



Innovative Skills for an Old Vocation

Innovative Skills for Quality Management

WP 04



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1 Introduction

This manual is a joint product of all partners from the Erasmus+ project "Innovative Skills for an Old Vocation" (ISOV, 2024-1-DE02-KA220-VET-000254492, <https://isov-project.eu/>). As all sectors, the sector of industrial footwear production faces the mega-trends of globalisation, digitalisation and sustainability. Main aims of the project are the development, pedagogical structuring and piloting of courses for apprentices, students and/or employees in industrial footwear production in Germany, Portugal and Romania, based on scientifically developed impact analyses on which of the dimensions of the trends influence which of the 18 Spheres of Activity (SoA) of the sector. The courses and the manuals refer to 12 chosen concrete SoA in which the participants are working, are supposed to work, or want to work.

Basic materials for the courses are the manuals. As the estimated impact of the dimensions respective sub-dimensions of the trends differ between partner countries and as the equipment of training providers with modern technology is differing, as well, the manuals follow a modular structure:

Chapter 2 documents the, partly shortened or updated, "state of the art" manual from previous projects "Integrating Companies in a Sustainable Apprenticeship System" (ICSAS, <http://icsas-project.eu/>) respective "Developing Innovative and Attractive Continuous Vocational Education and Training (DIA-CVET, <https://dia-cvet.eu/>).

Chapters 3-5 illustrate the expected impact of the various (sub-)dimensions of the 3 trends in the near future (up to 5 years) on the work-processes of the chosen SoA.

This approach has the huge advantage that, for example, if the sub-dimension "additive manufacturing" is estimated to have high impact on a certain SoA and a training provider has no 3-d printer, he can, with respect to this sub-dimension, rely on the "old" manual referring to subtractive manufacturing – but still impart the impact of other subdimensions, where the equipment is available.

Finally, chapter 6 offers a case study of apparent good practice, demonstrating not only what, but also exemplarily how to teach.

Or, to put it different, this manual should not be read as a "receipt", where all condiments should be added or imparted in a fixed row and a defined quantity – but as a "toolbox", aiming at inspiring trainers to impart not only "state of the art" knowledge, skills and competences (KSC) – but to prepare their apprentices, students or participants in continuous vocational education and training (CVET) for upcoming work-processes.

2 Quality management in the Footwear industry

2.1 Introduction to Quality Management (QM)

In increasingly competitive markets, organizations must strengthen performance by improving management practices and meeting the expectations of key stakeholders—customers, employees, shareholders, suppliers, and society. Effective quality management and quality management systems (QMS) play a central role in enhancing competitiveness, consistency, and trust.

Quality is influenced by many interconnected factors and should not be treated purely as a technical issue. Instead, it must be embedded in overall management of operations and procedures. Sustainable results depend on a preventive, process-oriented culture that emphasizes continuous improvement, risk awareness, and shared responsibility across the organization.

To support this, internationally recognized standards provide structured frameworks for implementing management systems. The International Organization for Standardization (ISO) standard “ISO 9001 Quality management systems — Requirements¹” is widely adopted across industries to improve organizational efficiency, process control, and customer satisfaction. It is based on principles such as customer focus, leadership, process approach, and continual improvement.

Organizations applying ISO 9001 can seek certification from an independent body. This certification signals that the organization follows recognized best practices and meets defined requirements for quality management, serving as a strong credibility marker in the marketplace.

A QMS based on ISO 9001 primarily focuses on product and service quality as well as customer satisfaction, while separate management system standards exist to address areas such as environmental performance, energy management, and occupational health and safety.

2.2 Fundamental concepts on Quality

All organizations—whether businesses, schools, or hospitals—aim to deliver products or services that meet user expectations in terms of price, timeliness, and suitability. When these expectations are met, market success becomes more likely. Quality is therefore a key driver of competitiveness, especially in increasingly demanding and fast-changing markets.

To keep pace, organizations must continuously improve their offerings, shorten development cycles, and adapt to technological advances, changing regulations and evolving customer needs. This raises critical questions: How can organizations respond effectively? What capabilities are required to succeed? Does improving quality necessarily raise costs, or can an effective quality management system also enhance efficiency and generate added value and long-term benefits?

2.2.1 How to define Quality?

According to EOQC ("European Organization for Quality Control"), the Quality is the set of characteristics of a product (or service) that determine its ability to satisfy a given need.

¹ International Organization for Standardization. (2015). *ISO 9001:2015 Quality management systems—Requirements*. <https://www.iso.org/standard/62085.html>

Needs include:

- Regulatory and legal requirements (e.g., safety standards, social and environmental regulations)
- Societal expectations (e.g., environmental impact, ethics beyond regulations)
- Internal requirements (e.g., process efficiency, reliability)
- Customer needs

Quality management in accordance with ISO 9001 is based on the principle that quality is achieved by fulfilling all applicable requirements, with a strong focus on customer needs while also considering the requirements of other relevant stakeholders.

Meeting customer needs means that the product is suitable for use by the client. "Fitness for use" is a conceptual model that relates to the value the product provides and the resulting customer satisfaction². Therefore, quality is defined by the customer perception of how well the product satisfies their needs and intended use.

The "fitness" for use of a product can be characterized by the eight dimensions of quality:

1. Performance
Primary functions and operational characteristics of the product.
2. Features
Additional functions that enhance or distinguish the basic product.
3. Reliability
Ability to perform without failure over a defined period of time.
4. Conformance
Extent to which the product meets specified standards and requirements.
5. Durability
How long the product remains functional under normal use conditions.
6. Serviceability
Ease and speed of repair, maintenance, and after-sales support.
7. Aesthetics
Sensory aspects such as appearance, feel, smell, or taste.
8. Perceived Quality (Reputation)
Overall customer perception, influenced by brand and reputation.

The importance of each quality dimension depends on the type of customer, the type of product, and its intended purpose.

From a strategic and overall business perspective, quality has a dual focus: it must meet customer needs while also being evaluated in relation to competitors in the market, while fulfilling the regulatory requirements.

² Garvin, D. A. (1988). *Managing quality: The strategic and competitive edge*. Simon and Schuster

2.3 The Customer

A customer is ultimately the buyer of the product, but in practice the concept applies throughout the entire value chain. Internally, employees or departments act as customers of each other along the production process. Externally, customers may include retailers, distributors, importers, and end consumers who decide whether to repurchase the product.

Because of this, business strategy must balance the needs of all internal and external stakeholders. To maintain customer satisfaction, companies must:

- correctly identify customers,
- understand and meet their needs,
- respect deadlines,
- provide support,
- respond to feedback with corrective actions.

Meeting these needs requires reliable information about:

- product requirements,
- quality level,
- quantity,
- pricing,
- target market,
- competitor positioning.

Ultimately, product quality is what attracts and retains customers. A satisfied customer (internal as well as external) becomes a key promoter of the company, while poor quality can lead to significant costs and lasting damage to reputation and trust.

2.4 Management Standards and their evolution

The ISO 9000 series is a set of international standards for quality management systems focused on management processes rather than technical product specifications. It provides a framework for defining requirements, organizing responsibilities, and documenting quality systems.

The main standards include:

- ISO 9000 Quality management systems - Fundamentals and vocabulary
- ISO 9001 Quality management systems - Requirements
- ISO 9004: Quality management - Quality of an organization - Guidance to achieve sustained success

ISO 9001 is based on the PDCA (Plan–Do–Check–Act) cycle and specifies the requirements for a quality management system while allowing organizations flexibility in how these requirements are implemented. Its adoption is a strategic decision by top management, intended to support continuous improvement, operational efficiency, and customer satisfaction.

The standard is structured into key areas:

- **Context:** internal and external factors affecting the organization
- **Leadership:** top management responsibility and commitment
- **Planning:** risk-based thinking and quality objectives
- **Support:** resources, competence, and communication
- **Operation:** execution of processes to deliver products and services
- **Performance evaluation:** monitoring and analysis of results
- **Improvement:** actions for continual improvement

Together, these elements form a structured system to ensure consistent quality, efficiency, and continuous improvement.

Over time, similar management system standards have been developed for areas such as environmental management and energy management. Most modern management system standards follow a common high-level structure, which facilitates compatibility and integration within organizations. As a result, many organizations implement and certify multiple management systems that operate together in an integrated manner. An exception is ISO 13485, which does not fully follow this harmonized structure.

As of 2026, ISO 9001:2015 is still the current valid and certifiable version of the standard. A revised edition (often referred to as ISO 9001:2026) is expected to be published around September 2026. After publication, there will typically be a transition period of about three years, during which organizations can move from ISO 9001:2015 to the new version while maintaining certification.

2.5 Approach to Management by Processes

Process control principles in manufacturing involve evaluating both processes and products.

How to define a process

According to ISO 9001, the process approach:

- defines a network of interacting processes;
- considers inputs and outputs of each process, including their interfaces;
- ensures processes are controlled for effectiveness and efficiency.

Each organisation defines the processes and actions needed to meet compliance requirements and performance indicators.

A process is a system of interrelated activities that uses resources to transform inputs into outputs. It adds value through structured, sequential activities based on defined rules and procedures.

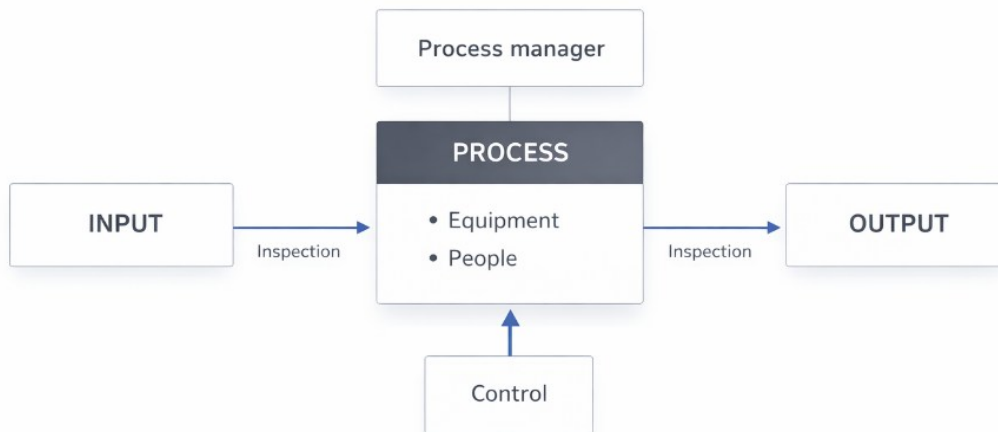


Fig. 1: Process

A process is guided by defined procedures and is typically assigned an owner or manager responsible for monitoring its performance and effectiveness. Processes are part of the organisation's value chain and are evaluated through performance indicators. Top management does not usually assess each process directly but ensures overall system performance, alignment with strategic objectives, and effectiveness of the quality management system.

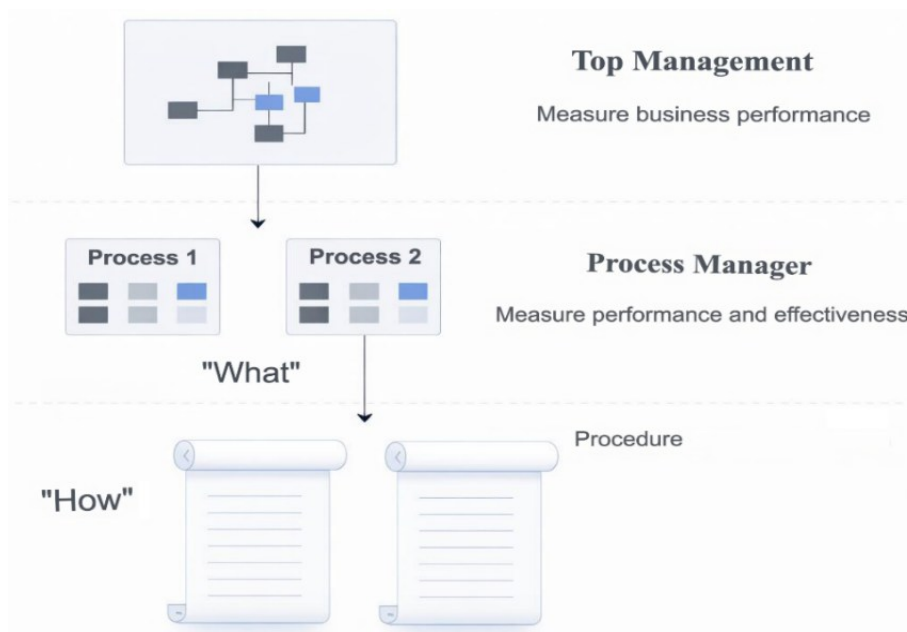


Fig. 2 : Operating Procedure ©CTCP

Even in process-oriented organizations, departments are often still organized and named after their main processes. However, traditional management approaches tend to manage these departments and functions in isolation, which can create silos and lead to local optimization rather than overall system performance.

The process approach, by contrast, focuses on managing interconnected activities across the organization as end-to-end processes, emphasizing flow, interaction, and overall effectiveness rather than individual departmental efficiency.

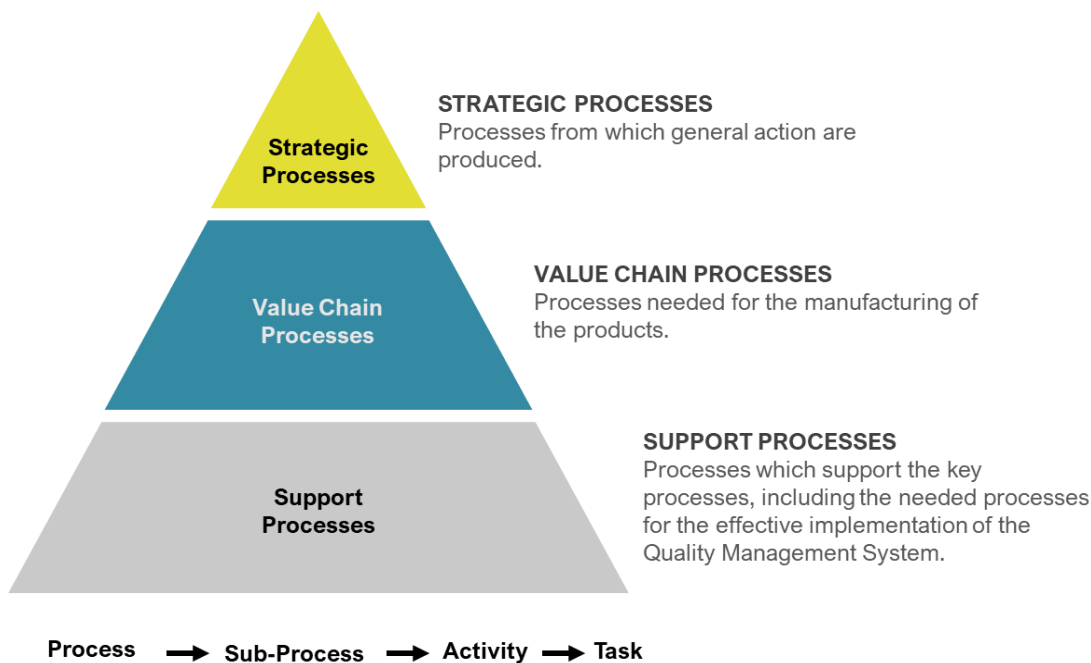


Fig. 3: Example of the chain of Processes in a company ©CTCP

How to define Objectives

Objectives in the process approach are defined results an organization aims to achieve within a specified time period.

- **Strategic (overall) objectives** – established by top management and aligned with the organization's quality policy, applying to the entire organization
- **Process objectives** – defined for individual processes to monitor performance and support continual improvement; they are managed by process owners and reviewed by top management.

Each objective is supported by an action plan that defines tasks, responsibilities, required resources, and deadlines.

Objectives must be SMART³:

- **Specific** – clear and focused
- **Measurable** – quantifiable
- **Achievable** – realistic and actionable
- **Relevant** – important for business/process goals
- **Time-bound** – defined deadline

How to Implement and Control a Process (PDCA)

The process approach is implemented through the PDCA (Plan–Do–Check–Act) cycle. PDCA is a management cycle used to systematically control and continually improve processes. It ensures that processes are planned, implemented, monitored, and improved based on performance evaluation, corrective actions, and opportunities for improvement.

³ Doran, G. T. (1981). There's a SMART way to write management's goals and objectives. *Management review*, 70(11)

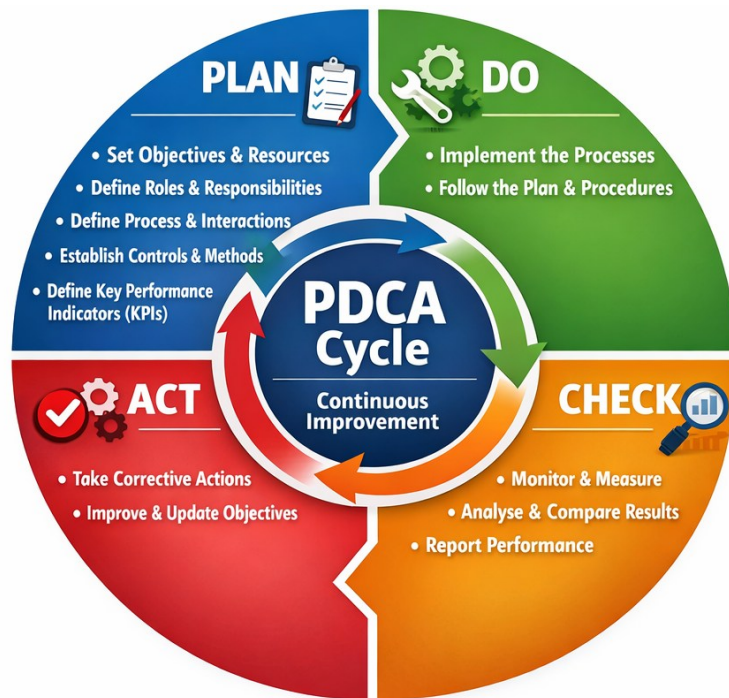


Fig. 4: PDCA Cycle ©PFI

2.6 Tips for Continuous Improvement

A Quality Management System should demonstrate a steady, linear improvement over time rather than fluctuating performance or short-term bursts of effort before audits. This is achieved through continuous improvement efforts that are sustained and embedded in daily operations instead of reactive, audit-driven actions.

10 Tips to improve Quality Management:

1. Saving on quality may reduce short-term costs but often increases long-term costs due to corrective actions and damage to reputation.
2. Quality is never accidental; it results from intentional and intelligent effort.
3. Quality should be designed based on customer needs and expectations.
4. It is better to reject a poor product than to lose a good customer because of it.
5. There is only one way to do things well: do them properly.
6. Define methods, implement them, and standardize them until they become routine.
7. A product return is more bothersome than an early rectification of error.
8. Product quality starts with the quality of suppliers.
9. It is easy to blame faults on wrong materials, they cannot defend themselves.
10. There is always room to improve what we do.

3 Globalization in QM

The TCLF sector is already highly globalized, with supply chains, production, and markets distributed across multiple countries. Efforts to increase transparency, such as those driven by the EU Corporate Sustainability Due Diligence Directive (CSDDD), are expected to shape the sector by requiring companies to monitor and report on environmental and social impacts throughout their supply chains. Advances in digitalization are likely to further facilitate data exchange and traceability, helping to address current transparency and control gaps and enabling more data-driven supply chain management in the future.

3.1 Demography

Changes in demography influence quality management in the TCLF sector by affecting both the workforce and consumer expectations. An aging workforce increases the need for knowledge transfer, ergonomic support, and targeted training to maintain consistent quality, while younger generations bring different skill sets, digital competencies, and expectations regarding workplace culture and work-life balance, driving adaptations in how quality processes are designed and implemented. Migration and cross-border employment further diversify the workforce, introducing a wider range of cultural perspectives that may influence work practices and perceptions of quality. At the same time, shifting consumer demographics increase demand for more customized and functional products, leading quality management to place greater emphasis on performance, comfort, and compliance with regulatory and sustainability requirements across diverse user groups.

This particularly relates to Clauses 7.1.2 (People), 7.2 (Competence), 7.3 (Awareness), 7.4 (Communication), and 8.5.1 (Control of production and service provision) of ISO 9001.

3.2 Economic and Social Factors

Economic and social factors can significantly influence quality management (QM) in the TCLF sector, especially when production strategies shift due to cost, labour, or societal pressures. For example, rising labour and production costs in China have led many companies to relocate manufacturing to other countries, which introduces new challenges for QM: ensuring consistent product quality across different suppliers, adapting to varying labour skills, and maintaining process standards. Social factors, such as evolving labour regulations, employee expectations for safer working conditions, and increasing focus on sustainability, also shape how quality systems are designed and monitored. Companies must implement robust training, monitoring, and digital quality control systems to address these variations, while economic pressures push for cost efficiency without compromising product performance.

This particularly relates to Clauses 7.1 (Resources), 7.2 (Competence), 8.4 (Control of externally provided processes, products and services), and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

3.3 Qualification / Training / Knowledge

A declining interest among young people in the TCLF sector, combined with lower levels of qualifications, training, and industry knowledge, may lead to positions being filled by career changers or unskilled labour. This directly affects the rigor and consistency of quality management

execution, as employees may lack the specialized skills and understanding needed to maintain high standards. To mitigate this, companies will need to invest in targeted training, knowledge transfer programs, and digital support systems to ensure that quality processes are executed reliably despite workforce challenges.

This particularly relates to Clauses 7.1.2 (People), 7.2 (Competence), 7.3 (Awareness), and 7.5 (Documented information) of ISO 9001.

3.4 Markets and Consumers

Markets and consumers strongly shape quality management in the TCLF sector, as expectations for durability, comfort, sustainability, and design vary depending on how much people are willing to pay and the popularity of fast fashion trends. High-end or premium products demand stricter quality standards, while rapidly changing, trend-driven collections require agile, responsive quality processes to maintain consistency. Overall, QM must adapt to both consumer expectations and market dynamics to ensure satisfaction, compliance, and brand reputation.

This particularly relates to Clauses 5.1.2 (Customer focus), 8.2 (Requirements for products and services), 8.5.1 (Control of production and service provision), and 9.1.2 (Customer satisfaction) of ISO 9001.

3.5 Compliance

Compliance will remain a key factor in shaping quality management in the TCLF sector, as regulations demand strict adherence to product safety, labour, environmental, and sustainability standards. Although recent trends suggest a shift toward more lenient, industry-friendly regulations, standards remain high and the future level of regulatory strictness is uncertain. The automatic generation of reports from real-time data will make monitoring and documentation increasingly efficient and less time-consuming.

This particularly relates to Clauses 6.1 (Actions to address risks and opportunities), 8.2.2 (Determining the requirements for products and services), 8.6 (Release of products and services), and 9.1.1 (Monitoring, measurement, analysis and evaluation – general) of ISO 9001.

4 Digitalization in QM

4.1 New Era of Robots

The use of robots in the shoe industry is currently still limited, as many production steps remain highly manual due to the complexity of materials, shapes, and assembly processes. It is unlikely that this will change substantially in the next 5 years. However, should robotic systems become more common, the effects on quality management and quality management systems would be considerable. Increased automation could enhance process stability, reduce variability, and allow for more precise, repeatable operations. It would also enable comprehensive data collection across the production line, supporting predictive maintenance and early detection of potential issues. Overall, broader adoption of robotics would likely lead to more consistent product quality, improved traceability, and a more robust, efficient, and proactive QMS.

This particularly relates to Clauses 7.1.3 (Infrastructure), 7.1.4 (Environment for the operation of processes), 8.5.1 (Control of production and service provision), 8.5.6 (Control of changes), and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

4.2 Artificial Intelligence (AI)

In the future, artificial intelligence (AI) is poised to transform quality management systems by enabling more proactive, data-driven approaches. One of the most impactful applications is predictive maintenance, where AI algorithms analyse sensor data, equipment logs, and historical failure patterns to anticipate defects or malfunctions before they occur, reducing downtime and ensuring consistent product quality. Beyond predictive analytics, AI can significantly streamline the administrative side of QM systems, including the management of operational procedures, document control, and regulatory compliance. Routine tasks such as test planning, validation, and reporting can be automated or semi-automated, increasing efficiency, reducing human error, and freeing personnel to focus on higher-value activities. Additionally, AI-driven systems can assist in real-time validation and verification of processes, flag anomalies in testing data, and maintain comprehensive, organized records, creating a more agile, accurate, and scalable quality management environment.

This particularly relates to Clauses 7.1.3 (Infrastructure), 7.1.5 (Monitoring and measuring resources), 7.5 (Documented information), 8.5.1 (Control of production and service provision), 9.1 (Monitoring, measurement, analysis and evaluation), and 9.1.3 (Analysis and evaluation) of ISO 9001.

4.2.1 AI-Driven Predictive Maintenance in the TCLF Sector

Transforming Maintenance and Quality Management

Predictive maintenance is rapidly becoming one of the most impactful applications of artificial intelligence (AI) in the manufacturing industries. By combining IoT sensors, machine learning, and real-time data analytics, manufacturers can anticipate equipment failures before they occur—significantly reducing downtime, maintenance costs, and waste. Research shows potential downtime reductions of up to 45% and notable energy savings (35%) through smart monitoring

systems in the textile production⁴. This particularly relates to Clauses 7.1.3 (Infrastructure), 7.1.5 (Monitoring and measuring resources), 8.5.1 (Control of production and service provision), and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

From Reactive to Predictive

Traditional maintenance strategies—reactive (fixing after breakdown) and preventive (scheduled servicing) - are giving way to predictive maintenance. This advanced approach uses sensor data, signal processing, and machine learning models to estimate when a machine or component is likely to fail, enabling “just-in-time” interventions. Key benefits include:

- Optimised maintenance intervals
- Reduction of unnecessary maintenance work
- Improved spare parts management
- Extended service life of the systems
- Consistent product quality

Machine learning techniques trained on operational data from spinning, weaving, or knitting machines can classify equipment states, predict failure modes with high precision, and support intervention scheduling. Academic research reports classification accuracies above 90%⁵, while practical implementations in textile mills have improved mean time between failures by ~19% and reduced manual vibration monitoring by half—proving the economic and operational value of these systems⁶.

This particularly relates to Clauses 7.1.3 (Infrastructure), 7.1.5 (Monitoring and measuring resources), 8.5.1 (Control of production and service provision), 8.5.6 (Control of changes), and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

How Predictive Maintenance Works

Predictive maintenance lies between reactive and preventive strategies. It uses sensor data and machine learning to estimate when a component will fail and schedule maintenance just in time. The typical workflow includes:

1. Data Acquisition: Collect sensor data from looms, knitting machines, cutting presses, automated sewing machines, or moulding machines. Data types include vibration, temperature, motor current, pressure, speed, and environmental conditions.
2. Preprocessing: Clean and normalize raw data to remove noise (e.g., filtering vibration signals to isolate wear-related anomalies).
3. Feature Extraction: Use of condition indicators that change as systems degrade:
 - Textile: e.g. yarn tension variations, loom vibration amplitude, temperature fluctuations
 - Footwear: e.g. press force consistency, stitch quality deviations, mould surface temperature

⁴Kathirvel M., & Chandrasekaran M. (2025). Predictive Maintenance and Energy Optimization with AI-Driven IoT Framework in Textile Manufacturing Industry. *International Journal of Computational and Experimental Science and Engineering*, 11(2). <https://doi.org/10.22399/ijcesen.1584>

⁵Akyaz, Telat & Engin, Dilsad. (2024). Machine Learning-Based Predictive Maintenance System for Artificial Yarn Machines. *IEEE Access*. PP. 1-1. 10.1109/ACCESS.2024.3454548.

⁶Randjbaran, E., Khaksari, D., Ahmad Mehrabi, H., Zahari, R., Majid, D. L., Sultan, M. T., & Granhemat, M. (2025). Artificial Intelligence for Sustainable Textiles: A Review of Circular Economy Applications. *Textile Science & Research Journal*, 1(1).

4. Model Training: Train algorithms to detect anomalies, classify fault types (e.g., broken yarn, defective mould, misaligned stitch), and estimate Remaining Useful Life (RUL).
5. Deployment & Integration: Deploy models into monitoring systems (on-device or cloud) to evaluate incoming data and trigger alerts. Example: If vibration trends exceed thresholds, the system alerts maintenance teams to replace a loom bearing before failure.

What makes predictive maintenance powerful is its ability to predict failures, pinpoint emerging issues, and identify affected parts, enabling targeted and efficient maintenance planning.

Applications Across TCLF

While much of the current studies and implementations focus on textile machinery, similar principles apply to footwear manufacturing⁷. AI-enhanced maintenance and quality monitoring in cutting, moulding, and automated sewing systems ensure consistent stitching quality, press accuracy, and defect reduction. Beyond machinery, computer vision-based fabric and material inspection identifies subtle defects that human inspectors might miss, supporting consistent quality standards across batches.

Integrated predictive maintenance tools also enhance administrative functions—automating documentation, linking sensor data to validation records, and facilitating compliance reporting. As AI systems evolve, they are increasingly embedded in enterprise quality systems, helping TCLF manufacturers reduce waste, extend equipment life, improve product quality, and meet sustainability targets in a competitive global market.

Reports from the manufacturing industry demonstrate the practical value of this strategy. Implementations of AI-based predictive maintenance have produced significant performance gains⁸.

Many reports describing successful implementations of predictive maintenance do not disclose the names of the involved manufacturing companies, as most prefer to remain anonymous. This lack of transparency makes independent verification difficult.

The NGO Illinois Manufacturing Excellence Center (IMEC)⁹ reports a successful implementation at a manufacturer operating in the automotive components industry. Within the first six months, the manufacturer achieved several notable improvements:

- 40% reduction in downtime, as proactive issue identification eliminated unexpected machine failures.
- 30% decrease in maintenance costs, due to a shift from emergency repairs to planned maintenance.
- 20% increase in productivity, resulting from fewer operational interruptions.
- Extended equipment lifespan, enabled by early detection of wear and degradation.
- Improved product quality, as more stable machine performance reduced defect rates.
- Data-driven decision-making, with maintenance strategies based on real-time insights rather than assumptions.

⁷ Sudhakar, P. K., & Muthucumaraswamy, R. (2025). Optimizing energy, downtime, and throughput in footwear production through machine learning. *Scientific Reports*.

⁸ Randjbaran, E., Khaksari, D., Ahmad Mehrabi, H., Zahari, R., Majid, D. L., Sultan, M. T., & Granhemat, M. (2025). Artificial Intelligence for Sustainable Textiles: A Review of Circular Economy Applications. *Textile Science & Research Journal*, 1(1).

⁹ IMEC [Internet]. 2025 [cited 2025 Oct 16]. From Downtime to Uptime: Using AI for Predictive Maintenance in Manufacturing - IMEC Site. Available from: <https://www.imec.org/from-downtime-to-uptime-using-ai-for-predictive-maintenance-in-manufacturing/>

Similarly, Mutually Human, a digital engineering firm, reported a 32% reduction in unplanned downtime and an 18% reduction in maintenance costs during a 90-day pilot project with a global manufacturer using the Microsoft Fabric platform (Mutually Human, Predictive Maintenance with Microsoft Fabric: A Manufacturing Case Study)¹⁰.

Jaya Shree, one of India's leading linen and wool manufacturers, operates linen production facilities equipped with over 42,000 spindles and a variety of production machinery, including hackle, weaving and knitting machines, spinning lines, silver blending systems, dyeing machines and associated auxiliary equipment. To monitor the condition of this extensive machine base, the company has implemented SenseGrow, Inc.'s ioEYE Predict condition monitoring platform for critical components such as bearings, gearboxes and industrial fans. This allows emerging faults to be detected early and maintenance measures to be planned proactively, rather than reacting after failures occur. This has resulted in a 19% increase in overall equipment reliability, reflected in increased mean time between failures (MTBF) and higher machine availability¹¹.

Integration into ERP systems:

Today, several ERP systems already include predictive maintenance tools to help businesses optimize their equipment and asset management. These systems generally rely on a combination of IoT, machine learning, and data analytics to forecast maintenance needs. Some of the major ERP systems with this capability are: SAP S/4HANA, Microsoft Dynamics 365, Infor CloudSuite, Oracle ERP Cloud, IFS Applications and Sage X3.

4.3 Big Data

Big data will significantly influence quality management in the TCLF sector (Textiles, Clothing, Leather, Footwear) by shifting it from reactive control to predictive, data-driven quality assurance across the entire value chain.

Building on the previous section on AI-enabled predictive maintenance, big data plays a central role in extending these approaches to quality control. The large volumes of data generated through predictive maintenance systems—such as machine sensor data, operational parameters, and maintenance records—can be further analysed to identify patterns that directly affect product quality. By integrating these datasets into quality management processes, deviations can be detected earlier, root causes can be traced more effectively, and quality issues can be prevented before they occur. This creates a strong feedback loop between predictive maintenance and quality control, improving process stability, product consistency, and overall production performance.

This particularly relates to Clauses 4.4 (Quality management system and its processes), 7.1.5 (Monitoring and measuring resources), 7.5 (Documented information), 8.5.1 (Control of production and service provision), 9.1 (Monitoring, measurement, analysis and evaluation), and 10.2 (Nonconformity and corrective action) of ISO 9001.

¹⁰ Predictive Maintenance with Microsoft Fabric: A Manufacturing Case Study | Mutually Human. Available from: <https://www.mutuallyhuman.com/predictive-maintenance-with-microsoft-fabric-a-manufacturing-case-study/>

¹¹ Pratishtha Yadav. SenseGrow. 2024 [cited 2025 Oct 16]. Textile Industry Case Study for AI Driven Predictive Maintenance - SenseGrow. Available from: Textile Industry Case Study for AI Driven Predictive Maintenance - SenseGrow

4.4 3D Printing

The existing and future influence of 3D printing on quality management in the TCLF sector will most probably be limited. If any impact exists, it is actually the other way around: robust quality control systems and big data analysis are essential to ensure that 3D-printed products meet performance and consistency requirements. Data-driven monitoring of printing parameters, materials, and process conditions becomes critical to guarantee the reliability of each customised or functional part.

This particularly relates to Clauses 4.4 (Quality management system and its processes), 7.1.5 (Monitoring and measuring resources), 7.5 (Documented information), 8.5.1 (Control of production and service provision), and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

4.5 Combination of Digitalisation and Sciences

With increasing data-driven decision making, quality management in the TCLF sector is becoming more proactive and predictive rather than reactive. Insights from materials science provide a deeper understanding of fibres, leather, polymers, and composites, while digital simulations and testing allow these insights to be applied systematically. Together, they ensure that products consistently meet durability, comfort, and performance standards, shifting quality management from end-of-line inspection to an integrated, science- and data-based approach throughout the entire production process.

This particularly relates to Clauses 4.4 (Quality management system and its processes), 7.1.5 (Monitoring and measuring resources), 7.1.6 (Organizational knowledge), 8.5.1 (Control of production and service provision), 9.1 (Monitoring, measurement, analysis and evaluation), and 10.3 (Continual improvement) of ISO 9001.

4.6 Virtual and Augmented Reality

Virtual and augmented reality (VR/AR) can enhance quality management in the TCLF sector by improving training, inspection, and design validation. Operators can practice complex processes in a risk-free virtual environment, while AR can overlay inspection criteria or guide remote experts during quality checks. VR simulations of products and production lines help identify defects or process issues early, supporting more proactive and consistent quality control. While their overall impact is moderate, VR/AR provides targeted improvements in operator performance and early defect detection.

This particularly relates to Clauses 7.1.3 (Infrastructure), 7.1.4 (Environment for the operation of processes), 7.1.5 (Monitoring and measuring resources), 7.2 (Competence) and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

5 Sustainability in QM

Sustainability will increasingly influence quality management by extending its focus beyond product conformity to include environmental and social performance. This development is reflected in the joint communiqué published on 22 February 2024 by the IAF and the International Organization for Standardization (ISO), announcing Climate Action Amendments to new and existing ISO management system standards in support of the ISO London Declaration. The purpose of these amendments is to ensure that climate change is explicitly considered by organizations when evaluating the effectiveness of their management systems. Applicable to 31 management system standards under the High-Level Structure (HLS), including ISO 9001, ISO 14001, ISO 50001, ISO 27001, and ISO 4500, the changes are incorporated into Clause 4.1 (Understanding the organization and its context) and 4.2 (Understanding the needs and expectations of interested parties). These require organizations to assess whether climate change is a relevant issue and to recognize that interested parties may have climate-related requirements. Consequently, climate change must be evaluated alongside other internal and external factors and, where relevant, integrated into risk assessments, ensuring that climate considerations are systematically embedded in organizational decision-making and management system effectiveness.

Other particularly relevant clauses of ISO 9001 are Clauses 6.1 (Actions to address risks and opportunities), 8.1 (Operational planning and control), 9.1 (Monitoring, measurement, analysis and evaluation) and 10.3 (Continual improvement).

5.1 Green Awareness

The integration of eco-label requirements and rising consumer awareness will have a significant impact on quality management. Quality management systems will need to go beyond traditional measures of product conformity to ensure that materials, production processes, and finished products meet environmental, ethical, and sustainability standards specified by eco-labels. Increased consumer awareness amplifies the importance of consistent verification and traceability, as buyers expect proof of sustainable practices and responsible sourcing. This drives QM to become more holistic, data-driven, and transparent, linking environmental performance with traditional quality criteria such as durability, functionality, and safety, while also reinforcing brand reputation and consumer trust.

This particularly relates to Clauses 4.1 (Understanding the organization and its context), 4.2 (Understanding the needs and expectations of interested parties), 7.5 (Documented information), 8.2 (Requirements for products and services), 8.5.1 (Control of production and service provision), and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

5.2 Energy and Process Efficiency

Quality management and energy and process efficiency go hand in hand, creating a positive feedback loop where improvements in one area reinforce the other. Efficient, well-controlled processes lead to more consistent product quality and often ensure energy and resource optimization. This trend is not entirely new or solely driven by sustainability; rising energy costs make process efficiency an important economic priority as well. While regulatory frameworks and bodies of standardization increasingly require the integration of sustainability efforts into quality management systems, energy efficiency also delivers tangible cost savings. By linking quality and

efficiency, companies can achieve higher productivity, reduce environmental impact, and meet both economic and consumer expectations.

This particularly relates to Clauses 4.1 (Understanding the organization and its context), 6.1 (Actions to address risks and opportunities), 7.1.3 (Infrastructure), 8.5.1 (Control of production and service provision), 9.1 (Monitoring, measurement, analysis and evaluation), and 10.3 (Continual improvement) of ISO 9001.

5.3 Resource Efficiency & Sustainable Materials

As companies increasingly adopt circular economy principles and eco-friendly materials, quality management must ensure that products maintain consistent performance, durability, and safety even when using recycled, bio-based, or alternative fibres and polymers.

Often, these sustainable materials are newly developed or adapted for products that were not previously made from them, requiring innovative research to go hand in hand with tight quality control, chemical hazard testing, and evaluation of durability and functional performance.

Unlike established materials, which benefit from a wide range of suppliers and standardized quality assurance frameworks, new materials may be offered by only a few suppliers, creating both quality management and economic risks.

Supplier audits can also be challenging: for example, established standards such as those from the Leather Working Group support sustainability reporting and supply chain management for leather, but equivalent frameworks are often lacking for new materials. This makes it essential for QM to integrate robust monitoring, testing, and verification processes to ensure that sustainability goals do not compromise product quality or supply chain reliability.

This particularly relates to Clauses 4.1 (Understanding the organization and its context), 4.2 (Understanding the needs and expectations of interested parties), 6.1 (Actions to address risks and opportunities), 7.1.5 (Monitoring and measuring resources), 7.4 (Communication), 8.4 (Control of externally provided processes, products and services), 8.5.1 (Control of production and service provision), and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

5.4 Sustainable Design & Circular Economy

Building on the section above on sustainable materials, the challenges associated with sustainable design and circular economy approaches are largely the same. Ensuring consistent performance, durability, and safety while enabling repair, reuse, and recyclability requires robust traceability, testing, and supplier management, reinforcing the need for a holistic and preventive quality management approach that integrates environmental and functional requirements.

A key enabler in this context is the Product Passport (often referred to as a Digital Product Passport, DPP). The product passport is a digital information system that compiles and stores standardized product-related data across the entire lifecycle, including material composition, origin, manufacturing conditions, repair instructions, and end-of-life options. Its main purpose is to increase transparency, traceability, and circularity, enabling stakeholders such as manufacturers, recyclers, and consumers to make informed decisions and to support reuse, repair, and recycling processes. In doing so, it also strengthens supply chain accountability and supports the verification of sustainability claims and regulatory compliance.

This particularly relates to Clauses 4.1 (Understanding the organization and its context), 4.2 (Understanding the needs and expectations of interested parties), 6.1 (Actions to address risks and opportunities), 8.4 (Control of externally provided processes, products and services), 8.5.1 (Control of production and service provision), 8.5.2 (Identification and traceability), 9.1 (Monitoring, measurement, analysis and evaluation), and 10.2 (Nonconformity and corrective action) of ISO 9001.

5.5 Chemical Safety

Chemical safety has long been a component of quality management in manufacturing, with regulations such as REACH requiring systematic chemical analysis to ensure products are free from hazardous substances.

PFAS (per- and polyfluoroalkyl substances) provide a clear example of not only why chemical safety is critical but also how it is an ever-evolving topic. Widely used in textiles and footwear as water- and stain-repellent finishes, their widespread application began decades ago, yet their harmful effects on human health and the environment were only acknowledged relatively recently. These “forever chemicals” are highly persistent, bioaccumulative, and linked to endocrine disruption, immune system impairment, and certain cancers, while also contaminating soil and water globally. The newly published PFAS norm EN 17681-1:2025 establishes standardized testing and limits for PFAS in textiles and footwear, reinforcing the importance of rigorous chemical monitoring, supplier audits, and traceability. The PFAS example demonstrates that chemicals once considered safe can later reveal serious risks, highlighting the need for adaptations in quality management.

This particularly relates to Clauses 6.1 (Actions to address risks and opportunities), 7.1.5 (Monitoring and measuring resources), 7.5 (Documented information), 8.2 (Requirements for products and services), 8.4 (Control of externally provided processes, products and services), 8.5.1 (Control of production and service provision), 8.5.2 (Identification and traceability), 8.6 (Release of products and services), and 9.1 (Monitoring, measurement, analysis and evaluation) of ISO 9001.

5.6 Social Responsibility

Social responsibility will continue to shape quality management in the future, even though many regulations in this area are already well established. Its influence is likely to deepen through increased transparency and traceability across supply chains, potentially extending to production sites and working conditions at the level of individual factories or processes. Quality management systems may therefore integrate social criteria more closely, such as fair labour practices, health and safety, and compliance verification, alongside traditional quality requirements. At the same time, this development requires a careful balance: tools used for transparency and traceability can support the protection and well-being of the workforce, but they also raise concerns about excessive control or surveillance of individual performance. Managing this balance responsibly will be essential to ensure that QM supports social responsibility without undermining trust, privacy, or workers’ rights.

This particularly relates to Clauses 4.1 (Understanding the organization and its context), 4.2 (Understanding the needs and expectations of interested parties), 6.1 (Actions to address risks and opportunities), 7.1.4 (Environment for the operation of processes), 7.5 (Documented information), 8.4 (Control of externally provided processes, products and services), 8.5.1 (Control of production and service provision), 9.1 (Monitoring, measurement, analysis and evaluation), and 10.2 (Nonconformity and corrective action) of ISO 9001.

6 Case study and Project Work

6.1 Case Study - Assessment of TPR Outsoles

6.1.1 Background

As part of this case study, we examined thermoplastic rubber (TPR) outsoles from the perspectives of production, quality, chemical compliance, social compliance and future circularity.

The purpose of the study was to understand how TPR outsoles are manufactured, which quality requirements they must fulfil, and what factors need to be considered when developing more circular outsole solutions in the future.

TPR is widely used in footwear because it offers flexibility, grip, durability and good moulding possibilities. At the same time, the final performance of the outsole depends strongly on the material formulation, production controls and the way the outsole is attached to the shoe.

6.1.2 Production Process of TPR Outsoles

During the case study, we reviewed the main production steps used for TPR outsoles.

The process begins with the selection of raw materials. These normally include thermoplastic polymers, rubber-based components, oils, fillers, pigments, stabilisers and other additives. The exact formulation determines the hardness, flexibility, colour, grip and durability of the outsole.

The materials are mixed and compounded under controlled temperature conditions to create a uniform TPR mixture. The compounded material is usually processed into pellets or granules.

These granules are then heated until they become soft and flowable. The material is injected into a mould using an injection-moulding machine. The mould determines the shape, tread pattern, dimensions and surface design of the outsole.

After moulding, the outsole is cooled and removed from the mould. Excess material is trimmed, and the finished outsole is checked for defects such as air bubbles, deformation, cracks, colour differences or incomplete moulding.

Depending on the shoe design, the outsole may also undergo surface treatment, printing, colouring or preparation for bonding with the upper.

The production process showed that consistent material formulation, temperature control, mould condition, cooling time and contamination control are essential for achieving stable outsole quality.

6.1.3 Quality Assessment

The case study also reviewed the most important quality characteristics of a TPR outsole.

The main quality areas included:

- abrasion resistance;
- flex resistance;
- slip resistance on wet and dry surfaces;
- hardness and flexibility;
- tear strength;
- dimensional stability;
- resistance to heat, cold and ageing;
- outsole thickness and weight;
- colour and visual consistency;
- bonding strength between the outsole and the upper.

The assessment showed that laboratory performance alone is not sufficient. The outsole must also support the fitting, comfort, flexibility, balance and overall performance of the complete shoe.

Quality Management therefore has an important role in defining minimum standards and evaluating whether changes in material composition affect the final product.

6.1.4 Chemical Compliance

The TPR outsole was also considered from a chemical-compliance perspective.

The material must comply with applicable legal requirements, company standards and the relevant Restricted Substances List. The CADS RSL can be used as an important footwear-industry reference.

Particular attention should be given to chemicals that may be present in the TPR compound, pigments, plasticisers, fillers, adhesives and other additives.

The case study highlighted the importance of reliable supplier information, clear material specifications and risk-based chemical testing.

6.1.5 Social-Compliance Perspective

The production of TPR outsoles should also meet recognised social-compliance standards, including the principles of amfori BSCI.

- The assessment should cover:
- occupational health and safety;
- safe handling and storage of chemicals;
- personal protective equipment;
- working hours and wages;
- prevention of forced labour and child labour;
- worker training;
- grievance mechanisms;
- safe use of production machinery;
- responsible waste handling.

The case study showed that product quality and circularity must be supported by safe and responsible production conditions.

6.1.6 Circularity Assessment

The study also considered the potential circularity of TPR outsoles.

Because TPR is a thermoplastic material, production scraps may potentially be collected, ground and reprocessed. Recycled TPR may also be introduced into future formulations.

However, the study found that the circularity potential depends on several factors, including:

- the exact TPR formulation;
- the number and type of additives;
- contamination from adhesives or other shoe components;
- the percentage of recycled material;
- separation of the outsole from the upper;
- availability of collection and recycling systems;
- whether recycled TPR can still meet the required quality standards.

The study also showed that strong permanent bonding can make separation and recycling more difficult. Therefore, the outsole construction and bonding method are important for future circular shoe concepts.

Connection to the Complete Shoe

Although the main focus was the TPR outsole, the case study also considered its role within the complete shoe.

A full-shoe assessment should include:

- design and CAD specifications;
- upper, lining, insole and outsole materials;
- fitting and comfort;
- size consistency;
- physical and mechanical quality tests;
- restricted-substance compliance;
- bonding and construction quality;
- durability;
- social-compliance requirements;
- repair, separation and recycling possibilities.

The study confirmed that a recyclable outsole alone does not make the complete shoe circular. Circularity must be considered through the full shoe design and construction.

6.1.7 Stakeholder Input

The case study requires input from several departments and industry experts.

Quality Management provides the technical and performance perspective. Product Development assesses design, fitting, construction and commercial feasibility. Sustainability and Compliance teams review chemical requirements, traceability, social compliance and circularity.

6.1.8 Conclusion

The case study showed that TPR outsoles offer good functional performance and may provide opportunities for future circular solutions.

However, circularity depends on maintaining consistent quality, understanding the full material composition, ensuring chemical and social compliance, improving separability and confirming that recycled material can meet the same performance standards as virgin material.

The assessment therefore concluded that a future circular TPR outsole must remain durable, safe, comfortable, compliant and suitable for industrial-scale production.

6.2 Structure of the project work

6.2.1 Quality Management & QMS in the Footwear Industry (PDCA-Based Project)

1. Assignment Title

Design and Improvement of a Quality Management System for a Footwear Manufacturing Process Using the PDCA Cycle.

2. Assignment Purpose

This project assesses your ability to apply Quality Management (QM) principles and the PDCA cycle to a real industrial context in the footwear industry, focusing on process control, quality assurance, and continuous improvement. Students will analyse, design, and improve a footwear production process by applying QM principles and the PDCA cycle to ensure product quality, process control, and continuous improvement.

3. Task Description

You will analyse and design (part of) a Quality Management System (QMS) for footwear manufacturing (e.g., running shoes, safety shoes, casual footwear) and apply the PDCA cycle to improve quality performance. Focus on one of the key processes.

Your work must include:

- Process mapping of the footwear production value chain and selection of one key process to focus on
- Definition of quality requirements and KPIs for the selected key process
- Application of PDCA (Plan–Do–Check–Act) to the key process
- Identification of issues and improvement actions
- Documentation of results and recommendations

4. Deliverables

- Process map of footwear production
- Defined QMS structure (roles, procedures, controls)
- KPI dashboard or performance summary
- PDCA cycle documentation
- Final improvement recommendations

5. Expected Learning Outcomes

Students will be able to:

- Understand QM principles in a real industrial context
- Apply QMS principles to key footwear production processes
- Use PDCA for continuous improvement
- Identify and solve quality-related production issues
- Link process control with customer satisfaction and product performance

6. Add-on challenge (future-oriented extension)

To increase the analytical depth of your work, you must **critically consider at least one future development** and evaluate its impact on your developed quality management system and PDCA:

Choose **one** of the following themes and its subtopics:

- Digitalisation
- Sustainability
- Globalisation

Your analysis should explain:

- what new risks or opportunities it creates
- how these predicted developments are influencing your developed QMS and PDCA application.

7. Grading Criteria

Criterion	Description	Points
Basic - (Total: 100 Points)		
Process Understanding	Clear mapping of footwear production and process logic	15
Application of PDCA	Correct and structured use of PDCA cycle	20
Quality Management Concepts	Use of QM/QMS principles, KPIs, and standards	15
Analysis & Problem Identification	Ability to identify issues and causes	15
Improvement Proposals	Quality and feasibility of corrective actions	15
Clarity & Structure	Logical structure, readability, and organization	10
Presentation Quality	Visuals (process map, tables, clarity), Oral presentation	10
Add-on challenge (future-oriented extension) (Additional: 20 Points)		
Risks and opportunities	Evaluation of risks and opportunities due to predicted future developments	10
Considerations for QMS and PDCA	Necessary considerations for QMS and PDCA due to predicted future developments	10

Tab. 1: Grading Criteria

7 List of Figures

Fig. 1: Process 8

Fig. 2 : Operating Procedure ©CTCP 8

Fig. 3: Example of the chain of Processes in a company ©CTCP 9

Fig. 4: PDCA Cycle ©PFI 10

Tab. 1: Grading Criteria 26

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