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QUALITY PRINCIPLES, TOOLS, TECHNIQUES AND METHODOLOGIES SHOULD REMAIN INEVITABLE PART OF DIGITAL QUALITY MANAGEMENT

Cvetanka Velkoska, Hannelie Nel, page 47-71

ABSTRACT

The digital transformation driven by Industry 4.0 has significantly reshaped quality management practices, leading to the emergence of Digital and Intelligent Quality Management (Quality 4.0). Despite the adoption of advanced technologies enabling automation, real-time monitoring, and data-driven decision-making, the role of traditional quality principles, tools, techniques, and methodologies remains insufficiently examined. This paper aims to examine whether established quality management instruments should remain an inevitable component of digital quality management systems. The study applies a mixed research approach combining a systematic literature review with an empirical case study conducted in automotive manufacturing companies in North Macedonia. The literature review analyzes the evolution of quality management principles and systematizes quality tools, techniques, and methodologies within the Quality 4.0 context. The empirical data was collected through a structured survey examining the frequency and purpose of applying quality management instruments. The results confirm that digital technologies enhance rather than replace established quality methodologies. The study concludes that quality principles, tools, techniques, and methodologies must be systematically integrated into digital environments to ensure effective, sustainable, and human-centric quality management in the Quality 4.0 era.

Keywords: Quality management, Quality tools, Quality techniques, Quality methodologies, Digital quality management.

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1. INTRODUCTION

In the field of quality management, four distinct paradigms have been identified: the empirical, the reference, the reflective, and the emergence paradigm. Among these, the emergence paradigm remains the least developed conceptually, yet it holds significant promise for preventing the failure of quality management initiatives. This is because quality is inherently temporal and can only be defined intersubjectively within specific contexts. The emergence paradigm is particularly relevant in today's era of rapid and continuous change, as it emphasizes the dynamic interaction between quality systems and their environments (van Kemenade & Hardjono, 2019).

As Thomas Kuhn articulated in The Structure of Scientific Revolutions (1962), transformative change occurs when existing practices no longer align with the demands of the present environment. In the early 21st century, this phase has been characterized by the increasing influence of advanced technology on quality practice. Measurement systems now generate vast quantities of data, automation continues to proliferate, and systems thinking has become indispensable. We are currently experiencing this transition, only beginning to understand its long-term implications for quality management. As Kuhn suggested, this necessitates ongoing enhancements to quality management frameworks. Thus, the evolution of quality management is a continuing narrative shaped by a constantly changing world (Antony et al., 2022).

According to Velkoska (2024) the historical development of quality management can be traced through eight phases corresponding to five generations of quality evolution: Quality 1.0 (Inspection, Testing, and Quality Control), Quality 1.0 (Quality Assurance), Quality 3.0 (Total Quality Control and Total Quality Management), Quality 4.0 (Digital and Intelligent Quality Management), and the anticipated Quality 5.0 (Societal Quality Management). In the context of Industry 4.0, the hallmarks of Quality 4.0 include the automation of processes and systems, the digitalization of data analytics, and the integration of data, information, and knowledge across organizational functions.

The primary technologies and tools driving Industry 4.0 are extensive and transformative, including, but not limited to, the Internet of Things, Internet of Services, Cloud Computing, Radio Frequency Identification, Big Data Analytics, Data Mining and Real-time Decision Systems, Digital Twins, Virtual and Augmented Reality, Autonomous Robotics, Cyber-

Physical Systems, Blockchain, and Machine-to-Machine communication (Klaput et al., 2023).

Digital and Intelligent Quality Management encompass the use of advanced computational systems, software, and analytical tools to support the design, implementation, monitoring, and evaluation of quality-related processes. These digital technologies streamline data collection, automate analytical procedures, enhance accuracy, facilitate collaboration, and enable the real-time execution of quality control and assurance activities (Alrae, 2024). Specifically:

- ❖ Automation of quality processes enables comprehensive data acquisition, analysis, reporting, and informed decision-making while reducing manual workload, limiting human error, and ensuring consistent application of quality practices.
- ❖ Real-time monitoring and control of quality parameters allow organizations to continuously track performance, rapidly detect deviations or nonconformities, and initiate corrective actions before quality issues escalate, thereby improving overall product and service outcomes.
- ❖ Advanced data analysis capabilities empower organizations to derive actionable insights from large volumes of data. These capabilities support statistical evaluation, trend visualization, anomaly detection, and generation of comprehensive quality reports — all of which are critical for proactive decision-making and ongoing quality improvement.

Accordingly, this study seeks to motivate further scholarly inquiry into the application of quality tools and techniques within digital contexts. The paper initially examines how established quality principles, tools, techniques and methodologies perform and add value in the era of Industry 4.0 and Quality 4.0. To achieve this, the research encompasses a literature review followed by an empirical case study analysis. The study focuses on the following research objectives: RO1: To prepare an overview of previously known research tools, techniques and methodologies in the field of quality management. RO2: What is the new perspective within the Quality Management Principles? RO3: To what extent has scientific literature investigated the application of quality tools and methods? RO4: Are tools, methods and methodologies starting to be integrated in the context of Industry 4.0 and digital quality management?

RO5: Is a comparative analysis of research results on the application of quality tools and methods possible?

2. RESEARCH METHODOLOGY

This study adopts a systematic approach to ensure scientific rigor and transparency. Initially, review of existing literature was undertaken to establish the foundational knowledge base, generate specific knowledge, and identify theoretical gaps. This review also informed the development of this field of quality management, stimulated new insights, and highlighted avenues for further scholarly inquiry.

Subsequently, to obtain widely accepted and coherent findings regarding the implementation of quality tools, techniques, and methodologies, an empirical investigation was carried out within the automotive industry. The empirical component of this research focuses on a cohort of automotive manufacturing firms in North Macedonia. These organizations were selected based on their recognition of the critical role that quality tools, techniques, and methodologies play in continuous improvement. Additionally, they demonstrate a commitment to implementing certified management systems — including quality, environmental, and occupational health and safety systems — and adhere to relevant standards such as IATF 16949:2016 and VDA 6.3:2016.4. (Velkoska, 2020).

3. LITERATURE REVIEW

Within a quality management system, a range of principles, tools, methods (techniques), and methodologies are employed to support effective quality management practices. These quality principles and instruments are highly versatile, as they are utilized both in identifying and analyzing defects and in decision-making processes. A deep understanding of the causal relationships that underline problem-solving, decision-making, and outcome evaluation processes is particularly crucial for organizational leadership during the quality management process. This underscores the necessity for management to apply appropriate principles, methods, and quality tools that facilitate early detection of issues, implementation of corrective measures, enactment of necessary changes, elimination of root causes, and recognition of new conditions following intervention.

Employing these approaches enables systematic data collection and analysis as well as effective information presentation, thereby providing a sound evidential basis for management decisions aimed at achieving quality objectives (Velkoska, 2020).

Quality Management Principles

Quality management principles represent the fundamental attitudes and commitments of an organization and its staff toward quality in the broadest sense. These principles should be universally applicable, clearly articulated, and understood by employees at all levels within the organization (Skórnóg & Major-Kalinowska, 2025). Historically, organizations have most adopted principles such as those proposed by Deming, including the PDCA cycle (Plan–Do–Check–Act), teamwork, continuous process improvement (Kaizen), and Crosby's concept of zero defects (Velkoska, 2020).

The implementation of Total Quality Management (TQM) is also grounded in the seven quality management principles outlined in ISO standard (ISO 9001:2015). Since the 1990s, additional management approaches such as Talent Management, Value-Based Management, and Sustainable Development Management have emerged. Although these newer paradigms offer important contributions, their fragmented nature has thus far impeded the consolidation of a unified management framework capable of addressing the complex challenges posed by the Industry 4.0. These emerging challenges underscore the need to reconceptualize traditional quality management principles. Based on an extensive review of the literature, the study of Salimova et al. (2020) offers a preliminary model for transforming conventional quality management principles into foundational norms for contemporary business practice within the Industry 4.0 context. Figure 1 illustrates the comparison and evolution of quality management principles as they adapt to the Industry 4.0 environment.

In the study by Alrae (2024), eight core principles and concepts central to quality control and quality assurance are identified: customer focus, process orientation, ongoing improvement, active employee participation, leadership commitment, prioritizing prevention over detection, standardization, and decision-making based on data.

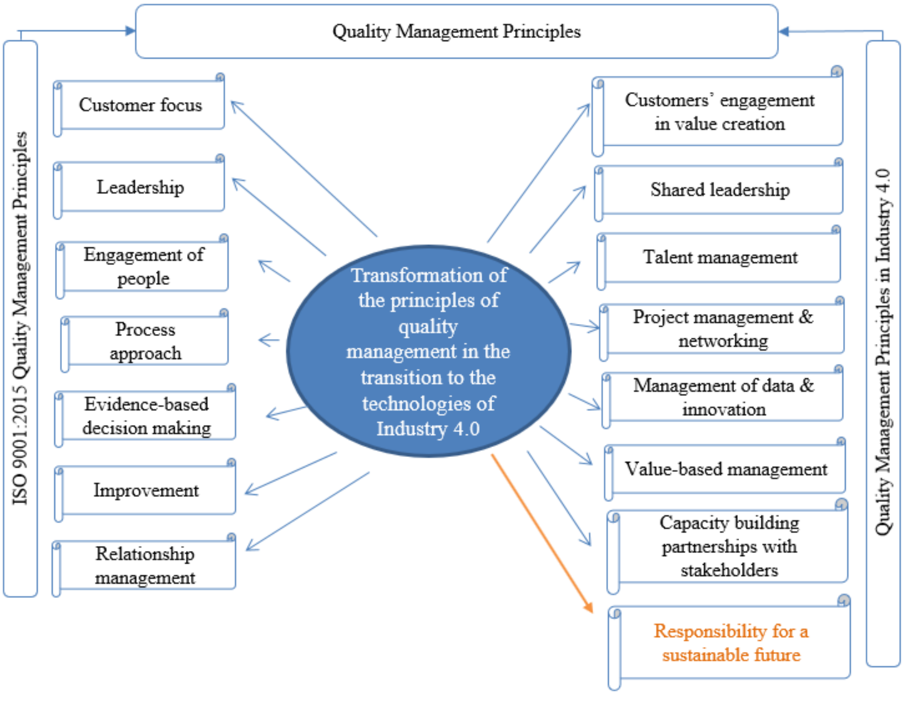


Figure 1. Comparation and transformation of the quality management principles in the environment of the Industry 4.0 (own creation based on Salimova et al., 2020)

Quality Management Tools and Techniques

The existing literature does not yet offer a universally accepted classification of quality management tools, methods, and techniques. Numerous efforts have been made to organize the wide array of available instruments using varying classification criteria, and proposals for systematizing these resources continue to emerge. Commonly, quality tools are categorized into traditional and modern groups, while some frameworks extend these classifications further to include statistical or supporting tools (Skuza, 2019). In the study by Skórnóg & Major-Kalinowska (2025), a structured compilation of selected quality management instruments, concepts, techniques, methods, tools, and principles is presented. These groups were developed through a review of relevant literature and are utilized across various phases of quality practice, including idea generation, planning, monitoring and control, evaluation of activities, and implementation.

For the purpose of this research, Figure 2 provides an updated synthesis of existing quality tools, techniques, and methodologies, organized into five principal clusters using an affinity diagram (Castello et al., 2020; Fernandes et al., 2013; Grigoryan & Golubkova, 2020; Kumar & Kothari, 2013; McDermott et al., 2023; Naeemah & Wong, 2021; Pawlak et al., 2023; Pramono et al., 2018; Skórnóg & Major-Kalinowska, 2025; Starzyńska, 2014; Tarı, 2005; Velkoska, 2018b). Furthermore, with the evolution of Industry 4.0, a new set of Quality 4.0 tools has been introduced, also grouped into five clusters as depicted in Figure 3 (Dovleac, 2021).

In practical terms, tools and techniques refer to actionable methods, capabilities, instruments, or mechanisms that support the execution of specified quality tasks. The concept of quality management techniques and tools encompasses practical procedures, skill sets, and instruments applicable to discrete tasks or to facilitate improvements and change. A quality tool is defined as a specific procedure or instrument that is task-focused and can be used independently or in combination, integrating external requirements with internal organizational results (Starzyńska, 2014).

According to McQuater et al. (1995), an individual “tool” can be described as a device with a clearly defined role. Common examples include histograms, pareto charts, cause-and-effect diagrams, control charts, and flowcharts. In contrast, a technique (or method) refers to a structured, step-by-step procedure intended to make practical actions more effective. Techniques generally encompass multiple tools and have broader applicability than individual tools. They represent comprehensive, integrated approaches to problem solving that rely on the coordinated use of supportive tools, often requiring greater expertise, training, and analytical insight (Castello et al., 2020).

For example, Statistical Process Control (SPC) is considered a technique composed of several statistical tools such as control charts, check sheets, histograms, and graphical analyses. Other techniques include Quality Function Deployment (QFD), Failure Mode and Effects Analysis (FMEA), Design of Experiments (DOE), and Taguchi methods. These are often described as “advanced and sophisticated,” in contrast to more “basic and simple” tools. From a practical standpoint, both basic and advanced tools and techniques play a vital role in problem solving and continuous improvement within quality management practice (Castello et al., 2020; Starzyńska, 2014).

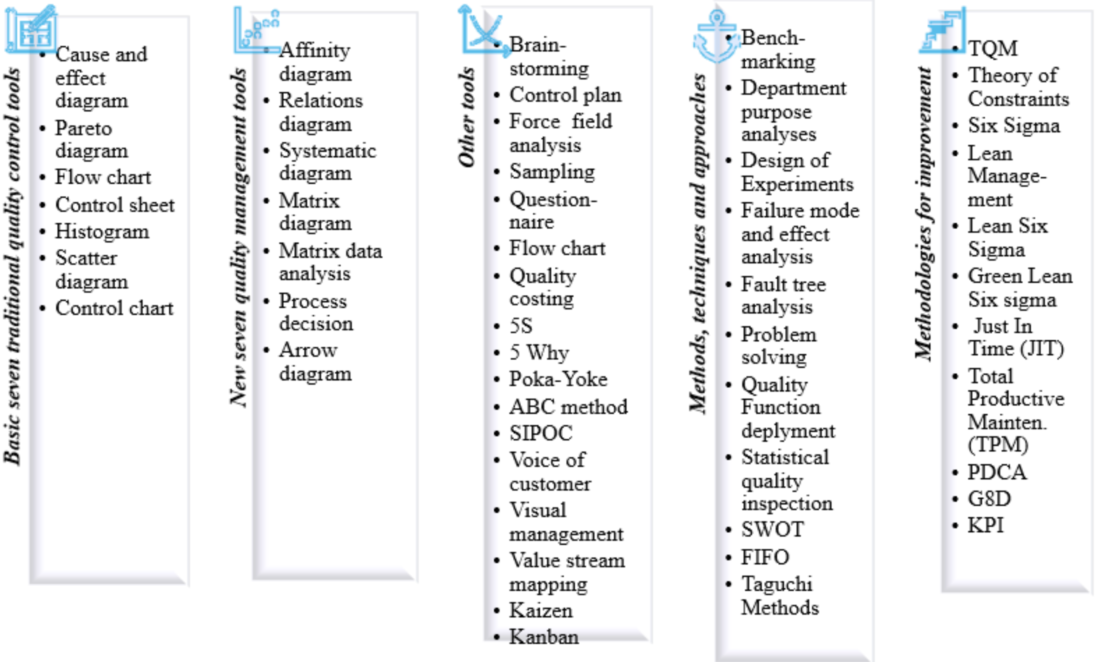


Figure 2. Summary of the existing quality tools, techniques and methodologies

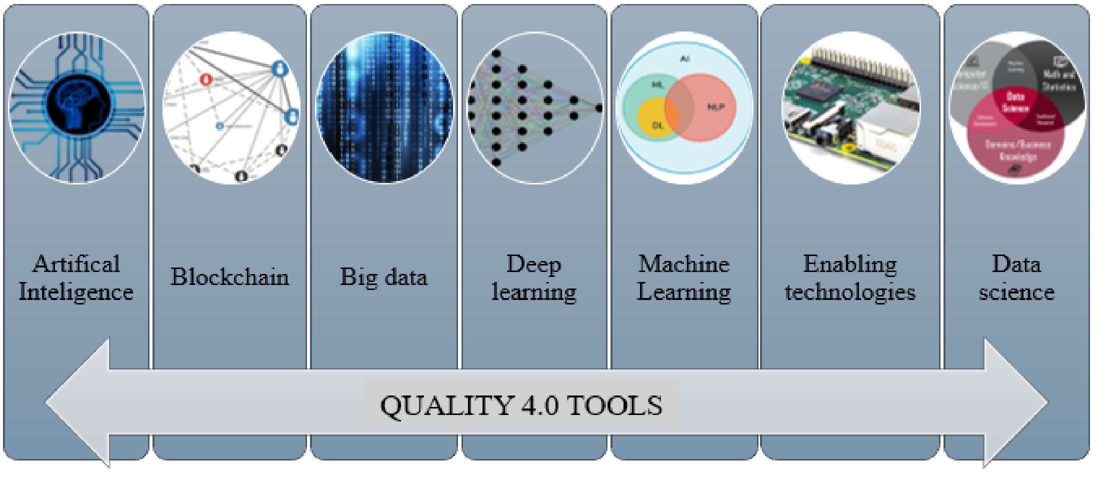


Figure 3. Quality 4.0 tools

Seven traditional quality control tools

Traditional quality control tools are based on basic statistical concepts, introduced by the Japanese professor Kaoru Ishikawa, and are concerned with quality control. Quality control tools: histograms, control charts and control sheets are used in the process of detecting errors; cause and effect diagrams, pareto diagrams, flow charts and scatter diagrams are used for the presentation and analysis of errors (Velkoska, 2020).

It is shown that seven traditional quality control tools can be used in all process phases, from the beginning of product development up to management of a production process and delivery. It is further shown how to involve these tools in some phases of continuous improvement process (PDCA), Six Sigma (DMAIC) and Design for Six Sigma (DMADV) methodologies, and Lean Six Sigma (Sokovic et al., 2009).

Seven new quality planning and management tools

The seven new quality management tools consist of the affinity diagram, matrix diagram, tree diagram, arrow diagram, relationship diagram, matrix data analysis, and the process decision program chart. They are used for quality planning and management. Research indicates that several foundational elements are essential for the effective implementation and sustained success of these tools in practice. First, a deep and comprehensive understanding of the process under study is crucial, as it enables practitioners to accurately interpret results and apply insights meaningfully. Second, formal training in structured problem-solving techniques enhances users' ability to employ the tools correctly and confidently. Third, the careful selection of appropriate tools that align with the nature of the problem or task at hand is critical to achieving desired outcomes. Finally, deploying simple, easily understood models across all organizational levels supports clearer communication, facilitates shared learning, and promotes broader engagement with quality initiatives (Pramono et al., 2018).

Methods, techniques and approaches

The use of quality management methods has a direct influence on the quality outcomes designed into a product. Among the most frequently applied approaches are QFD, FMEA, Value analysis of product design and processes, statistical quality control techniques, SPC, DOE, Shainin methods, and other related methodologies (Velkoska, 2020).

The quality cost technique is one of the well-known quality techniques. The quality cost technique represents one of the ways to measure the effect of the programs and initiatives for company quality improvement, and it remains a measure of a company's quality management maturity (Makhanya, Nel and Pretorius, 2018a). The stage and the systemic structure of the quality cost measurement system algorithm facilitate identification and tracking of the quality costs at the places where they occur and not at the places where they appear. This ensures timeliness, accuracy and reliability of the data and information about the costs of quality, opens possibilities not only for diagnostic analytics but also for predictive and prescriptive analytics of the costs of quality (Velkoska, 2018a; Makhanya, Nel and Pretorius, 2018b; Kau and Nel, 2019).

Future graphic interpretation of the quality cost (Tomov & Velkoska, 2021) facilitated with contemporary ambitious concepts such as Industry 4.0 and Quality 4.0 tools (Artificial intelligence), Business Process Reengineering, Innovation 5.0 will contribute to the development of a higher level of quality maturity which, in turn, will make the application of this technique more attractive (Velkoska & Tomov, 2021; Wojciech, 2020).

Table 1 presents the application of quality tools in the process of identification, analysis and decision-making within the quality costs technique (Velkoska, 2020).

Table 1. Application of quality tools within the quality cost technique.

Quality Costing Technique	Identification	Analysis	Decision making
Pareto diagram	❖		❖
Ratio Analysis		❖	❖
Correlation Analysis		❖	
Trend Analysis		❖	
Regression Analysis		❖	
"SIPOC" diagram (Supplier-Input-Process-Output-Customer)	❖		
Cause-effect diagram	❖		❖
Control Chart		❖	
Scatter diagram		❖	
Why-Why analysis	❖		❖
Critical to quality and critical to process	❖		
Index numbers		❖	
Influence diagram		❖	
Entity-relationship diagram		❖	
Brainstorming	❖		
Nominal group technique	❖		
Force-field analysis	❖		

Quality tools and techniques in the context of Industry 4.0

An important question in the context of Industry 4.0 and Smart Manufacturing concerns which factors influence the selection and suitability of specific quality tools and techniques for enhancing quality performance. Smart Manufacturing encompasses a wide range of advanced manufacturing practices, including computer-integrated systems, high adaptability to change, rapid redesign cycles, digital information technologies, and a more technically skilled and flexible workforce. From a quality management perspective, several studies have attempted to assess the relative priority and effectiveness of various tools and techniques for quality enhancement. However, recent research indicates a gap in understanding how traditional quality tools and techniques must evolve or be adapted to remain relevant within the dynamic environment of the Fourth Industrial Revolution (Hamid et al., 2020).

Findings from the survey reported in the study of Skórnóg & Major-Kalinowska (2025) reveal a divergence between industry practitioners and academic researchers in their tool preferences: practitioners tend to emphasize tools that facilitate practical implementation, whereas researchers prioritize analytical and conceptual methodologies. Additionally, the results underscore the necessity of integrating quality management tools within Industry 4.0 environments. The rapid changes associated with Industry 4.0 significantly influence how organizations manage quality, making it essential to identify which quality management instruments, concepts, techniques, methods, and principles are most valued by both scientific experts and industry professionals in this context. The study also highlights notable differences in preferences between academic and industrial stakeholders and draws attention to the interrelationships among individual tools.

Methodologies for quality improvement

In a highly competitive manufacturing environment, quality represents a critical determinant of market success. Efforts to enhance quality must be aligned with overall performance objectives. Philosophical frameworks such as Lean Manufacturing, Six Sigma, Lean Six Sigma, Total Quality Management, and the Theory of Constraints — as well as their various combinations — all strive toward the overarching goal of zero-defect production (Psarommatis et al., 2020).

The current era, in which principles from computer science are being incorporated into quality control practice, represents an evolution of quality standards and the ongoing "pursuit of performance excellence" through digital transformation. Manufacturing remains a cornerstone of the global economy, contributing between 10 % and 30 % of GDP in major industrialized nations. Innovation — understood as changes in the methods and processes of production and as a primary driver of economic development — is especially vital within manufacturing. In this context, artificial intelligence (AI), including machine learning (ML) and deep learning (DL) techniques, is integrated with established quality methodologies to address complex engineering challenges and promote innovation (Escobar et al., 2023). A paper titled "Quality 4.0 Trends and Application: A Systematic Literature Review" of publications between 2017 and 2023 found that digital transformation of quality, Quality 4.0, focuses primarily on enterprise-wide quality data management, that being the ability to collect, analyze and apply big data for quality improvement (Makhanya, Nel and Pretorius, 2023).

Research examining the integration of Six Sigma with Quality 4.0 tools, such as the case study by Escobar et al. (2023), demonstrates the superior performance of machine learning algorithms relative to traditional quality control techniques. The conventional Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) framework does not fully align with the complete life cycle of machine learning. As a result, certain patterns, such as three-dimensional quality defects that can be readily identified by ML models, remain undetected through conventional process monitoring methods. These early findings underscore the limitations of traditional Six Sigma paradigms in supporting manufacturing innovation and point to the need for a new Quality 4.0 paradigm that leverages the capabilities of AI without such constraints.

Similarly, in the integration of FMEA with Industry 4.0 tools, case studies on a “Smart Factory Line” (Klaput et al., 2023) have sought to evaluate the feasibility and practical applicability of FMEA within highly complex technical systems. These investigations reveal the considerable potential for combining FMEA with digital transformation technologies, suggesting that the method can serve as a robust instrument for quality planning and assurance in a Quality 4.0 environment.

The integration of the PDCA cycle with Quality 4.0 tools provides another example of adaptation. In this context, PDCA functions as a structured methodology for initiating the application of quality tools to problem-solving and for assessing the effectiveness of their implementation (Fernandes et al., 2013). Table 2 summarizes the application of quality tools throughout the PDCA cycle (Dovleac, 2021; Fernandes et al., 2013; Sokovic et al., 2009).

As more organizations adopt and benefit from Quality 4.0 practices, the repertoire of digital quality tools is expected to grow, and entirely new tools specifically designed to meet the evolving needs of modern enterprises may emerge (Dovleac, 2021).

Table 2. The application of quality tools throughout the PDCA cycle

	Quality Tools	P (Plan)	D (Do)	C (Check)	A (Act)
Basic Tools	Control chart	+		+	+
	Pareto diagram	+		+	
	Cause and effect diagram	+			
	Record sheet	+		+	+
	Histogram	+		+	
	Flow chart	+			+
	Scatter diagram			+	+
Others Tools	Brainstorming	+			
	5 Why	+			
	Design of experiment	+			
	Visual management		+		+
	Poka Yoke		+		
Quality 4.0 tools	R&R study	+			
	Data science		+	+	
	Deep learning		+		
	Machine learning		+	+	
	Artificial Intelligence	+		+	
	Blochchain	+			
	Enabling technologies	+			+
	Big data		+		+

Lean management is a philosophy that aims to reduce the number of resources, costs, human effort, inventory and time spent developing products to make them more appropriate to customer demand. The literature review reveals that lean management utilizes various tools and techniques. For instance, tools and techniques such as Value Stream mapping (VSM), 5S, Kaizen, Just-in-Time (JIT), Cellular manufacturing (CM), Single Minute Exchange of Dies (SMED), standardized work, Total Productive Maintenance (TPM), Poka-yoke, and Kanban are commonly employed. These methods are specifically designed to minimize waste, enhance process efficiency, elevate customer satisfaction, and boost overall productivity (Naeemah & Wong, 2021).

There are various tools or overall approaches to business management that allow them to increase work efficiency or production productivity or eliminate waste. In recent years, we can see an increase in the popularity of Lean or Six Sigma (Markulik et al., 2024).

An empirical study conducted within Indian manufacturing firms demonstrated that, among the Industry 4.0 technologies examined, the combined implementation of the Lean Six Sigma methodology and the Internet of Things (IoT) was statistically shown to have a positive influence on organizational performance. Nonetheless, despite evidence supporting this synergy, there remains considerable uncertainty regarding the core determinants that underpin the integration of Lean Six Sigma with emerging technologies within the Quality 4.0 paradigm (Velkoska, 2024).

Some studies confirm the future development of quality tools, techniques and methodologies into digital and intelligent environment is certainty for the following: Statistical Quality Control, DOE, 8D method, Root Cause Analysis (RCA), Exploratory Data Analysis (EDA), Confirmatory Data Analysis (CDA), FMEA, Cause effect diagram, Brainstorming, and Affinity Diagram (Velkoska, 2024).

Case study

The results of the nine companies surveyed in the North Macedonia, regarding the application of the quality tools, methods and methodologies are presented in the following figures: Figure 4. Application of the basic seven traditional quality control tools, Figure 5. Application of the seven new quality planning and management tools, Figure 6. Application of the other quality management tools, Figure 7. Application of all eighteen quality tools in the descending order, Figure 8. Application of the quality management techniques and methods, and Figure 9. Application of the quality improvement methodologies (Velkoska, 2020).

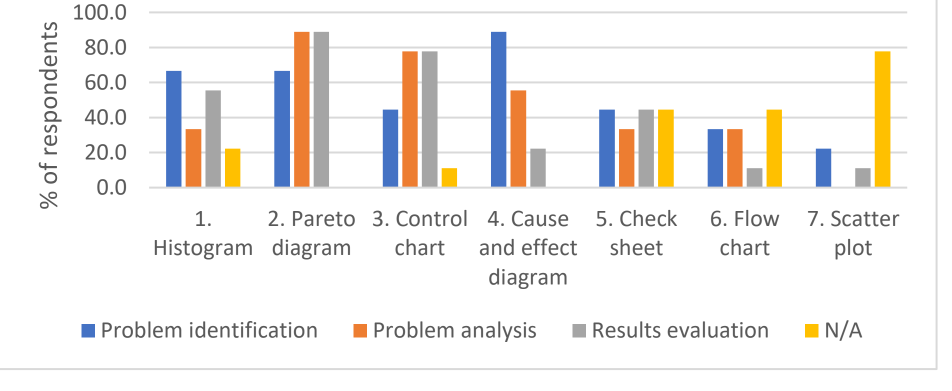


Figure 4: Application of the basic seven traditional quality control tools

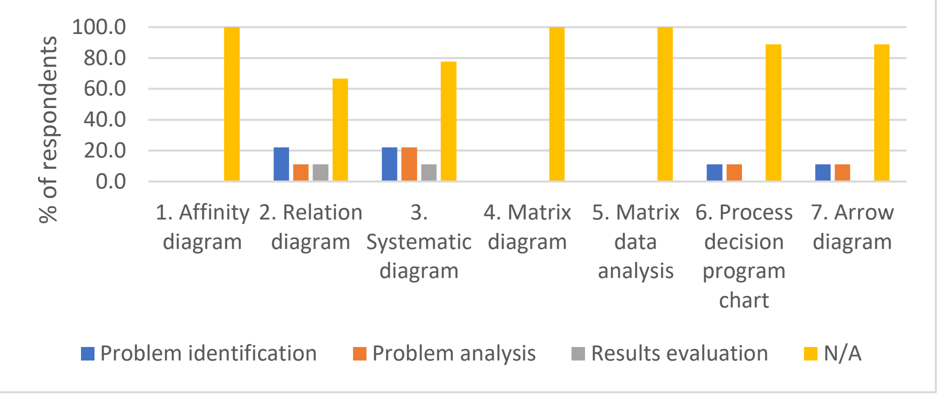


Figure 5. Application of the seven new quality planning and management tools

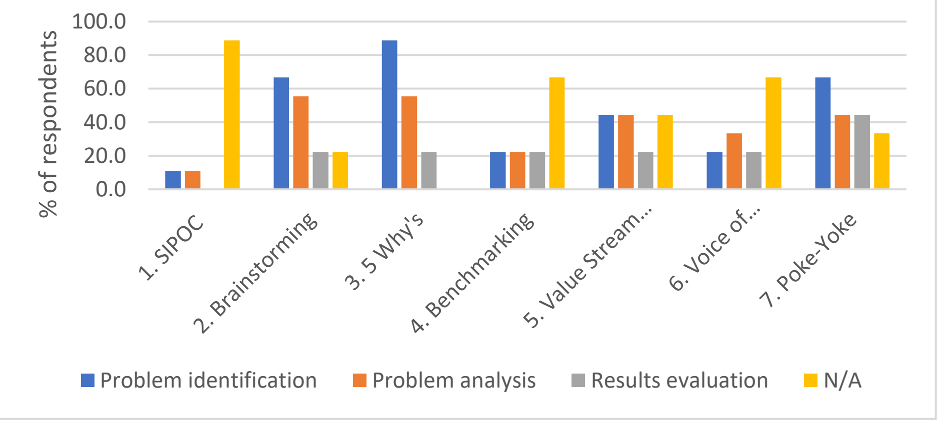


Figure 6. Application of the other quality management tools

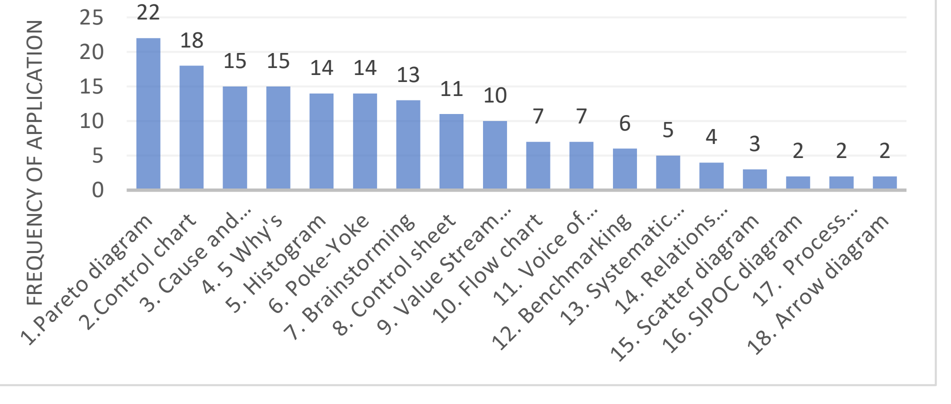
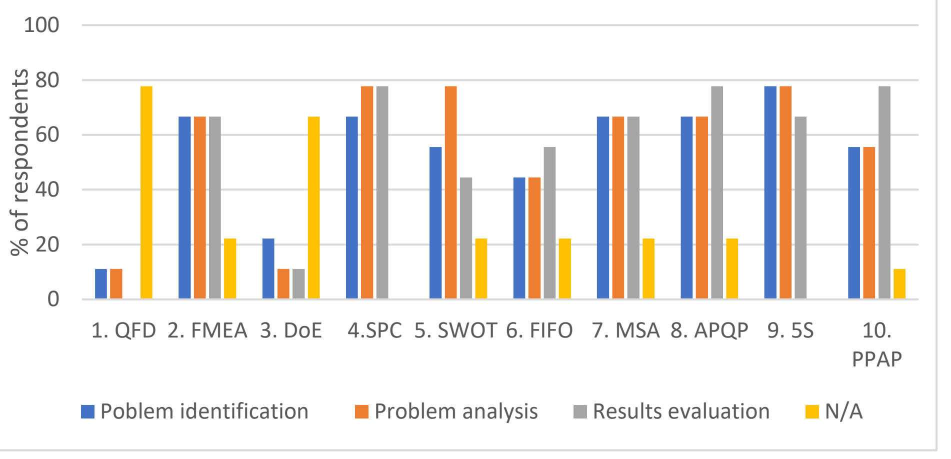


Figure 7. Application of all eighteen quality tools in the descending order.



MSA (Measurement System Analysis; FIFO (First In – First Out; PPAP (Production Part Approval Process)

Figure 8. Application of the quality management techniques and methods.

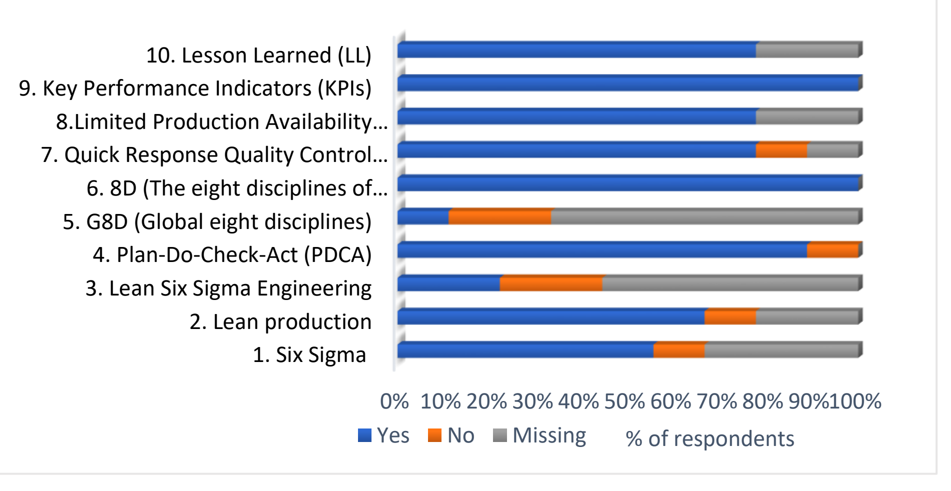


Figure 9. Application of the quality improvement methodologies.

3. FINDINGS AND DISCUSSION

The review and systematization of quality tools, techniques and methodologies shows that the literature records a large number of such mechanisms that participate in quality management. The literature review shows that the seven existing principles under ISO 9001 have experienced added value and an eighth principle is being added - responsibility for a sustainable future. This is aligned with the requirements for sustainable quality and brings a new perspective within quality management (Velkoska, 2021).

The survey results reported by Starzyńska (2014) reveal that quality tools are applied most frequently during the manufacturing stage of the production process, followed by the production set-up and measurement phases. Based on the types of application, quality tools and techniques can be classified into three principal groups: process-oriented tools, which are designed for use at specific stages of production; problem-oriented tools, which focus on specific types of issues across stages; and "island-like" tools, which serve problem-specific needs across adjacent stages of production. Regarding management-related problems, the most applied quality tools are brainstorming, followed by flowcharts. These tools support problem identification and conceptual solution generation within managerial contexts. For issues related to process performance, descriptive statistics emerged as the tool most frequently used, with Pareto diagrams and process capability indicators also widely utilized. These tools facilitate quantitative analysis of performance deviations and process outcomes. In the domain of process supply, the check sheet was the most frequently applied tool, complemented by statistical inspection of deliveries and the FMEA method, indicating a reliance on both traditional and risk-based approaches to ensure material and supply quality.

The manufacturing sector commonly employs the seven basic quality control tools alongside various quality improvement techniques as part of its quality management practices. In contrast, research indicates that quality managers in both Britain and Australia tended to rely on a relatively limited set of methods, primarily using brainstorming, control charts, and Pareto analysis as their main quality tools (Hamid et al., 2020).

The survey results indicate that the use of quality tools and techniques within wind power sector companies is generally high, with internal audits, flowchart diagrams, and cost-of-poor-quality measures being the most frequently applied instruments. These findings also suggest that certification to ISO 9001 fosters a supportive context for the adoption of quality tools and methodologies, although opportunities remain for wider application of more advanced methods such as design of experiments and quality function deployment (Castello et al., 2020).

Supporting evidence from research conducted in Poland shows that among surveyed enterprises, techniques such as brainstorming, 5S, Pareto analysis, and FMEA are the most used quality management methods, while practices associated with Lean manufacturing and Six Sigma are notably less prevalent (Skuza, 2019).

A related study involving 202 managers from Portuguese organizations certified to ISO 9001 found that, at a 95 % confidence level, both industrial and service sectors exhibit similar reliance on basic and advanced quality tools. Larger companies tend to employ advanced tools more often than smaller firms, while the use of basic tools does not differ significantly by company size. In this context, check sheets, flowcharts, and histograms (in services) or control charts (in industry) were the basic tools most frequently utilized, although about 22 % of surveyed organizations reported not using basic quality tools at all, highlighting a significant area for improvement (Fonseca et al., 2015).

Other research has shown that only a small proportion of respondents believe that the seven new quality tools can address most problems in manufacturing, with Tree diagrams being the most used and arrow diagrams the least. The application of these newer tools is generally stronger in manufacturing contexts and much weaker in research and development activities (McDermott et al., 2023).

Finally, in the context of Industry 4.0, studies exploring appropriate quality management tools for smart manufacturing environments further underscore the need to identify and apply suitable methods that align with modern production paradigms (Saifuddin & Rizal, 2020).

The analysis of the data obtained from empirical research conducted in automotive companies yields the following results (Velkoska, 2020):

- ❖ Traditional quality control tools are extensively utilized across all three stages of quality activity: identifying problems, analyzing causes, and evaluating outcomes (Figure 4). Among these, histograms, the pareto chart, cause-and-effect diagram, and control chart are the most employed instruments, whereas the scatter diagram is used least frequently.
- ❖ Newly developed quality management and planning tools (Figure 5) are rarely adopted by companies in practice.
- ❖ Within the category of other quality management tools and techniques (Figure 6), the 5 Why method is most frequently applied during problem identification, followed by brainstorming and poka-yoke. For problem analysis, both the 5 Why and brainstorming techniques are prevalent. Conversely, tools such as

Benchmarking, SIPOC diagrams, and Voice of the Customer (VOC) are among the least used in organizational settings.

- As shown in Figure 7, the pareto chart, control chart, cause-and-effect diagram, and the 5 Why technique emerge as the most widely implemented tools and techniques in surveyed companies. In contrast, relationship diagrams, matrix diagrams, and matrix data analysis tools have negligible applications.
- Analysis of quality management techniques (Figure 8) included ten methods; seven show broad applicability across all three considered stages, whereas QFD and DOE demonstrate limited practical use.
- Among the ten quality improvement techniques examined (Figure 9), the 8D problem-solving approach and KPIs are reported by all participating firms. The PDCA cycle is used by 88.9 % of companies, while QRQC, LPA, and LL practices are each implemented by 77.8 % of firms. Overall, 67 % of the tools and techniques considered are widely used, with G8D and Lean Six Sigma Engineering exhibiting the lowest adoption rate.

4. CONCLUSION

A review of the existing literature of known quality tools, techniques and methodologies in the field of quality management shows that this area is rich with such mechanisms. Also, existing literature indicates that quality control, planning, and management tools and methods have not been thoroughly examined, either in theoretical development or through empirical studies. This gap, however, does not diminish their relevance to the field of quality management. Rather, the limited scientific attention poses a significant challenge to their wider integration and harmonization within digital environments, especially in the context of Industry 4.0, where new technologies are reshaping traditional practices. Research in this area remains relatively nascent, with scholars actively working to define and conceptualize Quality 4.0 and its components, but many aspects are still underexplored.

Despite the transformative potential of digital technologies, traditional quality management tools techniques, and methodologies should remain indispensable within Digital Quality Management. The enduring value of these mechanisms lies in their ability to structure problem-solving, guide analytical reasoning, and support continuous improvement efforts, even within digitally enhanced environments.

As more organizations adopt Quality 4.0 approaches and begin to realize their benefits, it is expected that additional tools tailored to digital quality management will be developed to better meet industry needs. Makhanya, Nel and Pretorius (2023) found that Quality 4.0 will make traditional quality management faster, smarter and more intelligent with the advent of big data analytics and data management. Yet the persistent shortage of robust case studies limits opportunities for comparative analysis and deep understanding of how quality tools and techniques are applied in practice. This lack of empirical evidence is widely acknowledged as a key research gap in literature.

The case study presented in this research is constrained by the small sample of automotive companies surveyed, a limitation largely attributable to the size of North Macedonia's economy. As a result, the research context and lack of replication restrict the generalizability of the findings. Moreover, improvement methodologies were not examined in depth within this study, leaving this as an area for future investigation.

To advance the field, future research should involve a broader and more diverse set of companies and consider cross-country analyses. Such work would not only strengthen empirical foundations but also support a more comprehensive understanding of how quality management practices evolve in the era of digital transformation.

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