TOOLS, METHODS AND TECHNIQUES USED IN QUALITY MANAGEMENT

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ABSTRACT: This paper examines the main tools, methods, and standards used in contemporary quality management, with a focus on their role in controlling variation, supporting decision-making, and improving organizational performance. It begins with the seven classic quality tools, which provide a practical foundation for data collection, visualization, prioritization, and process monitoring. Their continued relevance is discussed in relation to knowledge-based and complex organizational settings. The analysis then addresses advanced optimization approaches, including the Taguchi method and factorial experimentation, highlighting their contribution to robustness and cost-efficient experimentation. Six Sigma is presented as a structured, data-driven methodology centered on variation reduction and process capability, with attention to its integration with Lean principles and digital technologies. The paper also explores quality standards and frameworks, specifically ISO 9001 and excellence models such as EFQM, emphasizing their complementary roles in process governance and organizational maturity assessment. Finally, modern preventive and analytical techniques, including SPC, FMEA, and QFD, are discussed as an integrated system that links customer requirements, risk prevention, and process control. Together, these instruments form a coherent framework for managing quality in dynamic and technology-driven environments.
KEYWORDS: quality management, classic quality tools, process variation, Taguchi method, Six Sigma, ISO 9001, EFQM, Statistical Process Control (SPC), Failure Mode and Effects Analysis (FMEA), Quality Function Deployment (QFD), process optimization, data-driven decision-making

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1. INTRODUCTION

Quality management has evolved from a narrow focus on inspection and defect detection into a comprehensive, data-based approach to managing processes and organizational performance. In contemporary environments shaped by technological change, competitive pressure, and increasing process complexity, quality is closely linked to the ability to understand variation, control risks, and make informed decisions. As a result, organizations rely on a structured set of tools, methods, and standards that support both operational control and continuous improvement.

This paper addresses the main instruments used in quality management, ranging from the classic quality tools to modern statistical and preventive techniques. It also examines advanced optimization methods, such as the Taguchi approach and Six Sigma, alongside internationally recognized standards and excellence models. By presenting these elements in an integrated manner, the paper aims to clarify how different approaches contribute to process stability, robustness, and organizational maturity, particularly in knowledge-based and data-intensive contexts

2. THE SEVEN CLASSIC TOOLS

The seven classic quality tools were developed to support process analysis and to make quality management accessible across an organization. They emerged when organizations began to acknowledge process variability and the need for systematic control. Their adoption reshaped the understanding of responsibility for quality. Quality stopped being a strictly technical domain and became part of everyday practice, supported by straightforward methods that are easy to apply. Recent studies show that these tools are widely used in industry, healthcare, services, and the public sector because they support data-based decision-making. [1]

All these tools are grounded in a shared principle: every process exhibits variation, and understanding that variation is essential for control. This principle underlies all major quality management approaches, from inferential statistics to TQM, Kaizen, and Lean Six Sigma. The classic tools provide a practical way to observe processes and turn raw data into useful information. Their simplicity is intentional, since more advanced techniques rely on a solid foundational understanding.

Any quality initiative starts with structured data observation, and the check sheet plays a central role at this stage. It enables systematic data collection on defects, deviations, delays, or other relevant characteristics. The way data are gathered reflects an organization's level of operational discipline. Organized data collection supports an accurate view of reality and forms the basis for subsequent analysis. [2]

Collected data often vary due to time, operators, equipment, or contextual factors. Stratification separates data according to these variables and helps

reveal patterns that remain hidden in aggregated analyses. In complex organizations, where processes depend on many interacting factors, stratification reduces the risk of misleading interpretations and clarifies underlying structures. [1]
Once stratified, data can be visualized using histograms. A histogram shows how values are distributed and highlights deviations, unusual variation, or shifts that affect process stability. This type of visualization supports early problem detection that may not emerge from basic descriptive statistics. In practice, histograms are diagnostic tools that guide further investigation.
Visual insights allow the next step: prioritization. The Pareto chart highlights the causes that have the greatest impact on a process. In many cases, a limited number of causes account for a large share of effects. This tool supports efficient resource allocation and helps organizations avoid scattered or purely reactive actions. [2]
After identifying key problems, attention turns to cause analysis. The Ishikawa diagram organizes potential causes into structured categories, supporting focused technical discussion and reducing reliance on superficial explanations. In knowledge-based organizations, where many issues stem from information flow, procedures, or cognitive factors, this structure helps clarify assumptions and supports rigorous analysis. [1]
Relationships between variables are examined using scatter diagrams. These diagrams indicate possible correlations and trends. While they do not establish causality, they provide direction for deeper analysis, especially in processes influenced by multiple factors.
After causes and relationships are examined, the process must be monitored over time. Control charts assess process stability and distinguish between natural variation and variation caused by specific factors. This distinction helps avoid unnecessary interventions and prevents genuine issues from being overlooked. Control charts function as preventive tools for continuous process monitoring. [2]
The classic tools are most effective when used together. They form a logical sequence: the check sheet gathers data, stratification organizes them, the histogram visualizes them, the Pareto chart sets priorities, the Ishikawa diagram analyzes causes, the scatter diagram explores relationships, and the control chart monitors stability. Together, they provide a coherent problem-solving framework and encourage analytical thinking across the organization.
Research indicates that organizations that use these tools consistently develop stronger quality cultures. The tools support clearer communication between teams, reduce informational barriers, and improve collaboration. Their simplicity creates a shared language for specialists and non-specialists, narrowing hierarchical gaps and lowering resistance to data analysis. [1]

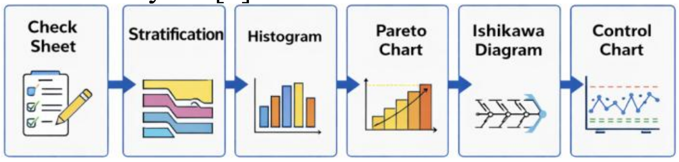

Figure 1. Logic Flow of the 7 Quality Tools

These tools also prepare organizations for more advanced methods. Techniques such as Design of Experiments (DOE) or advanced Statistical Process Control require disciplined data collection and interpretation. International studies show that organizations that consistently apply the classic tools achieve stronger results in Lean Six Sigma projects, cost reduction, and customer satisfaction. [2]
In knowledge-based organizations, their relevance is even clearer. Cognitive processes are inherently variable, and outcomes depend on intangible factors such as information clarity, cognitive load, and communication quality. The classic tools help make these aspects visible. For example, the Ishikawa diagram can highlight information distribution issues, check sheets can quantify communication problems, and control charts can reveal periods of overload or workflow disruption.

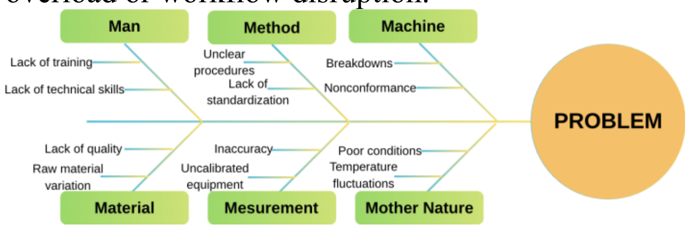

Figure 2. Ishikawa Diagram Model

The value of the classic tools lies in their ability to structure data and clarify processes. Applied consistently, they support a data-oriented organizational culture grounded in analysis and operational discipline. As processes grow more complex, these tools remain a reliable foundation for understanding and improvement.

3. THE TAGUCHI METOD AND FACTORIAL EXPERIMENS IN PROCESS OPTIMIZATION

The Taguchi method plays an important role in industrial process optimization by combining experimental efficiency with a focus on variation control. Its core principle is the design of robust products and processes that remain stable despite unavoidable variation in environment, materials, or equipment. This focus distinguishes it from statistical methods that emphasize maximizing average performance alone.

Today, the Taguchi method is applied in areas such as polymer synthesis, composite materials, functional property optimization, and parameter tuning in thermomechanical processes. Recent research confirms its usefulness in experiments that assess both performance and result consistency. [3]
Robustness is based on the idea that every process is affected by noise factors arising from natural variability, including material inconsistencies, environmental fluctuations, and batch differences. Rather than attempting to eliminate these disturbances, the Taguchi method evaluates how processes can remain stable despite them. Optimization therefore targets consistent performance under real operating conditions, not peak performance under ideal ones. [4]
To implement these principles, the method uses orthogonal arrays, which allow multiple factors to be studied with a limited number of experimental runs. Arrays such as L9, L16, and L27 are commonly used, each suited to different process structures. L9 is often applied to three factors at three levels, while L27 suits more complex systems, such as polymer formulations with varying nanofiller or modifier. [5] A key advantage is the independent estimation of main effects, which simplifies interpretation.

EXPERIMENT	FACTOR A	FACTOR B	FACTOR C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Figure 3. Taguchi Method. L9 Array

Another defining element is the signal-to-noise (S/N) ratio, which combines response mean and variability. The S/N ratio identifies factor levels that produce stable responses, depending on whether the objective is to maximize, minimize, or reach a target value. In technological processes where variability affects quality even when averages appear acceptable, S/N analysis supports reduced sensitivity to fluctuations. [3]
The robustness achieved through the Taguchi method results from an experimental structure designed to keep responses within acceptable limits under varying conditions. In reliability-focused industries, this approach helps identify factor combinations that maintain stable properties. Studies in composite materials show that the method can define temperature, pressure, and composition levels that preserve mechanical and functional consistency.[4]
A further advantage is reduced experimental cost. Orthogonal arrays limit the number of required combinations, saving time, energy, and materials. This benefit is especially relevant in polymer synthesis, where sample characterization can be expensive. Recent research shows that orthogonal designs provide sufficiently clear experimental models to guide later optimization steps. [6]
The method also shifts experimental thinking toward controllable factors. Instead of trying to eliminate noise, attention focuses on adjusting controllable parameters so that the process becomes less sensitive to disturbances. This approach is useful for sensitive materials such as biodegradable polymers or hybrid composites.[3]
The Taguchi method does have limitations. One frequently discussed issue is its reduced ability to detect complex factor interactions, particularly in designs with few runs. In systems with strong interactions, additional experiments or complementary methods are needed. Even so, research indicates that the method remains effective when combined with other statistical techniques. [5]
From an epistemological perspective, the Taguchi method is among the more accessible optimization approaches, since it does not require advanced statistical modeling. Its accessibility makes it suitable for organizations with limited statistical expertise and for those seeking clearer experimental structure. By reframing variation from something to be eliminated to something to be managed through robustness, the method has influenced many modern experimental design techniques. [6]

4. SIX SIGMA: A DATA-DRIVEN APPROACH TO VARIATION REDUCTION

Six Sigma is a modern quality management methodology centered on statistical control and variation reduction. Its basic assumption is that performance depends on process stability, which can only be achieved through structured, data-based methods. Originally developed at Motorola and later adopted by organizations such as General Electric, Six Sigma has become a reference point for defect reduction and process improvement. [7]
The concept of "six sigma" is defined mathematically by comparing process variation with specification limits. A process operating at the Six Sigma level produces fewer than 3.4 defects per million opportunities (DPMO), assuming a normal distribution and a 1.5 sigma long-term shift. This

framework supports realistic long-term process evaluation. [8]
Six Sigma emphasizes measuring and controlling variation rather than simply counting defects. Capability indices such as Cp and Cpk assess both theoretical potential and the alignment of the process mean with specification limits. This approach shifts focus from final inspection to stable, predictable processes. [8]
The DMAIC structure (Define, Measure, Analyze, Improve, Control) provides the methodological backbone for analysis and optimization. It ensures repeatability and consistency across industries and process types. [9]
DPMO serves as a standardized performance indicator for processes with different defect opportunities, enabling detailed comparison and prioritization of improvement efforts. [8]
Six Sigma relies heavily on capability analysis tools, including histograms, capability studies, and control charts, to detect deviations before they escalate into operational problems. Stable processes are considered essential for sustainable improvement. [9]

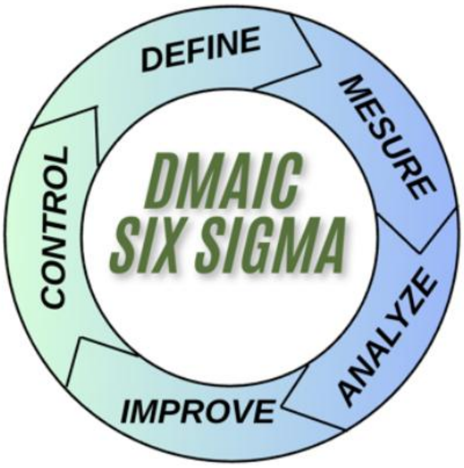

Figure 4. DMAIC Structure

Implementation is supported by a dedicated organizational structure with roles such as Green Belts, Black Belts, and Master Black Belts. These roles foster analytical competence and reinforce accountability. [8]
Six Sigma is applied beyond manufacturing, including services, healthcare, public administration, and education. In these contexts, reducing variation in human-centered or information-based processes directly affects reliability and cycle time.
Integration with Lean principles has led to Lean Six Sigma, which combines variation reduction with waste elimination. Recent studies show that this combination improves industrial efficiency and resource use. [10]
Digital transformation further expands Six Sigma's scope. Big data, machine learning, and predictive analytics enable real-time pattern detection and process adjustment within Industry 4.0 environments. [9]
Six Sigma also supports sustainability goals. Projects targeting energy use, resource optimization, and waste reduction show its relevance for environmental performance, including applications in the food industry. [10]
The methodology has limits. Highly dynamic environments may resist strict DMAIC application, and training and infrastructure costs can challenge smaller organizations. Technological advances, however, reduce these barriers through automated data collection and real-time monitoring. [8]

5. QUALITY STANDARDS: ISO 9001 AND EXCELLENCE MODELS

Quality standards help organizations structure processes, define responsibilities, and maintain operational stability. In competitive and uncertain environments, quality becomes part of governance and evaluation, not just a technical concern. ISO 9001 and excellence models such as EFQM offer complementary frameworks that combine normative requirements with organizational development perspectives. [11]
ISO 9001 is the most widely used quality management standard, applied across industry, services, public institutions, and NGOs. Its strength lies in providing a process architecture adaptable to different contexts. It is based on principles such as customer focus, leadership, employee involvement, process orientation, continuous improvement, data-based decision-making, and relationship management.
Operationally, ISO 9001 defines how processes are identified, documented, monitored, and reviewed. It specifies minimum requirements rather than prescribing detailed practices. Research shows that implementation clarifies responsibilities, reduces uncertainty, and strengthens organizational credibility through alignment with international norms.
A core principle is the use of objective evidence in decision-making. Process documentation, data monitoring, and periodic reviews support internal control and managerial accountability, particularly in public institutions where traceability is essential.
ISO 9001 represents a foundational level of organizational maturity, focused mainly on compliance. Organizations seeking further development often turn to excellence models such as EFQM, which assess leadership, strategy, culture, innovation, human capital management, and societal impact. [11]

The two frameworks complement each other. ISO provides process structure and audit criteria, while EFQM offers a strategic view of value creation and adaptation. ISO supports operational foundations, while EFQM evaluates broader organizational maturity.

Both rely on continuous improvement. ISO uses the Plan-Do-Check-Act cycle, while EFQM emphasizes learning, adaptability, and innovation. In knowledge-based organizations, EFQM is particularly useful for assessing intangible dimensions such as culture and internal climate. [11]

In practice, ISO functions as a governance mechanism and EFQM as a maturity assessment tool. ISO adoption often precedes the implementation of more complex models like EFQM.

EFQM extends ISO through a systemic view of performance, examining links between leadership, strategy, processes, and results, with strong attention to stakeholders and social impact. [11]

Unlike ISO standards, which regulate processes, EFQM addresses aspects that cannot be standardized, such as leadership style, culture, and adaptability. Its effectiveness depends on organizational maturity and the existence of a solid process infrastructure.

Both ISO 9001 and excellence models support external legitimacy. In environments that demand transparency and accountability, they demonstrate that organizations monitor processes and accept regular evaluation.

6. MODERN ANALYSIS AND PREVENTION TECHNIQUES: SPC, FMEA, QFD

In contemporary industrial and organizational settings shaped by rapid technological change and complex processes, quality is defined by process maturity, variation control, risk prevention, and the translation of customer requirements into measurable technical criteria. Modern techniques such as Statistical Process Control (SPC), Failure Mode and Effects Analysis (FMEA), and Quality Function Deployment (QFD) form a core toolkit for quality management.

SPC analyzes process variation using real data and distinguishes between common-cause and special-cause variation. Special causes signal disturbances that require intervention to prevent capability loss or defects. Research shows that SPC improves stability and supports data-based decisions, shifting attention from final inspection to continuous control. [1]

Control charts are central to SPC, visualizing process behavior and revealing deviations beyond natural limits. Pattern interpretation helps detect issues early. Capability indices Cp and Cpk assess alignment with technical specifications. SPC is widely used where small deviations have significant impact, such as precision manufacturing and automated processes.

Integration with Industry 4.0 enables real-time data collection and predictive analysis, transforming SPC into a continuous feedback system.

FMEA evaluates risks associated with processes, products, or systems by identifying potential failure modes, their causes, and their effects. It is widely used in sensitive industries such as automotive, electronics, and pharmaceuticals.

Risk evaluation relies on the Risk Priority Number (RPN), calculated from severity, occurrence, and detectability. RPN supports pragmatic risk prioritization. Continuous updates are necessary as equipment, materials, or conditions change.

QFD translates customer requirements into technical product or process characteristics. While SPC controls processes and FMEA assesses risks, QFD clarifies how design should meet customer expectations. It supports customer-focused development by identifying explicit and implicit requirements and setting technical priorities.

The House of Quality matrix links customer needs to technical characteristics, improving cross-functional communication and reducing development time.

Together, SPC, FMEA, and QFD form an integrated quality management system. QFD defines requirements, FMEA evaluates associated risks, and SPC maintains process stability, supporting consistent quality from design through production. [1]

Digitalization expands their capabilities. SPC integrates real-time analytics, FMEA connects with simulation tools, and QFD draws on digital data about customer behavior.

7. CONCLUSIONS

The analysis confirms that Total Quality Management, Lean Management, and Kaizen function most effectively when they are treated as interconnected elements of a single improvement system. Each philosophy addresses a different layer of organizational reality. TQM establishes direction, supports consistency, and anchors quality in leadership and culture. Lean improves process efficiency by reducing waste and clarifying value flows. Kaizen ensures continuity by embedding improvement into daily work through employee participation. Their integration produces effects that extend beyond operational efficiency. Lean initiatives gain stability when supported by the cultural and strategic framework of TQM, while Kaizen facilitates acceptance of change and sustained engagement at the operational level. Together, these approaches contribute to process stability, reduced variability, and improved performance over time. In knowledge-based organizations, this synergy is particularly relevant. Managing information flows, reducing cognitive overload, and supporting incremental innovation require more than technical solutions. The combined TQM–Lean–Kaizen framework supports these needs by aligning managerial structures, processes, and learning practices. Overall, the findings suggest that durable performance improvements depend less on the adoption of individual techniques and more on the coherence between strategy, processes, and people. Viewed in this way, TQM, Lean, and Kaizen represent not separate methodologies, but a shared way of thinking about organizational development and continuous improvement.

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