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Total Quality Management 4.0 Framework: Present and Future

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ABSTRACT

Utilising socio-technical system theory, this study explores the Total Quality Management 4.0 (TQM 4.0) framework on the integration of quality management principles and industry 4.0 tools. The systematic literature review technique was applied to 203 articles from the Web of Science database to establish a theoretical framework for TQM 4.0. After an in-depth analysis of twenty key papers, twenty-one indicators for TQM 4.0 practices are proposed. Using the Pareto analysis, thirteen of the most important are identified. The research also explores the five major pillars of TQM 4.0, including technical elements, social elements, smart organisation, smart factory, and smart product. The study thoroughly understands TQM 4.0 and its related trending topics by employing a bibliometric technique to examine the publications' keywords. The result of the bibliometric analysis shows that TQM 4.0 research addresses not only issues associated with Industry 4.0 techniques, such as big data, artificial intelligence, and machine learning but also digital transformation, sustainability, and quality culture. Especially organisational performance has been a relatively recent topic of interest to TQM 4.0 researchers. The study provides a TQM 4.0 framework for scholars to conduct additional research and for practitioners to implement the TQM 4.0 to gain long-term sustainability, as well as provides an overview of the current TQM 4.0 and suggests possible future research trends in the TQM field.

Keywords: *TQM 4.0, Bibliometric technique, Pareto analysis, SLR methodology, Socio-technical System theory*

1. INTRODUCTION

The Fourth Industrial Revolution (called Industry 4.0) includes characteristics such as big data analytics, autonomous robotics, artificial intelligence (AI), cyber-physical system (CPS), the internet of things, additive manufacturing, and machine learning (Chiarini, 2020; Sordan *et al*., 2022). This revolution impacts the competitive context of many sectors, including quality management. Total Quality Management (TQM) is an essential management strategy for businesses to maintain and increase their competitive edge. TQM is a critical aspect that assists businesses in achieving success (Kafetzopoulos *et al.*, 2015; Pertusa-Ortega *et al.*, 2021). In the evolution of technology in Industry 4.0, TQM procedures have evolved in response to new challenges and opportunities. Therefore, it is vital to identify the core elements of TQM practices in Industry 4.0. Some researchers have started to identify the key components of TQM techniques in the context of Industry 4.0 (called Quality 4.0 or TQM 4.0) (Sony *et al*., 2020; Sader *et al.*, 2021). Throughout the Fourth Industrial Revolution, TQM 4.0 practices were developed and numerous current technologies were integrated into the QM principles. As described by Sader *et al.* (2022), TQM 4.0 is an improved approach to quality management in which new technologies are integrated with traditional quality methods (QC, QA, TQM) to widen the quality management scope and boost quality activities. Nguyen *et al.* (2022) analysed TQM 4.0 practices, including social and technical components, whereas Chiarini & Kumar (2022) introduced TQM 4.0 practices with eleven categories. However, TQM 4.0 research is in its infancy, with most studies focusing on the definition of TQM 4.0 / Quality 4.0. Providing a comprehensive summary of TQM 4.0, particularly focusing on indicators of TQM 4.0 practices, remains unanswered. It is crucial to have a comprehensive system of these practices and to determine which TQM 4.0 practices are most important based on previous research.

In addition, some authors argue that the majority of studies lack a theoretical foundation (Chiarini, 2020; Nguyen *et al.*, 2022). It is necessary to define the main pillars of the TQM 4.0 practices framework based on theory. The purpose of this paper is to use the socio-technical system (STS) theory to identify the main pillars of TQM 4.0 practices. According to the researchers, STS theory can be applied to

Industry 4.0 (Davis *et al.*, 2014; Cimini *et al*., 2020; Sony & Naik, 2020). The authors develop a theoretical framework for TQM 4.0 based on STS theory and the key TQM 4.0 practices gleaned from a comprehensive examination of numerous studies.

The relationships between TQM 4.0 practices and other factors are largely unexplored. It is possible that companies are beginning to adopt TQM 4.0 practices, so this discovery is in its infancy. Tradition TQM typically has a positive impact on performance, so if TQM 4.0 is geared towards a sustainable business model, will it enhance sustainable performance? Or, within the context of Industry 4.0, do TQM 4.0 practices influence digital transformation? In research and practice, it is vital to investigate these relationships between TQM 4.0 practices and others. Therefore, it is essential to propose a TQM practices model with surrounding relationships for future research in this study.

The authors intend to discover an overview of the current TQM 4.0 and the trending TQM 4.0 themes in the future to fulfill the above gaps. Therefore, the authors use the STS methodology, bibliometric technique, and Pareto tool to solve the three following questions.

***Research question 1**: What are key TQM 4.0 practices? What are the most important?*
***Research question 2**: What are the main pillars of the TQM 4.0 practices framework?*
***Research question 3**: What agendas of the TQM 4.0 practices framework will necessitate attention in the future?*

This study's contribution is to provide a comprehensive summary of TQM 4.0, particularly focusing on indicators of TQM 4.0 practices and determining which are most important. Twenty-one indicators for TQM 4.0 practices are proposed after thoroughly examining twenty key papers. Thirteen of the most significant are determined using the Pareto tool.

This research will develop TQM 4.0 model framework based on key important TQM 4.0 practices and socio-technical system (STS) theory. The study also provides an overview of TQM 4.0's current and future developments using the Bibliometric technique. In the context of Industry 4.0, this study will give practitioners with a TQM 4.0 practice applicable in organisations to adapt to a fast-changed environment.

2. LITERATURE REVIEW

2.1 Industry 4.0 Definition

The Fourth Industrial Revolution, also known as Industry 4.0, has introduced intelligence digitalisation and integration of information technologies. It constructs both physical and virtual means and integrates with traditional quality practices (QC, QA, TQM) to expand the quality management scope and improve quality activities (Zhou *et al.*, 2020; Sordan *et al*., 2022).

The First Industrial Revolution began in the 18th century when steam power was first utilised in England, thus called "mechanisation". The Second Industrial Revolution started in the 19th century and was characterised by the use of electricity to create mass manufacturing lines in response to rising demand, thus called "electrification". The Third Industrial Revolution appeared in the 1970s with robots programmable for production optimisation. The advantages of automation and technological integration in production cleared the path for a greater industrial leap. People began to generate autonomously using computers, mobile phones, and the internet, thus called "digitisation".

The Fourth Industrial Revolution, which is currently occurring, is characterised by the use of Cyber-Physical Systems (CPS), Artificial Intelligence (AI), Robotics, Big-Data, Machine Learning (ML), Internet of Things (IoT), Cloud Computing (CC), Augmented Reality and Virtual Reality (AR/VR) (Chiarini, 2020; Zhou *et al*., 2020; Sordan *et al*., 2022). These technologies have produced new production systems, including smart factories, machines, and products. In addition to TQM 4.0, Agribusiness 4.0, Logistics 4.0, Health 4.0, and Service 4.0, the word 4.0 has been used in several additional disciplines. etc., demonstrating the effects of Industry 4.0 on these concepts.

2.2 Development of Total Quality Management (TQM)

TQM is the managerial strategy in the industrialised world, and it gives the principles, tools, and processes by which senior management and workers achieve stakeholder satisfaction in their organisations (Zhang *et al*., 2020; Kafetzopoulos *et al*., 2015; Alshourah, 2021). In addition, TQM embraces every part of a company, such as production, marketing, human resources, and finance.

Some scholars describe TQM as quality management standardisation like ISO 9001; other researchers provide TQM by using business excellence models (EFQM, Baldrige Malcolm Quality Award, and Deming Prize). ISO 9001 defines the requirements for a quality management system (QMS). This standard is based on various concepts of quality management, including a strong customer focus, continuous improvement, involvement of leader, and process approach. ISO 9004 contains guidance for strengthening an organisation's capacity to attain sustainable development and a self-assessment instrument for determining the degree of adoption (ISO, 2021).

Sader *et al.* (2019) illustrate that quality control, quality assurance, and Total Quality Management are included in the development of TQM. Additionally, the TQM was combined with Industry 4.0 tools to a new approach (see **Figure 1**). While quality control focuses on the product via inspection and specific instruments, quality assurance ensures the quality of goods and increases process stability. While TQM is a management paradigm that encompasses all product, process, and system quality challenges, TQM 4.0 integrates customer, supplier, company, process, and product into one system.

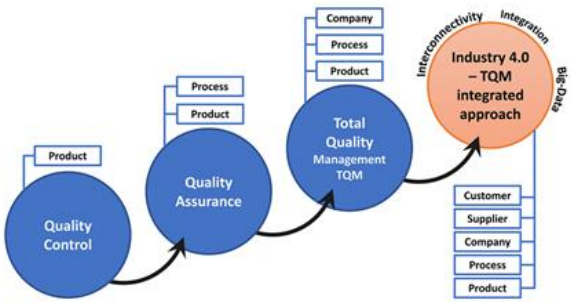

Figure 1 The development of total quality management (Source: Sader *et al.*, 2019)

2.3 TQM 4.0 practices

Many authors proposed four concepts for the quality revolution (Radziwill, 2018; Sader *et al*., 2019). The first is Quality Control with the inspection to remove poor-quality items from the entire production. The second, it focuses on process management (Quality Assurance). The third is an all-encompassing approach to quality known as Total Quality Management (TQM). The current fourth came from the establishment of an intelligent business and the instantaneous analysis of production-related data. It is Quality 4.0 (or TQM 4.0).

During the First and Second Industrial Revolutions, the quality management strategy began with product inspection. The inspection was then broadened to include inputs, processes, and outputs. Engineers used tools of statistical process control (SPCs) such as Checklists, Pareto charts, Fishbone diagrams, Flowcharts, Control Charts, Scatter Diagrams, and Histograms. These charts were utilised for problem-solving and process improvement by gathering and evaluating data to inform decision-making. During the Third Industrial Revolution, SPCs flourished and served as a foundation for developing several additional methods, such as Robust Design Methods and Design of Experiments (DOE). In the 1990s, the establishment and growth of Quality Management System (QMS) were significant. TQM is a philosophy that encompasses all aspects of a business. The first ISO 9001 standard by the International Organization for Standardization (ISO) was introduced in 1987. This standard provides a model for establishing and maintaining a management system to enhance the products and services quality and continuously satisfy the expectations of their consumers.

TQM 4.0 practices were developed and incorporated numerous current technologies into the QM principles throughout the Fourth Industrial Revolution. According to Sader *et al.* (2022), TQM 4.0 is an enhanced approach to quality management in which new technologies are integrated with traditional quality practices (QC, QA, TQM) to broaden the quality management scope and enhance quality activities. Nguyen *et al.* (2022) analysed TQM 4.0 practices, including both social and technical aspects. Chiarini & Kumar (2022) proposed TQM 4.0 practices with eleven themes regarding model development, top management, process mapping, data collection and integration with the ERP system, artificial intelligence use, machine-to-machine data communication, product identification and traceability, document control, and digital skills for quality staff.

Sony *et al.* (2020) indicate TQM 4.0 goes beyond technology. It's a novel way to use digital tools to boost an organisation's ability to deliver high-quality goods. TQM 4.0 uses empirical knowledge discovery, real-time data collection, and analysis to make smarter decisions (Escobar *et al.*, 2021). Finally, Sader *et al.* (2021) conclude that TQM 4.0 "is the new generation, evolution, or revolution of quality management", resulting from the development of Industry 4.0 tools. Most of the studies concentrate on defining TQM 4.0/ Quality 4.0. The unanswered issue is a comprehensive summary of TQM 4.0, concentrating specifically on indicators of TQM 4.0 practices. It is essential to have an exhaustive system of these practices and to determine, based on previous research, which TQM 4.0 practices are the most important.

3. METHODOLOGY

The authors employed a systematic literature review (SLR) and bibliometric technique to investigate Total Quality Management 4.0 (TQM 4.0) in this research. SLR method is the most frequently employed systematic literature review. Bibliometric analysis is a research method that aids in identifying current trends in the literature and provides direction and motivation for future research endeavours (Muhuri *et al.*, 2019; Sordan *et al.*, 2022; Soledispa-Cañarte *et al.*, 2023). Consequently, this paper employs bibliometric analysis to investigate TQM 4.0 from a broad perspective. The authors employ four stages of SLR methodology from Cruz-Benito (2016) and combine bibliometric technique (Nagpal *et al*., 2021) and Pareto analysis (Bajaj *et al*., 2018; Karuppusami & Gandhinathan, 2006) in the fourth step.

Step 1: *Identify criteria*

To analyse the framework of TQM integrating Industry 4.0 tools, this study investigates Total Quality Management, Industry 4.0, TQM 4.0, and Quality 4.0 as keywords. Quality management system (QMS), or quality methods, or quality tools such as Lean, Six Sigma, and Statistical Process Control are the inclusion criteria.

Step 2: *Perform a database search and retrieve pertinent information*

The authors conducted a search in the Web of Science (WoS) database, which is widely regarded as a premier scientific resource.

Step 3: *Evaluate the quality of the outcomes*

The inclusion and exclusion criteria were applied with great attention to each study. In addition, the writers rejected studies that lacked quality management content relevance.

Step 4: *Analyse data, discuss results, and give suggestions based on the outcomes*

The study investigates TQM 4.0 literature and explores the main themes of the TQM 4.0 model. The total number of articles and the number of publications by year are described. Year of publications, languages, journals, titles, authors, and keywords are exported in CSV format for the publications that fulfill the requirements. The retrieval occurred on May 31, 2021. Keywords, Co-authorship, Co-occurrence, themes, and trend subjects were analysed using. "Links attribute" and "Total link strength attribute" are two typical weight attributions that are applied (Stephan *et al.*, 2017; Nagpal *et al.*, 2021). Analysing the TQM 4.0 practices using Pareto tools. The chart illustrates the various factors in descending order and includes important indicators which distinguish the 80 cumulative percent (Bajaj *et al.*, 2018; Karuppusami & Gandhinathan, 2006).

4. RESULTS

4.1 Characterisation of the Publications

The Web of Science (WoS) database was searched four times for the articles published between 2011 and 2022. Firstly, the authors searched the keyword "QUALITY 4.0".

Secondly, the key phrase "TQM 4.0." was identified. Thirdly, the terms "TOTAL QUALITY MANAGEMENT" and "INDUSTRY 4.0" were found. Finally, the authors explored key phrases "QUALITY MANAGEMENT" and "INDUSTRY 4.0". The outcomes of four iterations of searching are displayed in **Table 1**.

Table 1 The number of articles in the WoS database

Keyword	Articles	Review Articles	Proceedings Articles	Total
Quality 4.0	40	9	7	56
TQM 4.0	3	0	0	3
Total Quality Management & Industry 4.0	27	7	4	38
Quality Management & Industry 4.0	95	40	15	150

In stage 1:

The authors examined the titles, keywords, and abstracts of all papers in order to organise them according to inclusion and exclusion criteria. The study removed the articles that focused on attaining specifications for electrical products, wood products, medicinal products, robot cells, aircraft fuselages, and wind turbine blades (device), a microneedle array, and CNC machines. The authors also excluded studies that lacked quality management content relevance. Authors maintained articles concentrating on TQM, and we utilised quality methods or quality tools such as Lean and Six Sigma. The outcomes are listed in **Table 2**.

In stage 2:

Based on the results of the first stage, the authors gathered all articles into a single file and deleted similar articles; only one was retained. Despite the fact that the keywords are extremely diverse, there are numerous documents that match. The result is 203 papers.

Table 2 The amount of articles for two stages

Keywords	Number	Stage 1	Stage 2
Quality 4.0	56	52	203
TQM 4.0	3	3	
Total Quality Management & Industry 4.0	38	35	
Quality Management & Industry 4.0	150	122	

Although the authors reviewed articles published between 2011 and 2022, the results demonstrate that these investigations were conducted after 2016, when Industry 4.0 became widespread. Almost all articles published between 2016 and 2018 were conference papers, and the number of articles published on this subject in 2019 will climb significantly (see **Figure 2**).

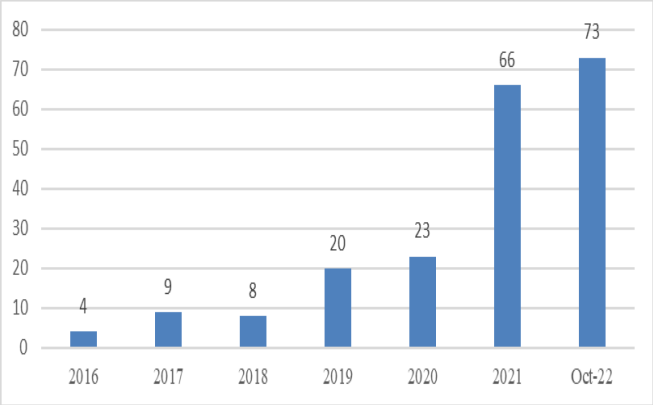

Figure 2 The number of publications by year

Several researchers have tried identifying the key elements of TQM techniques in the Industry 4.0 context; however, their findings are not theorised (Chiarini, 2020). In addition, Chiarini (2020) recommended that future studies focus on the integration of ISO 9001, quality function deployment (QFD), failure mode and effects analysis (FMEA), and Six Sigma (DMAIC). Digitalisation is now lacking in TQM literature (Carnerud *et al.*, 2020).

4.2 Analyse of TQM Practices in Industry 4.0 (TQM 4.0 Practices)

Developing components for TQM 4.0 practices is crucial for both research and practice. This issue has been the focus of investigation by scholars. However, various researchers have named and defined practices differently. The authors have attempted to synthesise TQM 4.0 practices from previous studies. **Table 3** details the main studies that mention TQM 4.0 practices. The majority of studies are in their beginnings, focusing primarily on qualitative analysis and literature review.

Table 3 Key papers of TQM practices in industry 4.0 (TQM 4.0)

No.	Authors	Journal	Method
1	Maganga & Taifa (2022)	The TQM Journal	Mixed methods (qualitative and quantitative methods)
2	Broday (2022)	International Journal of Quality and Service Sciences	Bibliometric method (Literature review)
3	Balouei *et al.* (2022)	The TQM Journal	Grey DEMATEL technique
4	Nguyen *et al.* (2022)	Total Quality Management and Business Excellence	Delphi and AHP method
5	Antony *et al.* (2022)	The TQM Journal	Qualitative interview approach
6	Carvalho, & Sampaio (2022)	International Journal of Quality and Reliability Management	Bibliometric analysis (literature review)
7	Chiarini & Kumar (2022)	International Journal of Production Research	Mixed methods (qualitative and

No.	Authors	Journal	Method
			quantitative methods)
8	Huang *et al.* (2022)	Sustainability	Structural equation modelling (SEM)
9	Kumar *et al.* (2022)	International Journal of Quality and Reliability Management	Literature review
10	Sader *et al.* (2021)	Total Quality Management and Business Excellence	Literature review
11	Sony *et al.* (2020)	The TQM Journal	Literature review
12	Fundin *et al.* (2020)	Total Quality Management and Business Excellence	Extensive data gathered during a workshop process
13	Wen *et al.* (2020)	Total Quality Management and Business Excellence	Literature review
14	Glogovac *et al.* (2020)	Total Quality Management and Business Excellence	Confirmatory factor analysis (CFA) and Structural equation modelling (SEM)
15	Asif (2020)	Journal of Cleaner Production	Literature review
16	Chiarini (2020)	The TQM Journal	Systematic literature review
17	Kupper *et al.* (2019)	Boston Consulting Group	Quantitative technique (descriptive statistics)
18	Park *et al.* (2017)	Total Quality Management and Business Excellence	Literature review
19	Efimova & Briš (2021)	Quality Innovation Prosperity	Literature review and a pilot study
20	Mtotywa, (2022)	Quality Innovation Prosperity	Exploratory factor analysis

In **Table 4**, the authors define TQM 4.0 practices. Summarising previous studies, the authors reviewed 21 elements for TQM 4.0 practices. The study identifies each item in **Table 4** and provides a detailed explanation of its meaning.

Table 4 Identification of key TQM 4.0 practices

No.	Code	Factors	Explanation
1	TM1	Top managements commitment for TQM 4.0	In TQM 4.0 model, top managements support for TQM 4.0 development.
2	TM2	Top managements support for TQM 4.0	In TQM 4.0 model, top managements support and provide resources for TQM 4.0 development.
3	TM3	TQM 4.0-driven mindfulness	TQM 4.0 model encourages employees self-leaders and to actively solve problems instead of waiting for regular processes.
4	SKILL1	Skills related to TQM 4.0	In TQM 4.0 model, quality staff should acquire more knowledge of skills related to data analytics, AI, CPS,…
5	SKILL2	Data scientists as quality experts	In TQM 4.0 model, data scientists as quality experts.
6	SYSTEM1	Lean structure organisation	TQM 4.0 will rise to lean structures organisation which bring operational efficiencies and make decision-making quicker by AI-based systems.
7	SYSTEM2	Collaboration all stakeholders	TQM 4.0 tools will help improve communication through connectivity features and social networking, facilitating innovation and sharing ideas between production parties and stakeholders (such as: suppliers, patterners, customers, and investors)
8	SYSTEM3	Managing networked firms in business ecosystems	In TQM 4.0 model, companies will provide a virtual platform used by buyers and sellers and credit cards. Companies and logistics providers also use the same platform to provide services seamlessly.
9	SYSTEM4	Stability in change	TQM 4.0 model will adapt fast-changing environment with exploration (external innovation such as innovation of products) and exploitation (innovation with an internal focus, for instance, on processes)
10	SYSTEM5	Link quality and sustainability	TQM 4.0 model needs to link quality and sustainability.
11	QC1	Real-time document control	In TQM 4.0 model, work instructions are automated and controlled in real-time.
12	QC2	Digital standard operating procedures (SOPs)	TQM 4.0 will provide digital standard operating procedures (SOPs) to ensure that workers have the most up-to-date instructions
13	QC3	Automatic data collection	In TQM 4.0 model, many types of product and customer data are automatically collected.
14	QC4	Real-time quality inspection	TQM 4.0 model will allow real-time quality inspection.
15	QC5	Total inspection	TQM 4.0 model will allow total inspection instead of sample inspection.

No.	Code	Factors	Explanation
16	QC6	A new kind of SPC based on machine learning	In TQM 4.0 model, a new kind of SPC [statistical process control] based on machine learning predicts all kinds of defects during machining and gives feedback to the machine itself, automatically correcting its parameters without human interaction.
17	QA1	Using AI software for prediction	TQM 4.0 model will use AI software for predictive maintenance in advance and preventive intervention to avoid downtime or system failure.
18	QA2	Using sensors at each production stage	TQM 4.0 model will aid processes' optimisation, improve efficiency and resource allocation by using sensors at each production stage and provide means to support quality activities that will minimise rework and scrape.
19	QA3	Big-data analysis	In the TQM 4.0 model, big-data analysis will collect real-time data generated during production and transform it into friendly useful information.
20	QA4	Predict market demand and consumption trends	TQM 4.0 model will support making accurate early predictions of market demand and consumption trends and changes.
21	QA5	Smart technologies for identification and traceability	In TQM 4.0 model, smart technologies can significantly assist companies in identifying and tracking products.

Table 5 provides the specifics of the practices identified by various researchers in their articles. Twenty key papers were exhaustively analysed in order to identify the TQM 4.0 practices. The TQM 4.0 practices outlined in the studies will be marked as "1", and then authors will count the number of practices present in the studies.

Table 5 Practices of Total Quality Management 4.0

No.	Authors	TM1	TM2	TM3	SKILL1	SKILL2	SYSTEM1	SYSTEM2	SYSTEM3	SYSTEM4	SYSTEM5	QC1	QC2	QC3	QC4	QC5	QC6	QA1	QA2	QA3	QA4	QA5
1	Maganga & Taifa (2022)	1	1		1									1	1		1	1	1	1		1
2	Broday (2022)	1	1		1			1	1					1				1		1	1	
3	Balouei *et al.* (2022)	1	1	1	1			1	1		1				1	1	1	1	1	1	1	
4	Nguyen *et al.* (2022)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Antony *et al.* (2022)	1	1	1	1			1			1	1		1	1	1	1	1	1	1	1	1
6	Carvalho, & Sampaio (2022)	1	1	1	1	1		1	1		1		1	1	1		1	1	1	1	1	1
7	Chiarini & Kumar (2022)	1	1		1							1		1			1	1				1
8	Huang *et al.* (2022)	1	1		1			1			1	1		1			1		1	1	1	1
9	Kumar *et al.* (2022)	1	1		1			1	1		1			1			1	1	1	1	1	1
10	Sader *et al.* (2021)	1						1	1					1	1	1	1	1	1	1	1	1
11	Sony *et al.* (2020)	1	1	1	1				1					1			1	1	1	1	1	1
12	Fundin *et al.* (2020)		1	1				1	1	1	1							1			1	1
13	Wen *et al.* (2020)								1					1		1			1	1	1	1
14	Glogovac *et al.* (2020)	1	1	1	1			1	1					1			1			1	1	
15	Asif (2020)			1	1		1		1				1	1				1	1	1	1	1
16	Chiarini (2020)		1	1	1			1				1	1	1			1	1	1	1	1	1
17	Kupper *et al.* (2019)			1	1	1							1	1			1	1		1	1	
18	Park *et al.* (2017)			1	1	1								1				1	1	1		
19	Efimova & Briš (2021)	1			1									1			1	1	1	1	1	1
20	Mtotywa, (2022)	1		1	1						1			1	1	1	1	1	1	1	1	1

Consequently, a criterion for selecting the practices was established, and the Pareto tool was applied to analyse the TQM 4.0 practices. The Pareto analysis is one of seven quality tools. It is a fundamental and effective statistical method that ranks elements in decreasing order of frequency. **Table 6** shows the frequency of occurrence, percentage of frequency of occurrence, and cumulative percentage of each TQM 4.0 practice.

Table 6 List of TQM 4.0 Practices According to Pareto Analysis

No	TQM 4.0 practice	Symbol	Frequency of occurrence	Percentage of frequency of occurrence	Cumulative percentage
1	Automatic data collection	QC3	18	7.8%	7.8%
2	Big-data analysis	QA3	18	7.8%	15.5%
3	Skills related to TQM 4.0	SKILL1	17	7.3%	22.8%
4	Using AI software for prediction	QA1	17	7.3%	30.2%
5	Predict market demand and consumption trends	QA4	17	7.3%	37.5%
6	A new kind of SPC based on machine learning	QC6	15	6.5%	44.0%
7	Using sensors at each production stage	QA2	15	6.5%	50.4%
8	Smart technologies for identification and traceability	QA5	15	6.5%	56.9%
9	Top managements commitment for TQM 4.0	TM1	14	6.0%	62.9%
10	Top managements support for TQM 4.0	TM2	13	5.6%	68.5%
11	TQM 4.0-driven culture	TM3	12	5.2%	73.7%
12	Collaboration all stakeholders	SYSTEM2	11	4.7%	78.4%
13	Managing networked firms in business ecosystems	SYSTEM3	11	4.7%	83.2%
14	Link quality and sustainability	SYSTEM5	8	3.4%	86.6%
15	Real-time quality inspection	QC4	7	3.0%	89.7%
16	Total inspection	QC5	6	2.6%	92.2%
17	Real-time document control	QC1	5	2.2%	94.4%
18	Digital standard operating procedures (SOPs)	QC2	5	2.2%	96.6%
19	Data scientists as quality experts	SKILL2	4	1.7%	98.3%
20	Lean structure organisation	SYSTEM1	2	0.9%	99.1%
21	Stability in change	SYSTEM4	2	0.9%	100.0%

Figure 3 is a graph illustrating the results of the analysis. The graph depicts the various factors in descending order and includes important indicators that distinguish the 80 cumulative percent and identify the remaining 20 percent that are the least significant. The result shows that the most important factors of TQM 4.0 practices are: Automatic data collection, Big-data analysis, Skills related to TQM 4.0, Using AI software for prediction, Predict market demand and consumption trends, A new kind of SPC based on machine learning, Using sensors at each production stage, Smart technologies for identification and traceability, Top managements commitment for TQM 4.0, Top managements support for TQM 4.0, TQM 4.0-driven culture, Collaboration all stakeholders, Managing networked firms in business ecosystems.

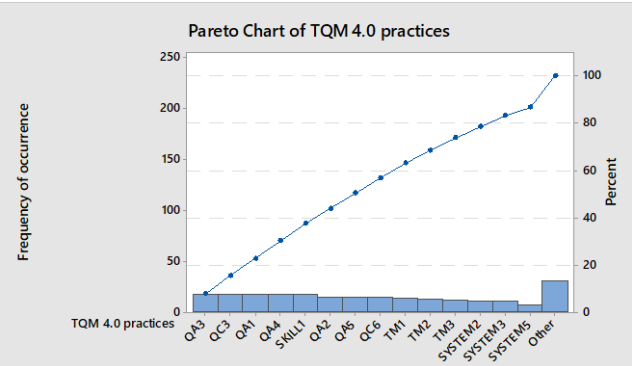

Figure 3 Pareto chart of TQM 4.0 practices

4.3 Bibliometric Analysis

In order to have a comprehensive understanding of TQM 4.0 and its related trending themes, the authors analysed the publications' keywords using a bibliometric method. Keywords that appeared more than twice in the WoS database were included in the final analysis. Among the 867 keywords, 207 met the threshold.

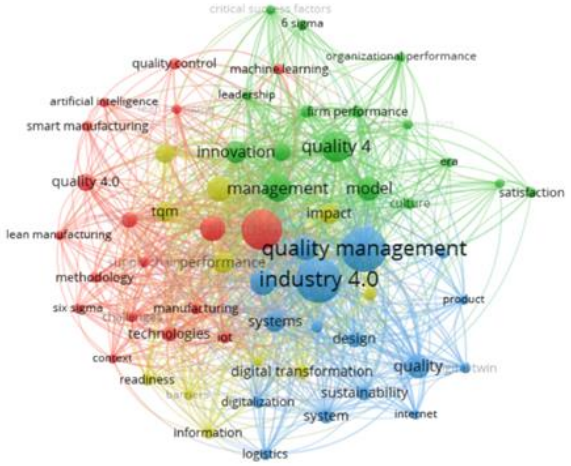

Figure 4 The publications' keywords

Figure 4 displays keyword co-occurrence. The size of the nodes determined the frequency of occurrence. The lines connecting the nodes indicate their co-occurrence in the

same publication. The greater the co-occurrence of two terms, the shorter the distance between two nodes. The keywords that appeared most were "Quality management" (total link strength 413; links other words 150 times), "Industry 4.0" (total link strength 350; links other words 153 times), "Quality 4.0" (total link strength 243; links other words 98 times.

Figure 5 The most of publications' keywords

Figure 5 provides details on the terms that appear more than five times. The size of the typeface indicates the frequency of occurrence. The most frequent occurrences of key phrases are "quality management", "industry 4.0", "innovation", "systems", "digital transformation", and "sustainability".

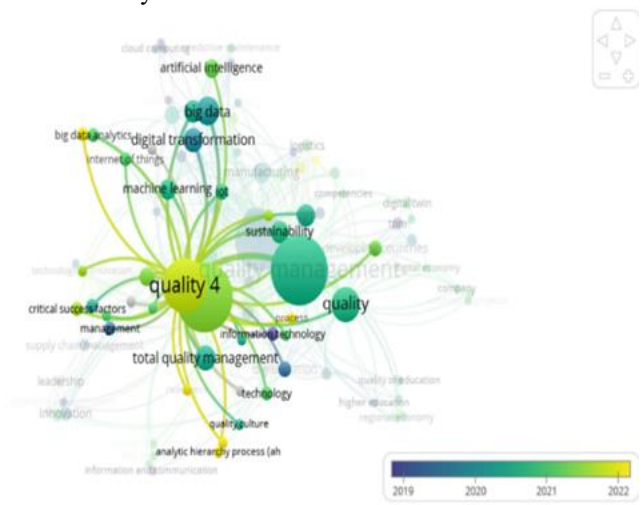

Figure 6 The keyword "Quality 4.0"

According to the keywords used between November 2019 and October 2022, the network map of trend subjects may be shown. The indicators display the current publications in a range from navy to yellow. Recently, some researches focusing on quality 4.0 have been released. Quality 4.0 studies frequently address the following subjects: digital transformation, sustainability, big data, artificial intelligence, machine learning, quality culture, etc (see **Figure 6**). The distance between the two circles represents their relationship. The size of the circles shows the frequency with which each keyword appears.

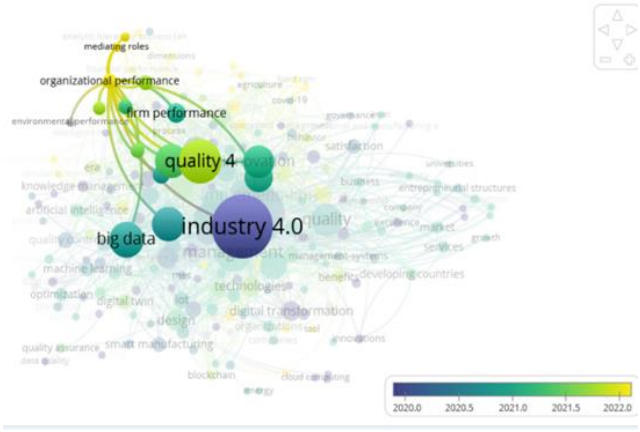

Figure 7 The most keyword "Performance"

Additionally, the authors emphasise new keywords on the map. According to data from November 2019 and October 2022, the "organisational performance" node is highlighted yellow in **Figure 7**, indicating that this notion is new to the quality 4.0 field. The result shows the relationship between this notion and other essential terms, such as mediating role, firm performance, environmental performance, innovation, big data, quality 4.0, industry 4.0, etc. These issues related to organisation performance in TQM 4.0 are interesting to researchers.

5. DISCUSSIONS

5.1 The Core Pillars of The TQM 4.0 Model Based on STS Theory

The authors construct a comprehensive TQM 4.0 framework based on the key TQM 4.0 practices gleaned from a thorough examination of numerous studies. To develop the extensive TQM 4.0 model, the authors employ STS theory**.** According to the researchers, STS theory is employed to investigate Industry 4.0 (Davis *et al.*, 2014; Cimini *et al.*, 2020; Sony & Naik, 2020). Based on STS theory, the authors developed a theoretical framework for TQM 4.0, which concludes five key pillars of TQM 4.0 (see **Figure 8**). There are two background pillars, comprising technological and social aspects, and three vertical pillars, including smart organisation, smart factory, and smart product, to create a TQM 4.0 house.

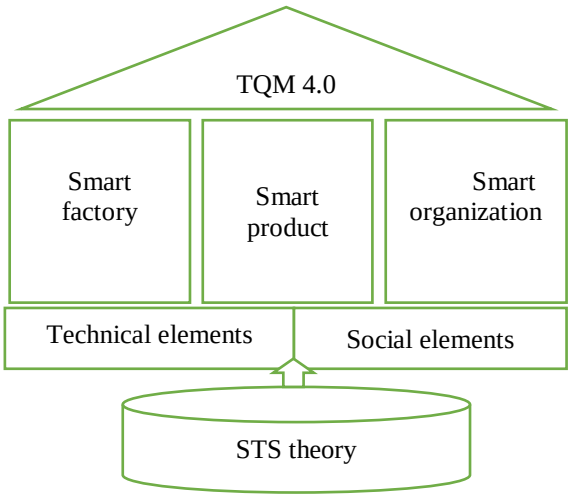

Figure 8 The main pillars of TQM 4.0 model

Technical elements: The TQM 4.0 model employs Industry 4.0 technologies like CPS, AI and machine learning, autonomous robotics, Big-Data, Cloud Computing, and the IoT. Utilising IoT has improved productivity at work, labour efficiency, interaction speed, workflow optimisations, and real-time product accessibility data capturing (Vass *et al.*, 2021). This is consistent with the most important TQM 4.0 practices from previous studies, including automatic data collection, big-data analysis, using AI software.

Social elements encompass both human aspects and cultural organisation. TQM 4.0 emphasises quality culture 4.0, encouraging employees' empowerment and self-leaders and actively solving problems instead of waiting for normal processes. Similarly to typical TQM, TQM 4.0 requires the participation of people and leadership. The commitment and support of top management for TQM 4.0 need to be emphasised. However, Industry 4.0 tools promote social networking-based communication and cooperation. People are connected in person and efficiently communicate in cyberspace. Specifically, TQM 4.0-related skills must be prioritised. Moreover, TQM 4.0 integrates quality, sustainability, and development sustainably to gain economic and social performance.

Smart organisation: Typical TQM is huge and cumbersome with several procedures, whereas TQM 4.0 focuses on lean organisational structures to adapt to a changing environment. Moreover, with the robust capabilities of Industry 4.0, this paradigm may promote regular and effective communication among all stakeholders. Specifically, quality specialists and data scientists will combine into a single profession known as "data & quality scientist". Even though the factor "Lean structure organisation" ranks only 20th in the analysis of the importance of TQM 4.0 practices, the author considers it an essential component of a TQM 4.0-applying business. Because the business environment is in ongoing change and there are numerous unpredictabilities (e.g., the Covid-19 pandemic), a lean structure that is adaptable is an essential element of the business. Consequently, the author proposes this is an important part of the TQM 4.0 model.

Smart factory: TQM 4.0 offers sophisticated smart quality control and smart quality assurance systems. For instance, statistical quality control (SQC) was previously implemented by checking a representative sample from the entire production population. In contrast, modern quality control procedures are automated; sensors will inspect automatically the whole population before, during, and after production and remove defective products. Additionally, modern quality assurance utilises advanced monitoring and computing systems to rely on process monitoring fastly in real-time. TQM 4.0 enables precise data and information to provide real-time monitoring and measurement. Therefore, the management can identify problems early on and make prompt decisions. Based on big data and AI, enterprises can dynamically engage with client demand and forecast impending equipment breakdowns or faulty goods. This is in accordance with the most essential TQM 4.0 practices identified in previous research, such as the use of AI software for prediction and a novel type of SPC based on machine learning.

Smart product: Industry 4.0 delivers instruments for intelligent market forecasting and product customisation. TQM 4.0 maximises quality and safety across all product and service attributes via the use of cutting-edge technology and cognitive computation. Instead of being passive recipients, the consumers may participate in the production process. It is simple to trace products by using RIFT or sensor technologies.

5.2 Conclusion and Future Research

Using specific inclusion and exclusion criteria, 203 articles from the WoS database were selected. The literature review was used to develop a theoretical framework for TQM 4.0 based on STS theory. The framework addresses six dimensions: objectives, people, infrastructure, technology, procedures/processes, and culture, and the five primary pillars of TQM 4.0, including technical elements, social elements, smart organisation, smart factory, and smart product.

While typical TQM focuses on standardisations, decreases variations to achieve process stability, and Industry 4.0 offers several tools and techniques, the function of people in the system seems to be nonexistent. The STS theory-based framework will resolve this problem. The STS promotes employee empowerment, such as through fostering more individual and team autonomy. This motivates adaptation, ingenuity, and flexibility in organisations. STS theory prioritises internal resources by enhancing staff productivity and fostering an enterprise culture that encourages creativity and innovation. Traditional TQM systems place a greater emphasis on external management than on internal management. Numerous organisations use TQM to satisfy client expectations. For internal management, TQM stresses process control, faulty product reduction, and cost reduction to achieve financial success. Although conventional TQM includes references to leadership commitment, employee participation, and human resource management, the efficacy of human factors in this approach is low. Traditional burdensome and bureaucratic TQM is cited as a factor by several writers. The research investigates the TQM 4.0 paradigm, which promotes employees and workers to be flexible in order to enhance individual and team self-control and stimulate organisational adaptation and creativity. This will enhance their environmental sustainability by emphasising human participation and team-based initiatives. This framework also takes into account the design of occupations and methods of arranging work, which contributes to enhancing the work experience of workers and achieving successful systems. The model's mix of social and technological techniques provides a solid foundation for organisation growth.

The integration of social and technological factors in the TQM 4.0 model provides a solid foundation for the growth of an organisation. From this basis, enterprises will construct and operate intelligent factories and organisations. Smart quality control, smart quality assurance systems, real-time and whole inspection, and real-time evidence-based decision-making are included into the smart factories. Smart organisation in the direction of lean organisational structures will adapt to the fast-changing environment. Lastly, TQM 4.0 provides intelligent market forecasts and individualises goods (smart products).

Employing a bibliometric method to analyse the publications' keywords, the study has a comprehensive understanding of TQM 4.0 and its related trending themes. Quality 4.0 researches address not only concerns connected to industry 4.0 tools such as big data, artificial intelligence, and machine learning but also other topics like digital transformation, sustainability, and quality culture. The authors believe that the connection between Quality 4.0 and topics such as digital transformation, sustainability, and quality culture are challenges that scholars need to overcome. Does TQM 4.0 promote enterprises to achieve sustainable development? Or, what role does digital transformation play in the TQM 4.0 implementation? In TQM, questions relating to quality culture also need to be investigated. All of these questions push researchers toward further TQM 4.0 discoveries in the future.

A very new topic also of interest to scholars in the field of TQM 4.0 is "organisational performance", because the node is highlighted in yellow in **Figure 7**. Performance is a measure of any system, so evaluating the effectiveness of TQM 4.0 practice requires assessing performance. Enterprises are currently in the testing phase and implementing TQM 4.0; therefore, the research on performance in this subject is highly fresh but significant.

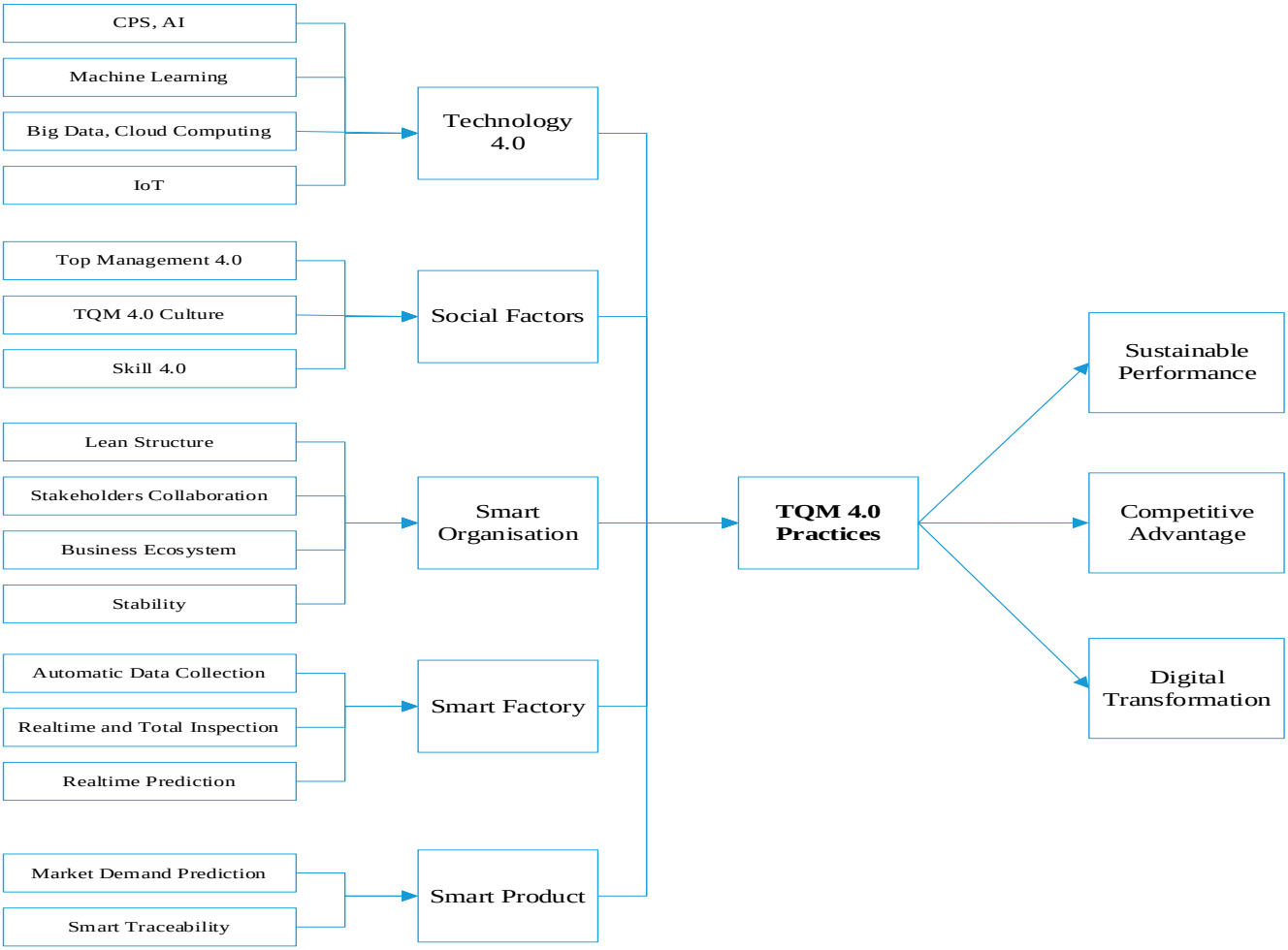

Figure 9 Proposing framework of TQM 4.0 practices in future research

To better understand the effectiveness of the TQM 4.0 model, researchers will need to examine this topic in a variety of areas, including manufacturing, services, education, and government, as well as in various geographic regions. Future chances for analysing the model's implementation must be created through the development of model-fulfillment constructs. The authors propose a comprehensive TQM 4.0 model connecting other constructs that need to be tested in future research (see **Figure 9**). Academics can use the model as a framework for future researches, while practitioner-led organisations can use it to achieve success and a competitive edge.

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