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Quality Control and Assurance in Industry 4.0: A Systematic Review

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Abstract

Quality 4.0 is an emerging concept that has been increasingly appreciated because of the intensification of competition, continually changing customer requirements and technological evolution. It deals with aligning quality management practices with the emergent capabilities of Industry 4.0 to improve cost, time, and efficiency and increase product quality. This article aims to comprehensively review extant studies related to Quality 4.0 to uncover current research trends, distil key research topics, and identify areas for future research. Thus, 46 journal articles extracted from the Scopus database from 2017 to 2022 were collected and reviewed. A descriptive analysis was first performed according to the year-wise publication, sources of publication, and research methods. Then, the selected articles were analyzed and classified according to four research themes: Quality 4.0 concept, Quality 4.0 implementation, quality management in Quality 4.0, and Quality 4.0 model and application. By extracting the literature review findings, we identify the Quality 4.0 definitions and features, develop the quality curve theory, and highlight future research opportunities. This study supports practitioners, managers, and academicians in effectively recognizing and applying Quality 4.0 to enhance customer satisfaction, achieve innovation enterprise efficiency, and increase organizational competitiveness in the era of Industry 4.0.

Keywords: Industry 4.0, Quality Management 4.0, Research Methodology, Customization, and Model

1. Introduction

Quality 4.0 is an emerging quality management concept that has recently attracted much attention because of the increasingly complex customer requirements coupled with fiercer competition and technological evolution. It refers to the future of quality in the environment of Industry 4.0. Quality 4.0 deals with aligning the practices of quality management with the technologies of Industry 4.0, like artificial intelligence (AI) and digitalization, to achieve innovation, enterprise efficiency and performance (Broday, 2022; Thekkoote, 2022). Quality 4.0 empowers quality managers to undertake daily tasks in completely new manners. Via implementing Quality 4.0, quality costs can be reduced significantly by improving product design and operational efficiencies, reducing non conformances and defect rates, and ensuring on-time deliveries (Antony et al., 2023). Furthermore, it can increase responsiveness and customer satisfaction because of early defect detection and root cause elimination and speed up the time to market products. The

main advantages of Quality 4.0 are related to the application of real-time and continuous monitoring systems, defect prediction systems, in-line intelligent quality control, and total inspection solutions (Christou et al., 2022; Antony et al., 2023). Therefore, the previously unavailable information can now be obtained in real time, handling advanced tasks can be faster, and control can be achieved via advanced systems for automatic quality monitoring and improvement (Maganga and Taifa, 2023).

Some literature reviews have been performed to investigate the Quality 4.0 topic from different perspectives. For example, Thekkoote (2022) conducted a literature review to analyze the factors contributing to the successful implementation of Quality 4.0 in the digital transformation era. Sony et al. (2020) performed a narrative literature review to identify key ingredients for the effective application of Quality 4.0. Broday (2022) conducted a literature review on Quality 4.0 to explore how traditional quality concepts are being adapted within organizations. Saihi et al. (2023) provided a systematic review on the state of the research leveraging Industry 4.0 technologies to improve quality management practices. Ranjith Kumar et al. (2022) conducted an integrative literature review of the literature on Quality 4.0 and developed a conceptual framework for quality management in the digital era. In Dias et al. (2022), biometric analysis and a descriptive literature review were carried out to analyze the literature related to Quality 4.0 and the influence of the digital transformation process on quality. Chiarini (2020) employed a systematic literature review to determine the relationships among Industry 4.0, quality management, and total quality management (TQM). Furthermore, Souza et al. (2022) provided a biometric analysis to review the papers related to TQM 4.0, and Baran and Korkusuz Polat (2022) presented a classification of Industry 4.0 studies in terms of TQM.

The literature reviews above provided valuable insights and interesting research suggestions in the Quality 4.0 field. Nevertheless, they mainly focus on a specific aspect of Quality 4.0 and have general limitations concerning the number of research articles, article screen, article classification, time determination, and subjective clarification. Unlike previous literature reviews, the present study aims to undertake a comprehensive literature review on the topic of Quality 4.0 to identify the current research trends, distil key research topics, and find out areas for future research. Thus, 46 journal papers published from 2017 to 2022 were selected from the Scopus database. These publications were analyzed and classified into four research themes, including Quality 4.0 definition, Quality 4.0 implementation, quality management in Quality 4.0, and Quality 4.0 model and application. A descriptive analysis was further conducted according to the year-wise publication, sources of publication, and research methods. Moreover, the Quality 4.0 definitions and features are discussed, and quality curve theory is introduced based on this literature review. This study can facilitate practitioners and academics to obtain a holistic understanding of Quality 4.0 research and grasp the research hotspots and emerging trends of the domain.

The rest part of this article is arranged as follows.

Section 2 presents the conceptual background of Industry 4.0 and Quality 4.0. Section 3 describes the research methodology for conducting the literature review. Section 4 provides the literature review results through descriptive and content analyses. Section 5 analyzes the Quality 4.0 definitions and features and develops quality curve theory. Section 6 presents current research gaps and outlines future research directions based on the in-depth literature analysis. Finally, Section 7 concludes this study with a summary of the research findings.

Conceptual background

This section 2 provides the background for the literature review and introduces the historical development of Industry 4.0 and Quality 4.0.

1.1 Industry 4.0

Industry 4.0 was initially proposed by the German Government in 2017 at the Hannover Fair Event to increase the competitiveness of the manufacturing industry in Germany (Sader et al., 2019). It aims to transform the industry into a smart manufacturing system by using novel technologies, including big data, AI, the Internet of Things (IoT), cyber-physical systems (CPS), digital twins, additive manufacturing, and cloud computing. In this new environment, all production facilities are interconnected with each other over the IoT and in the form of CPS. Thus, machines, logistic vehicles, warehouses, and the whole value chain can exchange information and control production flow. Industry 4.0 employs intellectual processes and products supported by autonomous data collection and analysis, leading to smart, intelligent, and efficient processes. Via the production processes integration and product connectivity, higher industrial performance can be obtained for firms by improving product quality, smoothing production processes, and increasing production efficiency (Asif, 2020).

The first industrial revolution, emerged in the 1760s, relied on steam power and mechanical production, thus called “mechanization”. The second revolution began in the 1870s, advanced the industry to mass production and assembly lines powered by electricity, thus called “electrification”. The third revolution, started in the 1970s, facilitated the automation of industrial production based on electronics, telecommunications, and computers, hence called “automatization”. Recently, the new fourth industrial revolution, called Industry 4.0, was launched by utilizing intelligent devices, identification technologies, localization and navigation machinery, and robotics technologies (Glogovac et al., 2022). These technologies resulted in new types of production systems, such as smart factories, machines, manufacturing, and products (Sader et al., 2022).

Industry 4.0 provides the ability to analyze big data collected in the entire value chain, translate it into useful information, replace the traditional monitoring and decision-making strategies, and provide a key enabler for industrial effectiveness and efficiency (Sader et al., 2019). It is built on self-configuring, knowledge-based; sensor- equipped, and spatially distributed networks of industrial resources (manufacturing machinery, robots, conveyor and storage systems, and production facilities). Industry 4.0 aims to develop autonomous and dynamic production that uses information and communication technologies to make mass production of highly personalized items easier. As a result, factories are becoming more intelligent, which can self-plan and self-adapt to provide more customized products and fulfill customer expectations autonomously.

1.2 Quality 4.0

Industry 4.0 provides great opportunities for quality management to become a leading power in improving organizational performance. With the advance of new technologies and diversity of customer needs, achieving high-quality levels with conventional quality management methods is difficult (Balouei Jamkhaneh et al., 2022). The tools of Industry 4.0 could help improve the quality of production processes, such as the quality of information for optimization, planning and operation, forecasting, simulations and prototyping, and improved employee participation and engagement (Glogovac et al., 2022). Through the implementation of Industry 4.0, traditional quality management has changed because of the digitalization of all functions of a company (Sony et al., 2020). By aligning quality management with Industry 4.0, Quality 4.0 can increase company operational efficiency, performance, innovation, and business models (Sony et al., 2020). Furthermore, new production schemes have emerged focusing on customized and complex products generated through dynamic and complicated manufacturing processes (Sader et al., 2022). Industry 4.0 technologies reduced the cost of quality, including sampling and inspection costs, and improved performance by monitoring processes and products simultaneously. Industry 4.0 also enhanced quality-

related decision-making activities supported by the instant data flow. As a result, quality management methods and practices have changed in the era of Industry 4.0. For example, quality control procedures are automated; sensors inspect the entire production process and eliminate defective products.

According to the American Society for Quality, Quality 4.0 is the future of quality and organizational excellence within the environment of Industry 4.0 (Jacob, 2017). It stands for the fourth evolution stage for quality management. As illustrated in Fig. 1, the first three quality management stages include quality through inspection and control (Quality 1.0), quality through standards and quality assurance (Quality 2.0), and quality through TQM (Quality 3.0) (Chiarini and Kumar, 2022). Quality control is a product-oriented approach to ensure that all products meet the specifications for satisfying customers' requirements. It excludes defective goods from production using inspection and statistical methods, such as statistical quality control and statistical process control. Quality assurance is a process-oriented method to ensure that the production processes are standardized and maintained to keep the same quality level of products. Its main purpose is to verify that all processes related to production are maintained to deliver non-defective products. TQM is a company-oriented approach to ensure that all activities within a firm are implemented to satisfy customers' requirements and expectations. Quality 4.0 provides an extended scope to quality management with intensive monitoring of all activities contributing to the product value chain. It transforms quality management activities from reactive or proactive to predictive with the help of automation inspection, advanced data analysis, and analysis result integration.

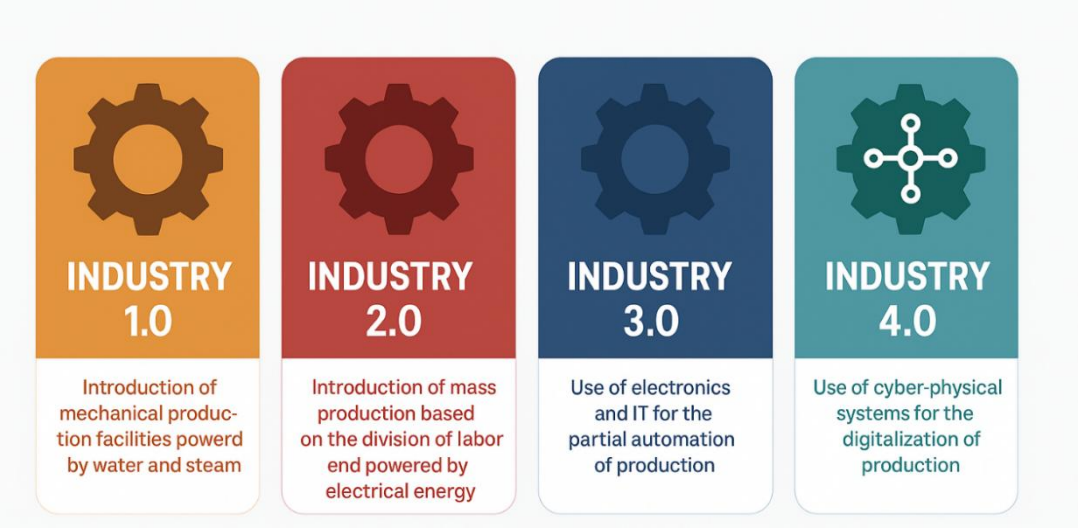


Figure 1: Illustration of Quality 4.0

2. Research methodology

This study employed a systematic literature review procedure to review the academic publications regarding Quality 4.0. The method is more transparent than other conventional or unsystematic review methods and has been widely applied in similar studies (Tan et al., 2021; Zheng et al., 2021; Gebhardt et al., 2022). It consists of retrieval keyword definition, data gathering and identification, literature analysis, and descriptive analysis. First, a list of search strings was created via an exploratory review of the existing Quality 4.0 studies. To ensure that the Quality 4.0 articles are fully captured, the keywords "Quality 4.0" and ("Industry 4.0" AND "Quality Management") are used for the literature search in article titles, abstracts, and keywords. Second, the Scopus database was adopted to acquire the relevant articles for the literature review because it has more than 50 million documents and is a reliable source for obtaining worldwide academic information

effectively (Di Vaio et al., 2022). Only English papers in peer-reviewed journals published from 2017 to 2022 were included in this stage. The initial retrieval result was comprised of 206 items. Via removing duplicate items, 175 papers were identified. Then, we reviewed the remaining articles' titles, abstracts, and whole texts to eliminate unrelated ones. The following rules were compiled to obtain target literature: 1) The article that focused on theoretical or empirical research on Quality 4.0 was retained; and 2) The article that discussed quality management in the context of Industry 4.0 was included. In the end, 46 documents were considered within the review scope and selected for further analysis. The initial literature related to the topic was published in 2017. Thus, the time range of this review study is from 2017 to 2022. Lastly, the classifications were determined according to the highlights and contributions of the selected papers. Figure 2 shows the detailed review process of this literature review study.

3. Results of the literature review

Table 1: Descriptive analysis

No.	Author(s)	Year	Title	Focus Area
1	Kagermann, H., Wahlster, W., Helbig, J.	2013	*Recommendations for implementing the strategic initiative Industry 4.0*	Foundational Industry 4.0 concept in Germany
2	Lasi, H., Fettke, P., Kemper, H.-G.	2014	*Industry 4.0*	Conceptualization and key principles
3	Hermann, M., Pentek, T., Otto, B.	2016	*Design principles for Industrie 4.0 scenarios*	Design principles of smart factories
4	Xu, X.	2017	*From cloud computing to cloud manufacturing*	Role of cloud computing in Industry 4.0
5	Schumacher, A., Erol, S., Sihn, W.	2016	*Maturity model for assessing Industry 4.0 readiness*	Industry 4.0 maturity measurement
6	Zheng, P., Lin, T.-J., Chen, C.-H.	2018	*Smart manufacturing systems for Industry 4.0*	Smart systems architecture
7	Lu, Y.	2017	*Industry 4.0: A survey on technologies and applications*	Survey of enabling technologies
8	Lee, J., Bagheri, B., Kao, H.-A.	2015	*A cyber-physical systems architecture for Industry 4.0-based manufacturing*	CPS framework for smart manufacturing
9	Frank, A. G., Dalenogare, L. S., Ayala, N. F.	2019	*Industry 4.0 technologies: Implementation patterns in manufacturing*	Implementation strategies and patterns
10	Moeuf, A., Pellerin, R., Lamouri, S.	2018	*The industrial management of SMEs in the context of Industry 4.0*	Adoption in small and medium enterprises
11	Javaid, M., Haleem, A.	2020	*Industry 4.0 applications and challenges*	Applications and adoption challenges
12	Müller, J. M., Kiel, D., Voigt, K.-I.	2018	*What drives the implementation of Industry 4.0?*	Motivators and barriers to adoption
13	Bibby, L., Dehe, B.	2018	*Defining and assessing Industry 4.0 maturity levels*	Maturity model development

14	Zhong, R. Y., Xu, C., Chen, C.	2017	*Big data analytics for physical internet-based intelligent manufacturing*	Big data in Industry 4.0
15	Wan, J., Tang, S., Li, D.	2017	*A manufacturing big data solution for active preventive maintenance*	Predictive maintenance and IoT
16	Strange, R., Zucchella, A.	2017	*Industry 4.0, global value chains and international business*	Globalization and digital trade
17	Kang, H.-S., Lee, J.-Y., Choi, S.	2016	*Smart manufacturing: Past research, present findings, and future directions*	Literature review on smart manufacturing
18	Oztemel, E., Gursev, S.	2020	*Literature review of Industry 4.0 and future perspectives*	General review and future outlook
19	Tortorella, G. L., Fettermann, D. C.	2018	*Implementation of Industry 4.0 and lean production in Brazilian manufacturing*	Case study approach
20	Raj, A., Dwivedi, G., Sharma, A.	2020	*Barriers to the adoption of Industry 4.0 technologies in the Indian manufacturing industry*	Barriers and solutions in emerging economies

In this section 3, we provide a descriptive analysis of year- wise publications and sources of publication. A primary mapping was conducted based on the annual production of articles to achieve a general view of the reviewed documents. There is an upward trend in the quantity of publications per year about Quality 4.0, indicating that this research area has gained increasing attention from researchers over the last years. From 2020, the publications began to rise rapidly, especially in 2022, resulting in about twofold the publications of 2021.

Table 1 displays the relevant journals with two or more papers on Quality 4.0. As can be seen, the International Journal of Quality and Reliability Management and TQM Journal are the top two journals in which Quality 4.0 articles are published. The majority of the articles have been published in quality-focused journals. Besides, the reviewed research was published in various journal types, involving manufacturing, operations, and sustainability, which shows the multifaceted impact of Quality 4.0. Regarding the research methods used, the reviewed articles utilized a wide variety of methods, with literature review (n = 21), analytical model (n = 10), and questionnaire survey (n = 9) being the most popular ones.

3.1.1 Quality 4.0 concepts

First, the reviewed literature showed that ten studies explored the related concepts of Quality 4.0 for adapting quality management in Industry 4.0. Table 1 summarizes the related publications based on their main contributions and conclusions. In this line, Souza et al. (2022) addressed the relationships between TQM and Industry 4.0 and developed an ecosystem for TQM 4.0 by integrating technology, quality, and people in the industrial scenario. The TQM 4.0 ecosystem consists of three spheres (Industry 4.0, TQM, and quality culture), each of which denotes a sub-sphere: Technology, quality, and people. Chiarini and Kumar (2022) explored the relationship between Industry 4.0 and quality management and developed a Quality 4.0 theoretical model based on an exploratory sequential mixed study of Italian manufacturing firms. The developed model includes eleven themes of Quality 4.0 across the categories of people, process, and technology. Through an extensive integrative literature review, Ranjith Kumar et al. (2022) identified the dimensions and capabilities of Quality

4.0 and presented a holistic frame- work representation of Quality 4.0 by linking people, process, and technology dimensions with Quality 4.0 attributes. Sader et al. (2022) proposed a balanced definition for Quality 4.0 based on the implication of Industry 4.0 and the independent development of quality management practices. The authors indicated that Quality 4.0 is an extended approach to quality management. New technologies are combined with traditional quality activities (quality control, quality assurance, and TQM) to expand the quality management scope. In Dias et al. (2022), a descriptive review of Quality 4.0 was conducted to provide a summary of main topics in the digital transformation process, and a definition for Quality 4.0 was suggested for a better understanding of the concept. The findings revealed that technology and its implications for quality, business management and strategy models, systems, and human or soft factors are the most common topics in Quality 4.0.

Antony et al. (2022a) investigated the concept of Quality 4.0 from a practitioner's perspective to understand and conceptualize Quality 4.0. Using a qualitative interview approach, different aspects of Quality 4.0, such as the benefits and motivating implementation factors, critical success factors, challenges and organizational readiness factors and the skills required by quality professionals, were determined. In Hyun Park et al. (2017), a new culture for quality and a multiway flow system were proposed for quality management in the era of Industry 4.0. Besides, the composite dimension, team creativity, total inspection, and new valuation methods based on big data, AI and IoT were introduced for realizing the multi- way flow in practical situations.

Broday (2022) examined the evolution of quality from inspection to Quality 4.0 to verify how traditional quality concepts are being adopted within organizations. The results showed that traditional quality methods would not be replaced but improved; the digitalization of traditional quality methods is mandatory for the success of Quality 4.0. Based on a literature review on quality management, Sureshchandar (2022) identified 12 critical dimensions of Quality 4.0 and further determined their relative importance in implementing Quality 4.0 using the analytic hierarchy process technique. By reviewing Quality 4.0 concepts biometrically and scientometrically, Maganga and Taifa (2023) explored the definitions, available models, readiness factors, motivations, and leveraged technology of Quality 4.0 for manufacturing industries.

3.1.2 Quality 4.0 implementation

Eleven examined papers looked into the reasons for, obstacles to, and associated elements of adopting Quality 4.0 in a company. Table 1 provides a summary of these publications for ease of reading and comprehension. Sony et al. (2020) identified eight essential elements for the successful implementation of Quality 4.0 through a narrative literature review: managing large data, improving prescriptive analytics, successful vertical, horizontal, and end-to-end integration, strategic advantage, leadership, training, corporate culture, and top management support. The top five reasons for implementing Quality 4.0 are as follows: top management support, quality culture, leadership, Quality 4.0 strategy, quality knowledge and awareness, customer centeredness, supplier-centric, training, and rewards; the top five obstacles are high cost, lack of resources, lack of knowledge, company culture, and unclear competitive advantage; and the top five motivations are reliable information, big data-driven quality management, higher customer satisfaction, improved productivity, and cost and time savings (Sony et al., 2021). Antony et al. (2023) investigated the organizational readiness elements for adopting Quality 4.0 at an international level using a quantitative research technique. The findings indicated that the top three preparedness elements for adopting Quality 4.0 are organizational culture, leadership, and top management commitment. Thekkoote (2022) investigated the elements necessary for the effective application of Quality 4.0 in the age of digital transformation, based on an extensive study. Thus, the key elements that contribute to the adoption of Quality 4.0 were determined to include data, analytics, connection, collaboration, APP development, scalability, compliance, organization

culture, leadership, and training. According to Ali and Johl's (2022) objective and subjective analysis of the relationship between TQM and Industry 4.0, top management commitment, customer focus, employee training and learning, the quality of big data and analysis, process management, continuous improvement, and product/service design are all crucial success factors for the successful implementation of Quality 4.0.

According to Sureshchandar (2023), Quality 4.0 is a multifaceted concept with twelve axes. The transformation of Quality 4.0 is largely dependent on both technical and traditional quality factors, such as data governance, innovation, and advanced analytics, as well as leadership, culture, customer centricity, quality systems, metrics, and data analysis. When Yadav et al. (2021) assessed the success factors for Lean Six Sigma in a Quality 4.0 setting; they discovered that 11 conventional variables and seven Quality 4.0 elements were crucial. Data processing software, enterprise resource planning (ERP) software, application software that can automatically adjust processes, radio frequency identification (RFID)-enabled inventory systems, data analysis and prediction systems, automation, and timely and accurate data availability are all essential components of Quality 4.0.

In order to increase the likelihood of successfully implementing Quality 4.0 initiatives, Escobar et al. (2021) addressed four challenges of big data initiatives in manufacturing: paradigm, project selection, process redesign, and relearning problems. They also introduced a seven-step problem resolution approach (identifies, accessorized, discover, learn, predict, redesign, and relearn). Using an assessment laboratory and a grey decision-making trial, Balouei Jamkhaneh et al. (2022) investigated the factors influencing human resources' preparedness and capacity to manage Quality 4.0 and examined their cause-and-effect linkages. "Technical talents and competence to solve issues" are the most significant drivers, according to the survey, which found 29 in the four areas of novel value, composite dimension, team innovation, and thorough examination.

To determine the degree of maturity of Czech manufacturing enterprises in adopting Quality 4.0, Nenadál et al. (2022) created a conceptual model of maturity evaluation. Maganga and Taifa (2022) observed that Tanzanian manufacturing enterprises had a high degree of Quality 4.0 awareness and recommended a Quality 4.0 transition framework for manufacturing industries based on the people-process-technology strategy.

3.1.3 Quality 4.0 and quality management

In our assessment of the literature, 14 papers looked at quality management practices or initiatives in the context of Industry 4.0. To make reading and comparison easier, Table 1 lists the relevant research in tabular form. In order to evaluate the maturity level of Quality 4.0, Glogovac et al. (2022) looked at how easy it was to use the components of the ISO 9004:2018 quality management system. The principles and linkages of ISO 9004:2018 were found to be useful for determining the degree of quality maturity in Industry 4.0 using confirmatory factor analysis. In order to facilitate digital conversion by fusing quality and excellence with Industry 4.0, Fonseca et al. (2021) determined the connections and implications between the European Foundation for Quality Management (EFQM) 2020 model and the Industry 4.0 paradigm. Elibal and Özceylan (2022) used an integrated fuzzy decision-making technique to assess Industry 4.0 maturity models from the standpoint of TQM principles.

Asif (2020) assessed how well-suited the existing approaches of quality management are to Industry 4.0. It suggested updating them with features like intellectual capital management, quality prediction from big data, and networked corporate management. Through a thorough analysis of the literature, Saihi et al. (2023) looked at how Industry 4.0 might affect quality management techniques and how digital technologies may be used to improve quality management. "Creating value within the company via quality analytics and artificial intelligence," "developing Quality 4.0 skills and culture for quality people," "customer value co-creation," and "CPS and ERP for quality assurance" are the most pertinent topics with Quality 4.0, according to Chiarini's

(2020) analysis of the relationships between Industry 4.0, quality management, and TQM. Using an integration of Industry 4.0, quality management, and supply chain management, Bui et al. (2022) developed supply chain quality management 4.0 and provided its evolutionary perspectives at their 2021 study, Kannan and Garad examined the competencies and abilities of quality professionals needed to adjust to Industry 4.0, using a case scenario at an electronics manufacturing business. By examining changes in factories, businesses, products, and customers, the study identified the technical, methodological, social, and personal competences gap of quality experts in the context of Industry 4.0. In order to examine the newly required quality management competencies for Quality 4.0 experts, Santos et al. (2021) conducted study on quality management staff in Portugal. Silva et al. (2022) emphasized the human-centered approach in the Quality 4.0 development, based on a case study of two IT projects. They advocated for the integration of the human element with the technology viewpoint in the age of digital transformation.

Antony et al. (2022b) investigated the possible impact of Quality 4.0 on a range of organizational performance measures using an integrated literature study. Research has shown that Quality 4.0 has a beneficial impact on internal business processes, learning and development, social performance, environmental performance, customer value proposition, and financial performance. In order to comprehend the performance measurement system and quality management in data-driven Industry 4.0, Tambare et al. (2022) examined the present practices, industry standards, and key performance indicators.

Furthermore, based on six dimensions—production and operations function, scope of quality management activities, enabling technologies, latent digitalization capabilities, performance metrics, and quality management principles Prashar (2022) created an organizing framework for quality management in the Industry 4.0 environment. For better quality management in Industry 4.0, Clancy et al. (2022) offered a hybrid digitization approach to process improvement framework that included digitalization with Lean Six Sigma.

3.1.3 Quality 4.0 model and application

The literature review has presented 10 studies that developed various Quality 4.0 models or focused on the application of Quality 4.0 technologies.. Zonnenshain and Kenett (2020) suggested a framework of applied and practical topics that can fill the context of Quality 4.0 based on the innovation elements of Industry 4.0. Sader et al. (2019) presented a theoretical framework for combining Industry 4.0 characteristics with the TQM principles and discussed the role of Industry 4.0 in implementing TQM practices. Baran and Korkusuz Polat (2022) conducted a literature review and classification study regarding Industry 4.0 and Industry 4.0 technologies for TQM. Sariyer et al. (2021) proposed a multi-stage model using big data analytics technologies for quality manage- ment in micro, small, and medium firms. The proposed model can detect defects automatically, predict the required numbers of re-works, and identify the problems' root causes. Ramezani and Jassbi (2020) developed a smart fault diagnosis model using neural networks and an expert system for dealing with control chart patterns.

Regarding the application of Quality 4.0 technologies, Alzahrani et al. (2021) explored the environment of higher education organizations against a Quality 4.0 framework and provided insights regarding their readiness for Quality 4.0 transformation. Singh et al. (2022) used the Quality 4.0 concept to digitalize the traditional quality management system and demonstrated its efficiency in an automotive manufacturing organization. Sozinova and Saveleva (2022) studied the problem of product quality management of Industry 4.0 in transborder markets. Emblemsvåg (2020) analyzed some crucial characteristics of project-based industries concerning Quality 4.0 and found that the credibility and transparency of Quality 4.0 technologies can support relational contracting. In Chris- tou et al. (2022), the authors presented the architecture, design, practical implementation, and evaluation of an end-to-end platform for Quality 4.0 applications.

4. Discussion

4.1 Quality 4.0 definitions

As the literature analysis above shows, there is no consensus on the precise meaning of Quality 4.0, but several papers have put forward definitions. Quality 4.0, according to Dias et al. (2022), is the delivery of higher quality by using cutting-edge technologies to improve the capabilities of both people and quality procedures. Sader et al. (2022) define Quality 4.0 as an expanded approach to quality management that combines new technology with conventional quality practices to broaden the scope of quality management and improve the effectiveness and efficiency of quality-related activities. Quality 4.0, according to Chiarini and Kumar (2022), is a customer-centric, digitally empowered approach that combines people, process, and technology to make evidence-based choices in collaboration with internal and external value chain stakeholders. Quality 4.0, according to Chiarini (2020), is the digitalization of TQM and its effects on quality processes, people, and technology. In order to enhance performance and make prompt, data-driven choices in an end-to-end situation, it emphasizes automation, intelligence, and connection while incorporating all stakeholders and offering transparency and visibility.

In order to achieve new optimums in performance, operational excellence, and innovation to meet an organization's vision, mission, and goals, Antony et al. (2022a) gave a comprehensive definition of Quality 4.0, which is defined as the use of modern technologies to design, operate, and maintain adaptive, predictive, self-corrective, and automated quality systems along with improved human interaction through quality planning, quality assurance, quality control, and quality improvement. According to Chiarini and Kumar (2022), Quality 4.0 is bringing quality management procedures and practices into line with the new capabilities of Industry 4.0. The structure and language it offers quality managers are industry-aligned and enable them to extract step-change performance gains that extend across the value chain, including customers, field service, logistics, manufacturing, engineering, and suppliers. Based on the definitions discussed above, this study proposes that Quality 4.0, the fourth stage of the evolution of quality management, is a framework that uses state-of-the-art technologies in an organization's quality management operations to achieve excellence in quality, increase enterprise efficiency, and boost performance. It is the use of contemporary technologies to digitize quality management (such as design quality, conformance quality, and performance quality). It takes into account automation, intelligence, and connectivity to enhance performance throughout the whole value chain.

Quality 4.0 is an approach to quality improvement wherein digital technologies enhance the organization's capacity to continuously provide consumers with high-performing goods. Quality 4.0 defines "quality" in terms of product requirements, responsiveness, adaptability, agility, and user experience. The shift from manual measurement to totally automated activities is what distinguishes Quality 4.0 from conventional quality (Sader et al., 2022). In order to minimize production halts or product rejections, Quality 4.0 combines manufacturing processes with quality management data and connects to real-time analytic tools that can monitor, analyses, and regulate the full value chain. Reduced quality costs through increased operational efficiency, increased revenue, improved product compliance, decreased non-conformances, on-time delivery, lower supplier failure rates, and more successful new product introductions are some of the benefits of Quality 4.0 (Antony et al., 2022a). By guiding the production process to create better goods at a cheaper cost, Quality 4.0 may increase competitiveness and responsiveness. Customer satisfaction, workforce reduction, market share growth, and financial implications on profit are all indicators of how successful Quality 4.0 is (Antony et al., 2022a).

4.2 Quality 4.0 features

The main evolution from TQM toward Quality 4.0 summarizes into four characteristics: 1) quality manage-

ment digitization, 2) predictive quality management, 3) mass personalization, and 4) intelligent quality manage- ment. Thus, this study proposes a four-dimension Quality

4.0 framework, as described in Fig. 6. In the following subsections, details of the Quality 4.0 features are explained.

(1) Quality management digitization

Quality 4.0 is first featured by digitization quality management. Quality 4.0 is the digitization of traditional quality practices and emphasizes using digital tools to enhance an organization's capacity to meet customer expectations with high quality. Managing Quality 4.0 means digitalizing all three phases of quality management, that is, design quality, conformance quality, and performance quality, using advanced techniques (Balouei Jamkhaneh et al., 2022). The use of digital technologies changes quality in different ways and improves the ability of companies to produce high-quality products. In Quality 4.0, digitization is employed in process adjustment, signal feedback, adaptive learning, and self-induced correction systems (Antony et al., 2023).

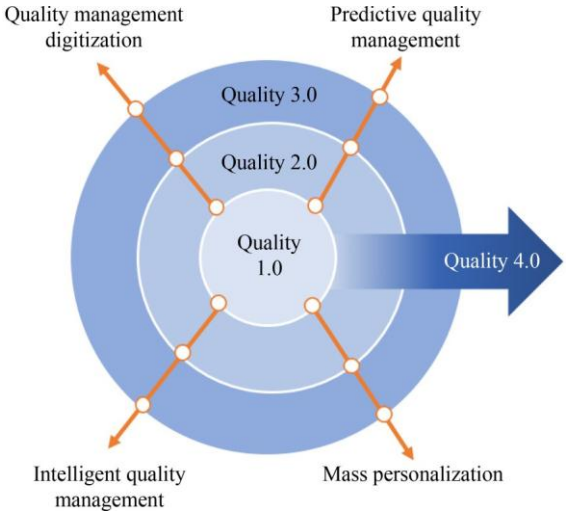


Figure 2: The four-dimension Quality 4.0 framework

Quality 4.0 requires the digitalization of quality technology, processes, and people. By automatically collecting and analyzing the product usage data in the hands of consumers using AI, the quality of performance can be efficiently monitored. Suppliers are instantly informed about inventory consumption and can fulfill demand just in time. Utilizing sensors and real-time inspection technologies allowed for the instant exclusion of defective products, not only from a sample of products but from the total population engaged in manufacturing. Additionally, the cost of quality is reduced since manufacturing errors are identified early and the underlying reasons are examined and fixed early thanks to sophisticated quality control systems that are in place across the whole production process. It is anticipated that Quality 4.0 would lead to exceptional company excellence, efficacy, and efficiency, as well as, eventually, increased customer happiness.

(2) Quality management that is predictive

The second feature of Quality 4.0 is predictive quality management, which uses just-in-time quality management by automatically gathering and analyzing quality data. Quality 4.0 has led to the replacement of conventional quality control with real-time quality monitoring. The function of quality management shifts from preventative to predictive due to the new sensor technologies and their strong analytical capabilities, which enable the prediction of process and product faults in advance (Chiarini and Kumar, 2022). In order to identify anomalous patterns in real time and take the appropriate corrective action to avoid product rejections, Quality 4.0 allows for the monitoring, analysis, and management of the whole value chain. Based on real-time data monitoring and analysis, Industry 4.0 technologies may manage the whole value chain, removing all waste and attaining high process quality and zero defects (Sader et al., 2022). They let the business to see quality indicators in real time, such as customer service, engineering manufacturing, supplier performance, and production efficiency. Additionally, smart gadgets have the ability to transmit information on product performance, usage, and problems, which helps to improve subsequent items. The outcome will be an early prediction of quality issues and a shift in the customer's position from receiver to contributor to the product value chain.

(3) Customization in bulk

Mass personalization is another aspect of Quality 4.0, since consumers are becoming more actively engaged in creating customized goods. These days, a broad range of small-batch, low-volume production is typical. With its ability to produce goods according to the preferences of each individual consumer, Quality 4.0 facilitates the development of new business models.

Customers will participate in the production process by offering communication channels before to, during, and after the manufacturing process as a result of Industry 4.0. Big data research enables a business to fully comprehend client needs, anticipate market demand in advance, and provide the appropriate items at the appropriate moment. Furthermore, AI will enable the management of the whole supply chain, including incoming logistics, manufacturing, outbound logistics, marketing and sales, and service, as well as the correct prediction of customer demands.

Customer choice over what they buy, how many items they buy, and the option to modify orders at any point throughout manufacturing without incurring extra fees are all part of Quality 4.0. Customers may get product consumption data and customized product utilization with smart goods (Kannan and Garad, 2021). With access to product information and technical data, consumers are more aware of and have greater expectations for the dependability and quality of items. Due to shifting consumer expectations and wants, trends in specific client requests may lead to more customized produced goods and more market instability.

(4) Intelligent management of quality

Smart factories, smart sensors, and smart machines working together to provide intelligent quality management in an integrated production system is the hallmark of Quality 4.0 (see Fig. 7). The smart factory will include fully automated systems, actors, and sensors for production. Smart sensors are able to recognize, track, and gather any kind of data related to raw materials, work-in-progress, and final goods. As a result, businesses may use analytics to predict maintenance needs and quality issues. Intelligent machines are networked and self-learning. They establish a cooperative community, collect and evaluate data, make independent and self-optimized choices, and manage productivity in a data-driven, objective way. New approaches may be able to notify machine health signals beforehand, which would save downtime and allow

for prompt repair.

One of the main components of Quality 4.0 is the quick and effective gathering and processing of data from various sources. By carrying information, communicating with people, and sending information back to the production systems for design and process optimization, the goods will be intelligent (Kannan and Garad, 2021). By analyzing and monitoring product performance, designers may also anticipate client use and repair needs. Under Quality 4.0, employees' responsibilities have shifted from being "machine operators" to overseeing the job that machines do. Workers now have to be adept at making decisions and addressing problems, and the job content has also shifted to a more coordinated posture.

5. Conclusions

We conducted a thorough evaluation of the existing literature on Quality 4.0 in this post. We found and examined 46 publications from scientific journals using descriptive and content analytics. The chosen papers were divided into four groups based on the specific study themes: Quality 4.0 idea, Quality 4.0 implementation, Quality 4.0 management, and Quality 4.0 model and application. According to the publishing trend, there have been a lot more papers on Quality 4.0 since 2019, with the most of them coming out in the last two years. Additionally, the International publication of Quality and Reliability Management is the leading publication for Quality 4.0 papers, and literature reviews are the most often utilized study methodology.

Based on this assessment, we defined Quality 4.0 broadly and listed its four features: intelligent quality management, mass personalization, predictive quality management, and digitization of quality management. In addition, we presented the quality curve theory to explain how quality might be established at various points in a product's value chain. Analyzing the chosen papers also helped to clarify the current research gaps and provide potential avenues for further investigation. In order to help businesses achieve greater competitive performance through enhanced customer satisfaction, product quality, and operational efficiencies, this review study offers guidelines and insights to scholars and practitioners on how to further refine the Quality 4.0 theory and apply the Quality 4.0 technologies.

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