.3. Employee Involvement

Employee involvement is another critical principle of TQM, as quality cannot be improved solely by management initiatives. Employees at all levels—from helpers and operators to supervisors and managers—play a direct role in preventing defects, maintaining process consistency, and identifying opportunities for improvement. According to Juran's quality trilogy, human participation is essential for effective quality control and problem-solving [2]. In apparel factories, employees are responsible for thread trimming, fabric inspection, sewing accuracy, machine handling, finishing tasks, and packaging compliance. Empowering employees through training, skill development, quality circles, and recognition programs leads to higher motivation, better communication, and improved performance. Ishikawa (1985) also emphasized that employee empowerment enhances teamwork, reduces rework, and strengthens the overall quality culture [3]. Organizations that successfully involve employees in quality improvement activities often see measurable reductions in Defects per Hundred Units (DHU), improved line efficiency, and higher Right-First-Time (RFT) performance. This principle directly supports sustainability by reducing wastage and rework.

2.2.4. Process Approach

The process approach is a core component of TQM and ISO 9001-based systems. It emphasizes that quality should be controlled and improved through well-defined, standardized, and measurable processes rather than relying on end-of-line inspection. In textile and apparel manufacturing, the process approach involves mapping and controlling every stage of production, including:

- Fabric inspection and approval
- Cutting operations
- Sewing line balancing
- Finishing and presentation
- Final inspection
- Laboratory testing
- Packaging and shipment

A stable process produces predictable results, reduces variation, and minimizes defects. According to ISO 9001:2015, organizations must identify process interactions, define inputs and outputs, establish quality criteria, and evaluate process performance regularly [5]. A process-focused approach helps manufacturers ensure consistent product quality, reduce operational waste, and enhance customer satisfaction.

2.2.5. Continuous Improvement

Continuous improvement (CI) is a fundamental pillar of TQM and refers to the ongoing effort to enhance products, services, and processes. CI is particularly important in the apparel industry, where variability in raw materials, equipment, and human performance can frequently lead to quality issues.

Common tools supporting CI include:

• PDCA (Plan–Do–Check–Act) • Kaizen • DMAIC (Define–Measure–Analyze–Improve–Control) • 5S workplace organization • Root Cause Analysis (RCA) • Corrective and Preventive Action (CAPA)

These methodologies help organizations identify inefficiencies, eliminate the root causes of defects, and create standardized systems for long-term improvement [10]. Kaizen, for example, promotes incremental improvements driven by frontline workers, while DMAIC provides a structured method for reducing variation and improving sewing and finishing processes.

Continuous improvement also helps organizations respond to evolving customer demands, new regulatory requirements, and global sustainability expectations.

2.2.6. Evidence-Based Decision Making

Evidence-based decision making is a TQM principle that emphasizes using reliable data, statistical tools, and factual analysis to guide decisions rather than relying on assumptions or intuition. In the textile and apparel industry, evidence-based decisions help improve quality consistency, optimize processes, and reduce unnecessary costs.

Key tools include:

- **SPC (Statistical Process Control)** for monitoring variability in GSM, shrinkage, stitch density, and seam strength, ensuring accuracy, consistency, predictability, stability, and reliability.
- **AQL sampling (ISO 2859-1)** for controlling inspection quality
- **Trend analysis** for identifying recurring defects
- **CAPA systems** for root cause elimination
- **Pareto analysis** to focus on the major contributors to defects

Montgomery (2019) notes that data-driven decision-making supports the early identification of quality issues and reduces the risk of major product failures. This approach is highly beneficial in textile and apparel operations where measurement deviations, shade variations, and sewing defects can significantly impact product acceptance [10].

3. Application of TQM in Textile and Apparel Production

The textile and apparel manufacturing process consists of multiple interdependent stages, each of which plays a critical role in determining final product quality. Total Quality Management (TQM) emphasizes the need to control, monitor, and continuously improve every step in the production chain to prevent defects, reduce variation, and enhance customer satisfaction. The following subsections describe how TQM principles are practically applied across essential apparel operations.

3.1. Fabric Inspection and Approval

Fabric constitutes the largest cost component and contributes most significantly to garment quality. Because fabric attributes vary depending on fiber content, yarn properties, dyeing method, and finishing processes, TQM requires robust inspection and approval procedures prior to cutting. Standardized fabric evaluation practices include:

- **The 4-Point System** to classify defects such as holes, slubs, knots, stains, and weaving faults and determine fabric acceptance levels.
- **Fabric relaxation** to allow knitted and woven materials to return to their natural state, preventing shrinkage-related distortions during cutting.
- **Shade band controls** to ensure consistent color across rolls, lots, and bundles, reducing the risk of shade variation after garment production.
- **GSM verification** using calibrated instruments to confirm that the fabric meets buyer specifications for weight and thickness.
- **Shrinkage testing** through washing and drying cycles to determine dimensional stability before marker planning.
- **Visual inspection under standardized lighting** (e.g., D65) to detect shade differences and surface defects.

Implementing these TQM practices helps eliminate common defects such as spirality, bowing, skewness, barre, and shade mismatch, ensuring that the fabric entering production meets predefined quality standards [11]. Effective fabric inspection also reduces material wastage, minimizes rework, and supports a more efficient downstream manufacturing process.

3.2. Cutting Room Quality Management

The cutting department plays a critical role in determining garment fit, measurement accuracy, and seam alignment. Poor cutting quality often results in irreversible defects that cannot be corrected during sewing. TQM applies a systematic and preventive approach to cutting room operations through:

- **Marker efficiency analysis** to optimize fabric utilization, reduce cost, and ensure correct placement of grain lines.
- **Control of fabric lay height** to maintain marker accuracy and prevent shifting or spreading inconsistencies.
- **Machine calibration** of cutting tools such as straight knives, band knives, and round knives to ensure clean and accurate cuts.
- **Cut numbering and bundling systems** to maintain panel identity, simplify sewing operations, and avoid mismatched components.
- **Pattern accuracy verification** to confirm that templates match measurement specifications before bulk cutting.
- **Defect tagging and isolation** to prevent flawed panels from moving into the sewing line.

Through these standardized TQM controls, cutting defects such as incorrect notches, uneven edges, panel mismatches, and off-grain issues can be significantly minimized [12]. As cutting accuracy directly affects sewing efficiency, TQM in the cutting stage enhances operational flow and increases RightFirst-Time (RFT) performance.

3.3. Sewing Line Quality Management

Sewing is the most labor-intensive and defect-prone stage of apparel production. Common issues such as open seams, skipped stitches, seam puckering, needle cuts, and uneven hems frequently originate from operator error, machine conditions, or inadequate process controls. TQM implementation in sewing lines includes:

- **Operator skill assessment and training programs** to enhance competency in machine handling, stitch formation, and defect prevention.
- **Line balancing and motion study** to improve workflow, reduce bottlenecks, and stabilize output.
- **Standard Work Instructions (SWI)** to ensure uniformity in stitch density, seam allowance, and operational sequence.
- **Needle change and needle control policies** to prevent needle breakage, metal contamination, and fabric damage.
- **Total Productive Maintenance (TPM)** to keep sewing machines properly lubricated, tension adjusted, and aligned.
- **Real-time defect reporting systems** enabling supervisors to track, analyze, and correct defects as they occur.
- **Inline and end-line inspections** based on AQL criteria to monitor quality throughout the production process.

These practices, grounded in TQM and Lean principles, significantly lower Defects per Hundred Units (DHU), reduce rework, and improve the overall efficiency and consistency of sewing operations [13]. Effective sewing line TQM also enhances employee productivity and minimizes quality-related delays.

3.4. Finishing and Packaging Quality

The finishing and packaging stages determine the garment's final appearance and customer perception. Even if earlier processes are well-controlled, poor finishing can lead to shipment rejection. TQM emphasizes strict quality controls in this stage, including:

- **Accurate measurement verification** to ensure garments conform to size specifications after ironing and relaxation.
- **Standardized ironing and pressing techniques** to eliminate wrinkles, distortions, and shine marks.
- **Thread and loose fiber trimming** to improve garment neatness and presentation.
- **Metal detection procedures** for identifying broken needles or metal fragments before packing.
- **Polybag, hangtag, and carton compliance** to meet brand-specific packaging requirements.
- **Carton assortment accuracy** to ensure correct size ratios, labeling, and color combinations during packing.

Finishing and packaging controls play a major role in reducing buyer complaints, product returns, and image inconsistencies [14]. A strong TQM presence in these stages ensures that garments shipped to customers are visually appealing, compliant, and defect-free.

3.5. Laboratory Testing and Compliance

Laboratory testing provides scientific validation of product performance, safety, and compliance with regulatory standards. Under ISO/IEC 17025, textile laboratories must follow internationally recognized methods and maintain calibrated instruments to ensure accuracy and repeatability. Key testing areas include:

- **Colorfastness to wash, rubbing, perspiration, and light** to ensure durability and customer satisfaction.
- **Dimensional stability and shrinkage testing** to verify that garments maintain their size after laundering.
- **Tensile, bursting, and tear strength assessments** to confirm mechanical durability.
- **Seam slippage resistance** to evaluate stitching integrity.
- **pH testing** to ensure skin safety.
- **Restricted Substances List (RSL) screening**, including tests for azo dyes, formaldehyde, heavy metals, and other hazardous chemicals.

Validated lab results support effective decision-making and reduce compliance risks related to product recalls, brand penalties, and regulatory violations [15]. Integrating lab data within a TQM framework strengthens consistency, transparency, and buyer confidence.

4. Tools and Techniques Supporting TQM

The implementation of Total Quality Management (TQM) in textile and apparel operations is supported by a variety of structured tools and improvement methodologies. These tools provide organizations with systematic approaches to problem-solving, process control, waste reduction, and continuous improvement. In the apparel sector—where production involves complex fabric behavior, multiple processing stages, and variable human performance—these tools are indispensable for achieving consistent quality and operational excellence. The following subsections outline key TQM tools widely applied across the industry.

4.1. PDCA (Plan–Do–Check–Act) Cycle

The PDCA cycle, also known as the **Deming Cycle**, is a fundamental continuous improvement model used to plan, test, evaluate, and standardize improvement actions. It provides a structured approach for identifying quality issues, implementing changes, and ensuring that improvements are sustainable.

Application in Textile & Apparel Industry:

- **Plan:** Identify quality problems such as high DHU, shade variation, or measurement inconsistency. Develop hypotheses and improvement strategies.
- **Do:** Implement corrective actions—e.g., calibrating machines, updating SOPs, revising marker plans, or improving fabric inspection procedures.
- **Check:** Measure results using KPIs such as DHU %, RFT %, AQL pass rate, or lab test consistency.
- **Act:** Standardize successful practices and document improvements for future reference.

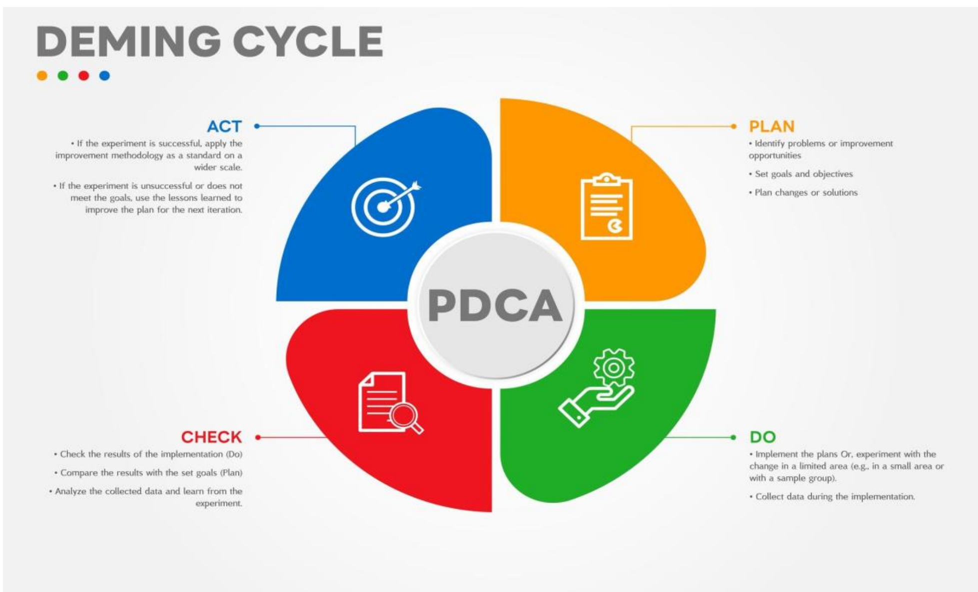

Figure 1: *PDCA (Plan–Do–Check–Act) Cycle model illustrating continuous improvement*. Source: Adapted from Deming (1986)

PDCA supports continuous improvement across all production stages—from fabric inspection to sewing, finishing, and packing. Deming (1986) emphasized that PDCA drives learning and process optimization, making it essential for TQM implementation [1].

4.2. Six Sigma (DMAIC Methodology)

Six Sigma is a data-driven improvement methodology designed to reduce process variation and enhance operational capability. The DMAIC framework—Define, Measure, Analyze, Improve, Control—is widely used in apparel factories to address chronic quality issues **(GoLeanSixSigma, n.d.).DMAIC in Apparel Manufacturing:**

- **Define:** Identify defects such as seam puckering, broken stitches, needle cuts, shrinkage variation, or GSM deviation.
- **Measure:** Collect quantitative data (DHU, SPC charts, seam strength results) to understand baseline performance.
- **Analyze:** Use statistical tools to determine root causes, such as incorrect feed ratio, improper thread tension, machine misalignment, or operator errors.
- **Improve:** Implement targeted solutions—operator training, machine tuning, revised process settings, or improved material handling.
- **Control:** Develop control plans, checklists, standard work instructions, and monitoring systems to maintain improvements over time.

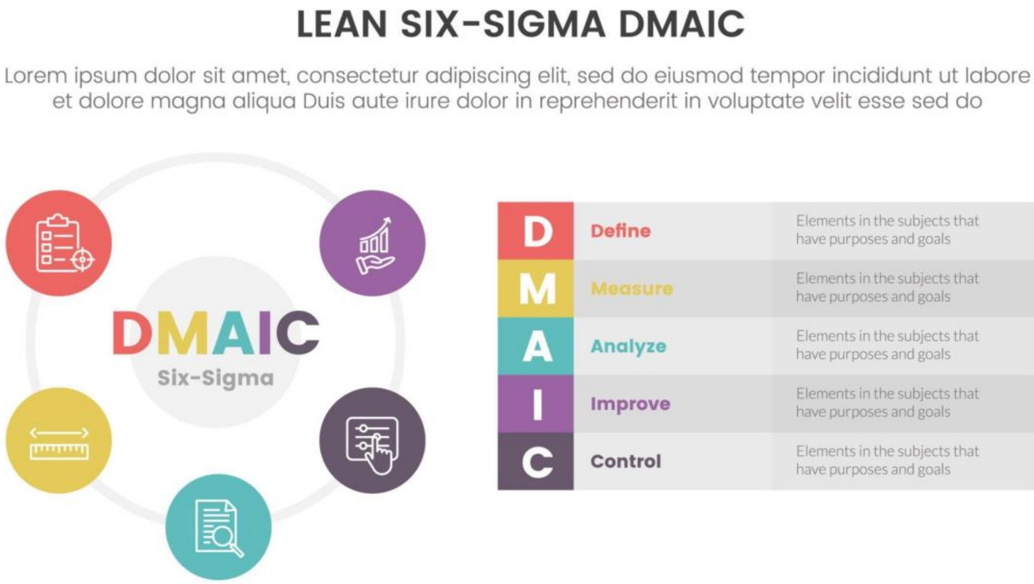

Figure 2: *DMAIC (Define–Measure–Analyze–Improve–Control) cycle used in Lean Six Sigma methodology*. Reprinted from GoLeanSixSigma (n.d.)

Six Sigma significantly enhances sewing quality, reduces rework, and improves overall efficiency. Montgomery (2019) highlights that Six Sigma minimizes variation and provides a robust framework for solving complex quality issues in manufacturing.

4.3. Statistical Process Control (SPC)

SPC uses statistical methods—mainly control charts—to monitor, analyze, and control process variation. In textile and apparel production, SPC is essential due to the highly variable nature of materials and operations.

Typical SPC Applications in Apparel:

- **Stitch density monitoring** using $\bar{X}$ and R charts to ensure consistent seams.
- **Shrinkage variation control** using pre-production test data.
- **GSM (fabric weight) variation tracking** to maintain fabric consistency across rolls.
- **Measurement deviation analysis** for garment dimensions.
- **Color shade consistency monitoring** using spectrophotometer readings.

By identifying assignable causes of variation early, SPC prevents defective products from moving downstream and reduces costly rework [16].

4.4. Acceptance Quality Limit (AQL) – ISO 2859-1

AQL is a globally recognized sampling methodology used for final product inspection. ISO 2859-1 provides standardized sampling plans that determine the number of units to inspect from a lot and the acceptable number of defects.

Importance in Apparel Industry:

- ➢ Ensures consistent outgoing quality across shipments.
- ➢ Defines acceptable defect levels based on buyer requirements (e.g., AQL 1.5, 2.5, 4.0).
- ➢ Reduces subjectivity in final inspection.
- ➢ Helps factories maintain alignment with international quality standards.
- ➢ Supports risk-based decision-making for shipment release.

AQL provides a statistical foundation for inspection decisions and is widely used in garment factories worldwide [17].

4.5. Lean Manufacturing Techniques

Lean manufacturing focuses on eliminating waste and improving process flow. Apparel factories often face inefficiencies due to excess motion, waiting time, overproduction, rework, and improper inventory management. Lean tools help improve productivity and reduce operational costs.

Key Lean Tools in TQM:

5S (Sort, Set, Shine, Standardize, Sustain)

The 5S system enhances workplace organization and reduces motion waste (Lean Enterprise Institute, n.d.). It improves safety by ensuring that tools, materials, and equipment are arranged logically for smoother workflow. Additionally, 5S supports continuous improvement by maintaining discipline, cleanliness, and visual control across the production floor.

In textile and apparel manufacturing, 5S plays a vital role in establishing a stable production environment.

- ➢ **Sort** eliminates unnecessary items from sewing lines, cutting tables, and inspection areas, helping reduce clutter and defects.
- ➢ **Set in Order** ensures every tool—such as scissors, thread cones, machine attachments, and inspection instruments—has a designated place, improving accessibility and reducing downtime.
- ➢ **Shine** promotes routine cleaning of machines, floors, and workstations, reducing contamination risks and preventing machine breakdown.

- **Standardize** creates uniform procedures such as visual markings, labeling, color coding, and checklist-based housekeeping across all departments, enhancing process consistency.
- **Sustain** focuses on training, audit systems, and daily discipline that ensures the 5S culture continues over time.

Figure 3: 5S (Sort–Set in Order–Shine–Standardize–Sustain) methodology used for workplace organization and efficiency. Reprinted from Lean Enterprise Institute (n.d.)

Overall, 5S increases production efficiency, strengthens safety practices, decreases defect opportunities, and builds the foundation for Lean, Kaizen, and continuous improvement initiatives in garment factories.

Value Stream Mapping (VSM)

Value Stream Mapping helps visualize the entire material and information flow, enabling manufacturers to identify bottlenecks and forms of waste across the production line (Lean Enterprise Institute, n.d.). In the garments industry, VSM supports lead-time reduction and improves end-to-end process efficiency.

- **Visualizes the entire production process,** including fabric inspection, cutting, bundling, sewing lines, finishing, packing, and shipment preparation.
- **Identifies bottlenecks** such as sewing imbalances, finishing delays, excessive WIP (Work-inProgress), or waiting time between operations.
- Highlights **non–value-added activities** like unnecessary motion, overproduction, rework loops, and transportation waste.
- Shows the relationship between **cycle time, takt time, and lead time**, allowing managers to align production capacity with customer demand.
- Supports decision-making for **line balancing, layout improvement, and manpower optimization**, especially in high-volume apparel operations.
- Helps implement Lean tools such as **Kaizen, Kanban, and 5S** by providing a clear baseline of current performance and identifying areas for continuous improvement.

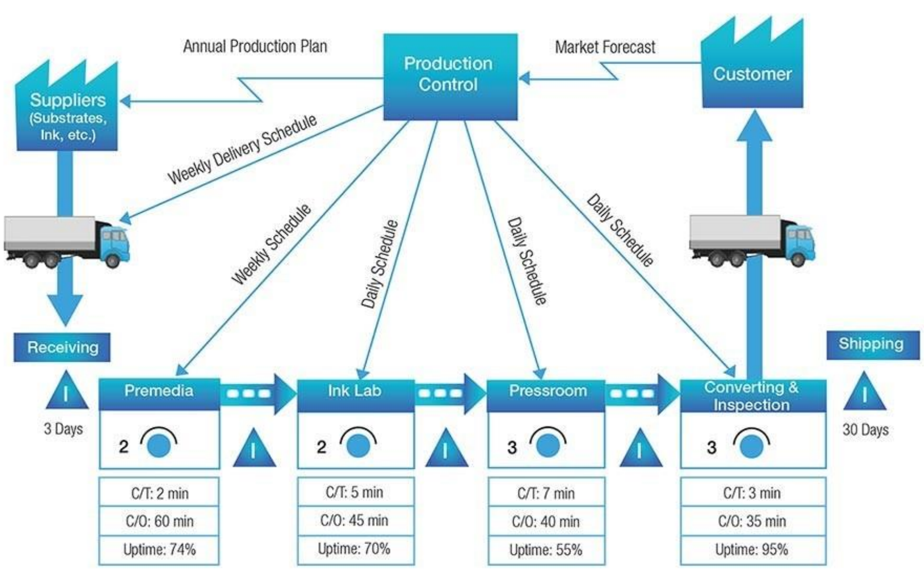

Figure 4: *Value Stream Mapping (VSM) diagram showing material and information flow in a Lean manufacturing process. Reprinted from Lean Enterprise Institute (n.d.).*

SMED (Single-Minute Exchange of Die)
SMED (Single-Minute Exchange of Die) is a Lean methodology designed to minimize machine changeover time, enhancing flexibility and responsiveness in manufacturing operations. In garment production, frequent style changes, fabric variations, and machine adjustments make SMED essential for maintaining high efficiency.

- **Reduces changeover time**, allowing faster transitions between fabric types, stitch classes, folder attachments, or cutting markers.
- **Increases flexibility**, which is critical in fast fashion and short lead-time orders.
- Separates **internal setup** (machine stopped) from **external setup** (machine running), significantly reducing downtime.
- Improves **sewing line continuity** by enabling quick parameter adjustments such as tension, stitch density, needle type, and presser foot settings.
- Enhances **quality consistency** by standardizing setup procedures and reducing errors caused by improper machine preparation.
- Supports **line balancing and WIP reduction**, especially in multi-style or mixed-model sewing lines.
- Lowers operational cost by maximizing machine uptime and reducing changeover-related delays.

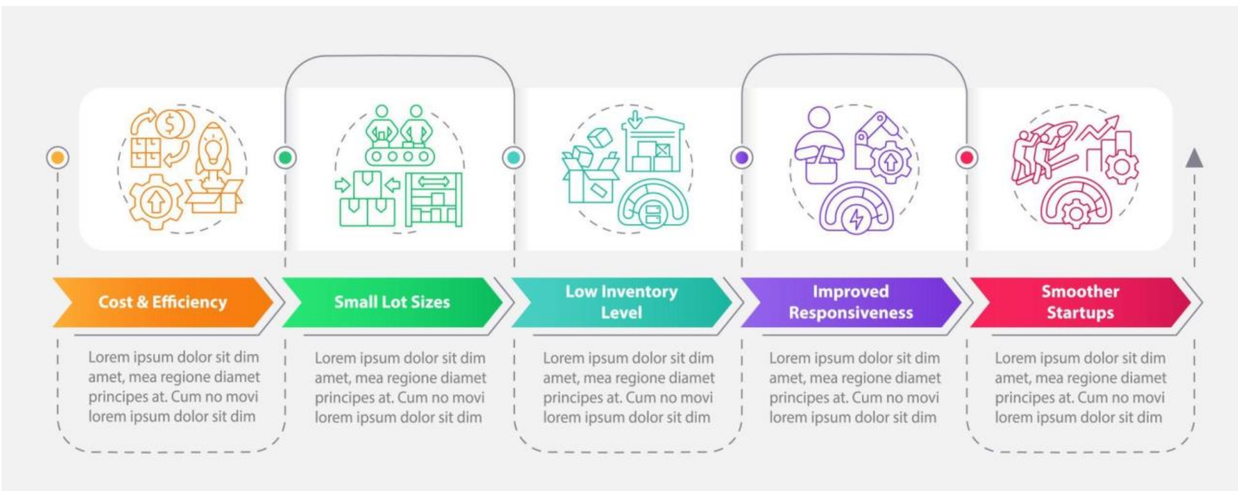

Figure 5: *Single-Minute Exchange of Die (SMED) methodology illustrating internal and external setup reduction. Reprinted from Lean Enterprise Institute (n.d.)*

SMED ultimately increases productivity, agility, and operational flow in cutting, sewing, and finishing departments across apparel factories.

Waste Reduction Strategies
Lean waste reduction focuses on eliminating non–value-added activities that increase cost, delay processes, and reduce product quality. In the textile and garments industry, removing these eight wastes is essential for improving production flow and achieving consistent performance (Lean Enterprise Institute, n.d.).

- **Defects:** Reduce rework and quality issues such as stitching errors, measurement faults, and fabric damage.
- **Overproduction:** Avoid producing ahead of demand through balanced sewing lines and accurate cutting markers.
- **Waiting:** Minimise delays by ensuring timely availability of materials, trims, and work instructions.
- **Non-Utilised Talent:** Engage operators in Kaizen, skill building, and problem-solving initiatives.
- **Transportation:** Optimise layout to reduce unnecessary movement of fabric bundles, trolleys, and finished goods.
- **Inventory:** Control excess WIP using pull systems and Kanban to stabilise sewing and finishing flow. • Motion: Apply 5S to place tools and materials ergonomically, reducing fatigue and unnecessary movement.
- **Extra-Processing:** Eliminate redundant inspections, trimming, and approvals that do not add value.

Figure 6: *Lean waste categories (TIMWOODS) illustrating major non–value-added activities reduced through Lean implementation in textile and apparel manufacturing. Reprinted from Lean Enterprise Institute (n.d.)*

Womack and Jones (2003) emphasise that Lean significantly improves operational excellence in labour-intensive garment manufacturing environments [19].

5. Benefits of TQM in the Apparel Industry

Total Quality Management (TQM) offers significant operational, economic, and strategic advantages to the apparel industry, which is characterized by intense global competition, complex supply chains, and strict buyer compliance requirements. When implemented effectively, TQM transforms organizational culture, reduces inefficiencies, and enhances long-term competitiveness. The following subsections elaborate on the key benefits TQM provides to apparel manufacturers.

5.1. Reduction in Rework, Waste, and Cost of Poor Quality (COPQ)

Rework and wastage are major cost drivers in apparel manufacturing. Fabric defects, cutting inaccuracies, and sewing errors often lead to high Defects per Hundred Units (DHU), increasing production costs and delaying shipments. TQM reduces these losses by emphasizing standardization, preventive action, and early defect detection.

Techniques such as SPC, Kaizen, PDCA, and root cause analysis help eliminate recurring quality problems and reduce the cost of poor quality (COPQ). Montgomery (2019) notes that organizations adopting TQM typically experience substantial reductions in scrap, rework, and non-value-added activities [10]. In apparel production, even a small reduction in DHU can translate into significant savings due to the high volume of output.

5.2. Lower DHU and Enhanced Process Stability

DHU (Defects per Hundred Units) is one of the most important quality indicators in garment manufacturing. High DHU reflects poor process control and negatively influences lead times, productivity, and customer satisfaction. TQM tools—including AQL sampling, SPC charts, and Six Sigma—help stabilize processes and reduce variability, leading to lower DHU. Using standardized work instructions (SWI), operator training, and machine maintenance under TQM helps manufacturers achieve consistent RFT (Right-First-Time) output. According to Nuruzzaman and Haque (2020), TQM reduces defect levels significantly by improving operator competency and strengthening process discipline [18].

5.3. Improvement in Line Efficiency and Overall Productivity

TQM optimizes production processes through Lean tools such as 5S, value stream mapping, SMED, and line balancing. These improvements reduce waiting time, unnecessary motion, bottlenecks, and machine downtime. Efficient line balancing—supported by clear quality checkpoints—ensures smooth workflow, allowing factories to increase output without compromising quality. Womack and Jones (2003) highlight that Lean and TQM improve labor productivity and machine utilization by eliminating wasteful practices [19]. In the apparel industry, where sewing accounts for the majority of production time, improved line efficiency leads directly to higher capacity and lower production cost.

5.4. Higher Customer Satisfaction and Reduced Claims

Customer satisfaction is directly linked to product quality, consistency, and compliance with buyer requirements. TQM ensures that products meet customer expectations through:

- standardized inspection procedures
- accurate measurements
- consistent color and appearance
- compliance with safety and chemical standards
- reliable packaging and assortment accuracy

According to Evans and Lindsay (2020), TQM fosters long-term customer loyalty by improving reliability and reducing product returns or complaints. In the apparel sector—where customer relationships are critical—reduced claim rates enhance business credibility [16].

5.5. Strengthened Supplier–Buyer Relationships

Global apparel buyers, including fast fashion and premium brands, expect suppliers to maintain stringent quality standards and sustainability compliance. TQM improves the reliability and predictability of supplier performance, fostering stronger partnerships between factories and buyers.

Consistent TQM implementation helps suppliers achieve:

- higher audit scores
- better compliance behavior
- fewer shipment delays
- stronger traceability and transparency

As a result, buyers trust TQM-oriented suppliers and often prefer them for long-term sourcing. This stability contributes to increased order volumes and improved financial sustainability.

5.6. Enhanced Sustainability and ESG Performance

Sustainability has become a central requirement in the global fashion industry. TQM aligns closely with environmental and social governance (ESG) goals by supporting:

- efficient use of water, chemicals, and energy
- reduction of waste and carbon footprint
- safer working conditions
- compliance with environmental standards such as ISO 14001 and ZDHC

Khan and Choudhury (2020) emphasize that TQM-driven organizations integrate sustainability into daily operations, resulting in improved environmental performance and lower ecological impact [20].

5.7. Improved Compliance with Global Standards and Regulatory Requirements

Apparel factories must comply with international standards such as:

- **ISO 9001** (Quality Management Systems)
- **ISO 14001** (Environmental Management Systems)
- **ISO 45001** (Occupational Health & Safety)
- **ISO/IEC 17025** (Testing & Calibration Labs)
- **AQL/ISO 2859** (Sampling Standards)
- **RSL/ZDHC** (Chemical Safety)

TQM systems promote documentation, risk-based thinking, corrective and preventive actions, and standardized procedures, which directly support compliance with these frameworks.

ISO (2015, 2018) emphasizes that organizations with strong quality management practices achieve better audit results, reduced nonconformities, and improved consistency in certification maintenance [7,8].

6. TQM and Sustainability Integration

Sustainability has become a central pillar of competitiveness in the global apparel industry. Consumers, regulators, and international brands increasingly demand environmentally responsible, socially ethical, and economically viable production systems. Total Quality Management (TQM) naturally complements sustainability because it emphasizes waste reduction, process efficiency, continuous improvement, and stakeholder well-being. As a result, TQM has evolved beyond improving quality—it now serves as an enabling framework for strengthening sustainability performance across the textile and apparel value chain.

6.1. Environmental Sustainability Through TQM

Environmental sustainability focuses on reducing the ecological footprint of apparel manufacturing. TQM practices directly support this goal by reducing variability, optimizing resources, and preventing waste.

6.1.1. Reduction of Chemical Consumption

Chemical-intensive processes such as dyeing, washing, printing, and finishing contribute significantly to water pollution and environmental degradation. TQM promotes:

- standardized chemical handling procedures
- optimized recipe cards
- RSL/ZDHC compliance testing
- improved dosing accuracy
- real-time monitoring of chemical use

By integrating preventive controls and continuous monitoring, factories reduce hazardous chemical discharge and enhance chemical safety compliance [21].

6.1.2. Waste Reduction Across Processes

TQM's focus on defect prevention and process stability significantly reduces:

- fabric waste in cutting
- rework waste in sewing
- trimming and finishing waste
- packaging waste

Techniques such as PDCA, Lean (5S, VSM), and Six Sigma reduce non-value-added activities and minimize material loss. This aligns closely with circular economy principles in fashion.

6.1.3. Energy and Water Efficiency

TQM encourages the measurement and control of energy and water consumption. Through process optimization and equipment maintenance, manufacturers reduce:

- boiler inefficiencies
- excessive water use in dyeing
- air leaks in compressors
- unnecessary machine running hours

Such measures improve environmental performance and reduce operational costs.

6.2. Occupational Health and Safety (OHS) as Part of Sustainability

Sustainability also encompasses social well-being, including worker health and safety. TQM enhances OHS by:

- standardizing safe operating procedures
- implementing risk assessments (HIRA/JSA)
- ensuring machine guards and protective devices
- promoting ergonomics in sewing and finishing
- maintaining a clean and organized workplace through 5S

The alignment of TQM with ISO 45001 strengthens safety culture, reduces workplace accidents, and contributes to human-centered sustainability.

6.3. Resource Efficiency and Operational Optimization

Resource efficiency is a critical sustainability priority for global brands. TQM helps factories:

- reduce fabric consumption through accurate marker planning
- improve machine utilization
- minimize downtime
- optimize workflow layouts
- enhance productivity with lower environmental impact

Lean and TQM tools help apparel manufacturers transition toward low-waste, energy-efficient production systems.

6.4. Compliance With Sustainability and Environmental Standards

TQM reinforces compliance with globally recognized standards, including:

- **ISO 14001** for environmental management
- **ISO 9001** for consistent quality management
- **ISO 45001** for occupational health and safety
- **ISO/IEC 17025** for lab accuracy and chemical compliance testing
- **ZDHC MRSL v3.0** for safer chemical usage
- **Higg FEM & FSLM** for facility environmental and social assessments
- **Amfori BSCI** and **WRAP** for social compliance

By establishing systematic documentation, monitoring, corrective action, and preventive action frameworks, TQM ensures strong conformance to sustainability and compliance requirements (ISO, 2015, ISO, 2018).

6.5. Ethical Sourcing and Social Responsibility

TQM extends beyond technical quality into ethical quality. For apparel brands, sustainability increasingly involves:

- ensuring living wages
- preventing forced or child labor
- maintaining fair working hours
- guaranteeing safe working conditions
- promoting gender equality and skill development

TQM-driven organizations often outperform competitors in social audits because they maintain documented processes, risk-based thinking, effective training, and high operational transparency.

6.6. TQM and ESG (Environmental, Social, Governance) Integration

Environmental, Social, and Governance (ESG) reporting has become a strategic requirement for global apparel brands and their supply chains. Buyers now expect transparent sustainability performance aligned with frameworks such as the GRI Standards, UN SDGs, the Higg Index, and OECD Due Diligence Guidelines. Total Quality Management (TQM) strengthens ESG implementation by embedding structured processes, continuous improvement, stakeholder engagement, and robust monitoring systems across textile and garment operations.

Environmental (E)

- Reduced carbon emissions through energy-efficient machinery, optimized production layouts, and renewable-energy adoption.
- Lower waste and chemical discharge through improved chemical management, accurate dyeing processes, and effective wastewater treatment.
- Increased energy and water efficiency using recycling technologies, low-liquor-ratio dyeing, and Lean waste-minimization tools.
- Sustainable material utilization, improved fabric yield, reduced cutting scraps, and responsible raw-material sourcing.

Social (S)

- Enhanced worker safety and well-being through advanced EHS systems, ergonomics, and PPE adoption.
- Continuous training, skill development, and operator empowerment supported by Kaizen, cross-training, and skill-matrix programs.
- Improved labor standards through working-hour compliance, anti-harassment policies, and strong grievance mechanisms.
- Community development initiatives through CSR projects, local hiring, and educational support programs.

Governance (G)

- Strong documentation culture through SOPs, quality manuals, risk registers, and traceable audit trails.
- Robust internal audit systems ensuring compliance with ISO 9001, ISO 14001, ISO 45001, and buyer-specific requirements [5, 7-9].
- Ethical business conduct, anti-corruption policies, and accountable leadership practices.
- Integrated digital systems that enhance data integrity, real-time monitoring, transparency, and sustainability reporting.

Figure 7: *Environmental, Social, and Governance (ESG) sustainability framework illustrating key dimensions of responsible manufacturing. Reprinted from Corporate Finance Institute (n.d.)*

ESG-aligned TQM operations help garment manufacturers enhance global brand trust, secure long-term buyer partnerships, and remain competitive in increasingly sustainability-driven international markets.

6.7. Digital Sustainability Through TQM and Industry 4.0

Modern TQM integrates digital tools to monitor sustainability performance:

- IoT sensors for water, steam, and energy usage
- AI-based defect prediction reducing rework
- Digital chemical management systems
- Real-time dashboards for environmental KPIs
- RFID/barcode-based traceability

Digital quality management enhances predictive maintenance, accuracy, and resource optimization, reducing environmental impact.

6.8. Long-Term Strategic Advantages of TQM-Sustainability Integration

Integrating Total Quality Management (TQM) with sustainability creates long-term competitive advantages for apparel manufacturers by aligning quality excellence with environmental and social responsibility. This integration supports continuous improvement, enhances global compliance readiness, and strengthens the overall resilience of textile and garment supply chains [5].

Key Strategic Advantages

- **Enhanced brand positioning and reputation:** Sustainable quality practices build trust with ecoconscious buyers and strengthen brand credibility in international markets.
- **Reduced operational costs:** Lean waste reduction, energy efficiency, and process optimization lower production costs while improving resource utilization.
- **Improved regulatory compliance:** Integration with standards such as ISO 9001, ISO 14001, and ISO 45001 ensures readiness for environmental, social, and quality audits.
- **Better relationships with global brands:** Transparent sustainability performance helps manufacturers meet buyer expectations related to ESG, Higg Index, and traceability requirements.
- **Stronger resilience in global value chains:** Sustainable TQM practices increase adaptability to market disruptions, regulatory changes, and supply chain volatility.
- **Contribution to SDGs (Sustainable Development Goals):** Integrated TQM–sustainability systems directly support SDG 8 (Decent Work), SDG 9 (Industry & Innovation), and SDG 12 (Responsible Consumption & Production).

Ultimately, sustainability and quality are no longer separate disciplines—TQM provides the operational structure, discipline, and continuous improvement culture required for long-term sustainable transformation in the apparel manufacturing sector.

7. Modern TQM and Industry 4.0 Transformation

The emergence of Industry 4.0 has transformed Total Quality Management (TQM) in the textile and apparel sector by shifting quality assurance from reactive, inspection-based control to proactive, predictive, and data-driven management. Intelligent automation, cyber-physical systems, and advanced analytics now enable factories to maintain consistent quality while increasing speed, accuracy, and operational transparency. Modern factories use **real-time digital quality dashboards** to track essential KPIs—DHU, RFT, machine downtime, needle breakage rate, production efficiency, and operator performance—allowing QA teams to intervene early and prevent escalation of defects [16]. AI-driven defect detection systems further enhance inspection accuracy by identifying skipped stitches, seam puckering, color shading variations, print misalignment, fabric defects, and GSM inconsistencies faster than manual methods [10]. The integration of **IoT-enabled sewing machines** captures stitch density, thread tension, RPM, motor temperature, and machine health data, ensuring stable seam quality and reducing variability. These capabilities align with Lean and TQM principles by supporting standardized operations and continuous improvement [19]. Additionally, **RFID, NFC, and QR-code tracking** improve traceability across every production stage—cutting, sewing, washing, finishing, and packing—helping brands comply with global transparency standards, ZDHC chemical management, and Higg FEM sustainability reporting [21].

Digital transformation also extends to laboratory operations. **Cloud-based LIMS and QMS platforms**, aligned with ISO/IEC 17025, support automated data entry, calibration tracking, chromatograph uploads, and digitized test reporting (colorfastness, pH, bursting strength, chemical screening). These systems ensure accuracy, traceability, and audit readiness across all compliance frameworks [15]. Cloud-QMS systems further automate CAPA workflows, NCR management, document control, and internal audit scheduling, supporting continuous compliance with ISO 9001 and ISO 14001. Advanced Industry 4.0 tools such as **big data analytics, machine-learning forecasting models, and digital twins** allow factories to predict defect patterns, optimize resource allocation, and simulate production flows to improve line balancing, layout changeovers, and cutting efficiency. Robotic arms, automatic fabric spreaders, and AI-powered pattern systems also contribute to reducing manual errors and enhancing TQM reliability. Overall, the convergence of TQM with Industry 4.0 technologies delivers substantial strategic advantages, including improved accuracy, real-time visibility, reduced defects, higher operational agility, better ESG performance, enhanced buyer confidence, and stronger global competitiveness [18].

Case Study:
Comparative Analysis of TQM and Traditional Quality Practices in a Bangladesh-Based Knitwear Manufacturing Facility

Case Study Overview
This case study examines how Total Quality Management (TQM) influences production quality and operational performance in a large export-oriented knitwear manufacturing facility located in Chattogram, Bangladesh. Two parallel production groups were evaluated under identical working conditions, using the same fabric lot, garment style, workforce size, production volume, and delivery timeline. Group A operated under a structured TQM framework, while Group B followed a traditional inspection-based system.

Key performance indicators included Defects per Hundred Units (DHU), Right-First-Time (RFT) percentage, fabric waste, rework hours, AQL outcomes, documentation quality, and compliance readiness. Findings show that Group A consistently performed better across all production stages. Preventive control, data-driven decision-making, and standardized quality procedures enabled Group A to achieve superior process stability, product consistency, and operational efficiency. The results confirm that TQM provides a substantial competitive advantage in modern apparel manufacturing environments.

Garment Manufacturing Process

Fabric Inspection

Checking fabric for defects

Fabric Relaxation

Relaxing fabric tension

Pattern Making

Arranging patterns on fabric

Fabric Cutting

Cutting and bundling cut pieces

Sorting & Bundling

Sorting and bundling cut pieces

↓

Sewing (Assembly)

Sewing garment parts

↓

Inspection

Checking for defects

↓

Pressing and Finishing

Pressing and adding final touches

↓

Packing

Finished garments

Group A – TQM-Integrated Production System

Group A operated under a structured Total Quality Management (TQM) framework designed to ensure consistent quality, process reliability, and preventive control throughout production.

- Implemented a full suite of quality tools: PDCA, DMAIC, SPC, AQL (ISO 2859-1), 5S, Kaizen, RCA, CAPA, Lean, and FMEA.
- Maintained complete, ISO-aligned documentation including SOPs, WIs, QC checklists, calibration logs, and traceability records.
- Utilized advanced digital systems such as real-time QC dashboards, inline defect tracking, QR-based bundle identity, and preventive maintenance alerts.
- Operated in conformance with ISO 9001, ISO/IEC 17020, ISO 14001, ISO 45001, and ISO/IEC 17025, ensuring strong compliance and audit readiness.
- Built a preventive, data-driven quality culture supported by operator training, skill matrices, and team-based problem solving.

Group B – Traditional Production System

Group B represented a conventional, inspection-centered approach with limited process control and reactive quality practices.

- Relied primarily on **end-of-line inspection**, with minimal preventive checks.
- Documentation was **partial and inconsistent**, lacking structured SOP and traceability discipline.
- No application of SPC, DMAIC, RCA, CAPA, or Lean tools, **resulting in reactive, short term fixes**.
- Operational decisions depended on **supervisors' experience** rather than data.
- AQL (ISO 2859-1) used **only at final inspection**, reducing its effectiveness.
- High WIP, frequent bottlenecks, and recurring defects indicated **weak process control and low efficiency.**

8. Methodology

Both groups worked on **the same style**, same fabric lot, same production volume (10,000 pcs), and same delivery date.

Data were collected on:

- DHU (Defects per Hundred Units)
- RFT (Right First Time %)
- Rework and repair hours
- Wastage %
- Lead time & efficiency
- Customer claim rate
- Compliance and documentation quality

Detailed Comparison Across Each Production Stage

Stage 1: Fabric Inspection & Approval

KPI	Group A (TQM)	Group B (Traditional)
Inspection Method	4-Point System + Shade Band + GSM + Shrinkage, documented	Only visual checking
Defect Identification	Systematic (SPC chart)	Random
Rejection Accuracy	98%	78%
Shade Variation	Controlled	Detected late (after sewing)

Observation
TQM group prevented defects entering production. Traditional group detected problems only after sewing, causing rework.

Stage 2: Cutting Room Quality

KPI	Group A	Group B
Marker Efficiency	82% (Lean VSM optimisation)	75%
Panel Accuracy	Verified with template, tolerance within ±2 mm	Frequent mismatches
Wastage %	3.2%	6.7%
Bundling/Identity	Barcode/QR-linked	Manual slips (lost pieces)

Observation
Group A's cutting accuracy improved sewing efficiency and measurement approval rates.

Stage 3: Sewing Line Quality

KPI	Group A (TQM Tools Applied)	Group B (Traditional)
DHU %	6.8%	18.4%
RFT %	94%	71%
Needle Control	Digital log, change policy	Manual replacement
Machine Maintenance	TPM system	Reactive maintenance
Operator Skill	Training + Skill Matrix	No structured skill map
Inline QC	SPC chart + Kaizen QC	Random checking

Observation
Group A consistently achieved lower sewing defects—open seams, broken stitches, puckering—because of SPC, DMAIC, and training programs.

Stage 4: Finishing & Packing Quality

KPI	Group A	Group B
Measurement Accuracy	Verified with AQL reference samples	Verified only during final inspection
Presentation (Ironing)	Standardized method, temperature chart	Operator experience only
Metal Detection	Recorded, validated	Partial checking
Carton Accuracy	100% compliant	Frequent assortment errors
Final Audit Result	Pass (AQL 1.5)	Borderline (AQL 2.5)

Observation
Group B faced multiple finishing errors that increased shipment delay risk.

Stage 5: Laboratory Testing Integration

Area	Group A	Group B
Lab Testing	ISO/IEC 17025 aligned	Only buyer-required tests
Test Data	Used for PDCA, RCA	Not used for improvement
Chemical & Shrinkage Control	Preventive	Detected post-production

Observation

Group A used lab data for strategic process improvement, reducing compliance failures.

8.1. Quantitative Summary of Performance Differences

Overall Production Metrics

KPI	Group A (TQM)	Group B (Traditional)
Total DHU (%)	7.5%	19.2%
Rework Hours	120 hrs	410 hrs
Fabric Waste (%)	3.5%	7.1%
Line Efficiency	52% → **68%**	45% → 49%
Shipment Delay Risk	None	High
Customer Complaint	0	3 minor issues
Documentation Quality	Excellent	Poor
Cost of Poor Quality (COPQ)	Reduced by 32%	Increased by 18%

8.2. Major Differences Between the Two Production Approaches

A. Operational Differences

Area	Group A – TQM	Group B – Traditional
Quality Philosophy	Proactive & preventive	Reactive & inspection-only
Decision Making	Evidence-based (SPC, DMAIC)	Experience-based
Training System	Structured Skill Matrix	No formal system
Documentation	Complete traceability	Partial or missing
Problem Solving	RCA + CAPA	Ad-hoc solutions
Production Flow	Lean, low WIP	High WIP, bottlenecks
Digital Tools	Dashboards, QR tracking	Very limited

B. Cultural Differences

TQM Culture	Traditional Culture
Everyone responsible for quality	QC is responsible for quality
Continuous improvement mindset	"If defect found, repair it"
Team-based problem solving	Supervisor-dependent
High transparency	Limited visibility

9. Root-Cause Analysis Findings

A clear distinction emerged between the analytical capabilities of Group A and Group B, particularly in their approaches to identifying and eliminating the underlying causes of defects.

Group A (TQM)

Group A demonstrated a structured, data-driven approach to diagnosing quality problems. Root causes were identified early through the systematic application of established quality tools, including:

- Pareto analysis to prioritize high-frequency defects
- Fishbone (Ishikawa) diagrams to map potential causal factors
- Statistical Process Control (SPC) charts to detect process

variation

- Failure Mode and Effects Analysis (FMEA) for assessing high-risk operations

By integrating these tools within the PDCA and DMAIC improvement cycles, the team implemented effective Corrective and Preventive Actions (CAPA). As a result, recurring issues were eliminated, and DHU levels decreased significantly across the production stages.

Group B (Traditional System)
In contrast, Group B operated without structured root-cause analysis methods. Defects were often addressed superficially, and underlying causes remained unknown or only partially understood. The absence of analytical tools and documented CAPA processes led to:

- Recurring and unresolved defects
- Substantial rework and repair time
- Increased pressure on shipment deadlines due to quality-related delays

This reactive approach prevented long-term improvement and contributed to instability in quality performance.

10. Final Outcome of the Case Study

The comparative evaluation between the TQM-integrated system (Group A) and the traditional inspection-based system (Group B) revealed significant differences in operational performance, quality stability, and compliance readiness.

Group A (TQM System)
Group A consistently demonstrated superior performance as a result of structured quality management, preventive control mechanisms, and data-driven decision-making. Key outcomes included:

- **Improved product quality**, with stable DHU trends and fewer critical defects
- **Reduced operational cost**, supported by lower rework, minimized waste, and improved resource utilization
- **Higher production efficiency**, reflected in increased RFT and line performance
- **Zero customer complaints**, indicating strong alignment with buyer expectations
- **Enhanced audit readiness**, meeting ISO and buyer compliance requirements with wellmaintained documentation
- **Stronger sustainability and ESG performance**, driven by reduced waste, safer processes, and effective environmental controls

Overall, Group A's outcomes validate the strategic advantage of adopting TQM as a core operational framework.

Group B (Traditional System)
Group B's reliance on end-of-line inspection and reactive problem-solving resulted in multiple performance limitations. The major outcomes included:

- **Frequent rework,** caused by recurring and unresolved defects
- **Poor measurement consistency,** leading to higher rejection risk
- **Increased material waste,** particularly in cutting and sewing operations
- **Lower productivity,** due to unbalanced workflow and inconsistent process control
- **Higher Cost of Poor Quality (COPQ),** stemming from rework, delays, and defect-related losses
- **Greater shipment delay risk**, as quality issues often surfaced late in the production cycle

These results reflect the inherent weaknesses of traditional, detection-focused quality systems and emphasize the need for a structured, preventive approach.

11. Final Assessment

This case study provides clear and compelling evidence that the implementation of Total Quality Management (TQM) within a large export-oriented knitwear manufacturing facility leads to significant improvements in product quality, process stability, and overall operational performance. The comparison between the TQM-integrated production line (Group A) and the traditional inspection-driven line (Group B) demonstrates that a preventive, data-oriented quality system consistently outperforms a reactive, detection-focused approach. Group A achieved measurable improvements across all major performance indicators, including reduced DHU levels, lower rework hours, higher line efficiency, more accurate measurements, and stronger audit readiness. The absence of customer complaints and the consistency of output further validate the effectiveness of structured TQM practices in meeting buyer expectations and reducing the cost of poor quality.

These findings align strongly with established Total Quality Management literature, confirming that tools such as SPC, PDCA, DMAIC, AQL sampling, and Lean methodologies generate substantial operational benefits when properly implemented. Overall, the case study demonstrates that TQM is not merely a quality-control mechanism but a holistic operational strategy that enhances reliability, minimizes variation, and strengthens long-term competitiveness in the apparel manufacturing sector.

12. Challenges in Implementing TQM in Developing Countries

Implementing Total Quality Management (TQM) in developing countries remains a complex task due to structural, economic, and cultural constraints. Although TQM offers measurable benefits—such as improved process stability, lower defect levels, and enhanced competitiveness—several barriers limit its full adoption within the textile and apparel sector. First, **limited worker training and skill development** hinder operators' ability to follow standard procedures, identify defects, and participate in continuous improvement initiatives. Many factories depend on low-skilled labor, making it difficult to execute TQM tools such as SPC, Kaizen, or root-cause analysis [4]. Equally significant is **organizational resistance to change**, influenced by hierarchical management styles and a preference for traditional inspection-based quality practices instead of preventive approaches [6].

A major technological barrier is the **lack of digital tools**. Factories often operate without real-time monitoring systems, IoT-enabled equipment, digital QMS platforms, or predictive analytics. This limits data-driven decision-making—one of TQM's core principles [16]. Additionally, **high certification costs** associated with ISO 9001, ISO 14001, ISO 45001, and ISO/IEC 17025 create financial burdens for small and medium-sized manufacturers, particularly where margins are low and external funding is limited [5,8]. Many developing-country manufacturers also rely on **outdated machinery**, leading to inconsistent process performance, higher DHU, and increased downtime. Modern TQM requires stable, capable processes— conditions difficult to achieve without investment in upgraded equipment [10]. Beyond internal operations, **weak supplier infrastructure** contributes to variability in fabric quality, dyeing performance, and chemical consistency, undermining TQM efforts at the factory level [11].

Furthermore, **inconsistent documentation and poor recordkeeping** pose serious challenges. TQM frameworks rely on accurate SOPs, maintenance logs, CAPA records, and audit trails. Yet many factories lack discipline in documentation, resulting in poor traceability and recurring nonconformities during audits [5]. Overcoming these challenges requires **strong leadership commitment**, investment in digital transformation, comprehensive worker training programs, supplier capability development, and a long-term strategic orientation toward continuous improvement. Without these foundational elements, TQM initiatives often remain superficial and fail to deliver meaningful, sustainable performance improvements.

13. Conclusion

Total Quality Management (TQM) has become an indispensable foundation for success in the textile and apparel industry, particularly as global markets demand higher levels of quality consistency, social responsibility, environmental stewardship, and regulatory compliance. In an increasingly competitive environment—shaped by shorter lead times, stringent buyer expectations, and rising sustainability pressures—TQM provides a structured, holistic framework through which organizations can strengthen operational discipline, minimize process variation, and enhance customer satisfaction [16]. By embedding the core principles of continuous improvement, employee involvement, process orientation, and customer focus into everyday operations, TQM allows apparel manufacturers to transition from reactive, inspection-based systems to proactive, prevention-driven cultures. The integration of internationally recognized standards such as ISO 9001, ISO 14001, ISO 45001, and ISO/IEC 17025 further supports this transformation by formalizing documentation, risk-based thinking, environmental performance, and laboratory competence [7-9].

Moreover, the adoption of Industry 4.0 technologies—AI-driven defect detection, IoT-enabled machines, digital QMS platforms, and real-time data analytics—reinforces TQM's effectiveness by enabling faster decision-making, improved transparency, and predictive quality control. These innovations not only enhance production efficiency but also align with broader sustainability and ESG priorities, helping manufacturers reduce waste, optimize resources, and strengthen safety and ethical standards [21]. For export-oriented economies such as Bangladesh, India, Vietnam, and Cambodia, TQM is no longer optional, it is a strategic necessity for maintaining buyer trust, securing long-term contracts, meeting global audit requirements, and competing against technologically advanced production hubs. When implemented with strong leadership commitment, adequate training, and digital integration, TQM becomes a powerful driver of operational excellence, sustainable compliance, and long-term organizational resilience [22-24].

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