Total Quality Management 4.0 and Sustainable Excellence in Manufacturing Sector

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Doctoral Thesis Summary

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Faculty of Management and Economics

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Totální řízení kvality 4.0 a udržitelná excelence ve výrobním sektoru

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ABSTRACT

TQM 4.0 model, the integration of TQM and Industry 4.0, is being discovered and developed. Researchers have been building TQM 4.0 model, which is also called Quality 4.0, by integrating the Industry 4.0 tools into the TQM system. However, few empirical studies have indicated the indicators for the TQM 4.0 model. Presently, the implementation of TQM 4.0 focuses mainly on the manufacturing industry. Therefore, it is important to develop the TQM 4.0 framework from key factors to specific indicators and their ranking in manufacturing sector. Moreover, while some studies illustrate that TQM is a key strategy for enterprises to achieve successful performance, providing a comprehensive model to investigate the impact of TQM 4.0 practices on performance remains unexplored. Typically, TQM has positively affected performance; consequently, the question is whether TQM 4.0, designed towards a sustainable business model, can improve sustainable excellence. To address issues, my thesis investigates two main studies. The first study focuses on exploring TQM 4.0's indicators and factors in production sectors. The second study focuses on investigating the relationship between TQM 4.0 practices and Sustainable Excellence.

In the first study, the author employed AHP (Analytic Hierarchy Process) and Delphi approaches to determine the TQM 4.0's main indicators and factors in manufacturing organisations anchoring on the Socio-technical System (STS) theory. A comprehensive examination of two Delphi rounds involving experts from academia, consulting, and production/quality management identified ten factors and totally 41 indicators. During the 3rd round, the study assessed the significance of each factor and indicator by employing the AHP approach. The study indicated that social factors had higher importance than technical factors. The results revealed that the three most important factors of the TQM 4.0 framework are "top management, quality culture 4.0, and integrating sustainable development". In addition, the study found that "top management commitment, quality-driven mindfulness, and employee empowerment" were identified as the most important indicators in the TQM 4.0 model.

In the second study, the author investigates the relationship between TQM 4.0 practices and Sustainable Excellence (SE) as well as the role of digital transformation (DT) and digital leadership in this connection, anchoring on the stakeholder theory, the natural resource-based view (NRBR) theory, and the socio-technical system (STS) theory. Moreover, this study ranks the importance of TQM 4.0 factors to enhance sustainable excellence. The research employs the quantitative hybrid SEM-ANN (Structural Equation Model- Artificial Neural Network) method to analyse empirical data in the manufacturing industry in Vietnam. The findings demonstrate that TQM 4.0 practices positively influence both digital transformation and SE. The mediate role of digital transformation and the moderate role of digital leadership in the relationship between TQM 4.0 practices and SE were confirmed in this study. This investigation provides the

initial endeavour to rank the importance of TQM 4.0 practices to enhance SE using the ANN method. The findings could provide significant insights for researchers and practitioners in evaluating the application of TQM 4.0 in the manufacturing industry.

ABSTRAKT

Začíná se objevovat a rozvíjet model TQM 4.0, integrace TQM a Industry 4.0. Výzkumníci se pokoušeli vytvořit model TQM 4.0 (někteří ho nazvali Quality 4.0) a byl vytvořen integrací nástrojů Průmyslu 4.0 do systému TQM. Nicméně, několik empirických studií však naznačuje indikátory pro model TQM 4.0. V současné době se implementace TQM 4.0 zaměřuje především na zpracovatelský průmysl. Proto je důležité rozvinout naplňování modelu TQM 4.0 od hlavních faktorů ke konkrétním ukazatelům a jejich zařazení ve zpracovatelském sektoru. Některé studie zase dokladují, že TQM je klíčovou strategií pro podniky k dosažení úspěšného výkonu, či poskytnutí komplexního modelu pro zkoumání dopadu postupů TQM 4.0 na výkon ale zůstávají neprozkoumané. Pro TQM je typické, že pozitivně ovlivňuje výkon, v důsledku toho je otázkou, zda TQM 4.0, navržený směrem k udržitelnému obchodnímu modelu může take zlepšit udržitelnost (k úrovni exceleence). K vyřešení těchto problémů tato práce přináší dvě hlavní studie. První studie se zaměřuje na zkoumání faktorů a indikátorů praxe modelu TQM 4.0 ve výrobních podnicích. Druhá studie se pak zaměřuje na zkoumání vztahu mezi postupy TQM 4.0 a Sustainable Excellence (tedy udržitelné excellence).

V první studii autorka aplikovala techniky Delphi a analytického hierarchického procesu (AHP) a to ke zkoumání klíčových faktorů a specifických indikátorů implementace modelu TQM 4.0 ve výrobních podnicích ukotvených na teorii sociotechnického systému (STS). Analýza dvou kol metody Delphi prostřednictvím odborníků z akademické sféry, konzultantů a vedoucích/manažerů výroby/kvality zjistila deset faktorů a celkem 41 ukazatelů. Ve třetím kole studie navíc vážila důležitost každého faktoru a indikátoru prostřednictvím analýzy techniky AHP. Výzkum ukázal, že sociální faktory byly důležitější než technické faktory. Důležité je, že závěry naznačily tři klíčové faktory modelu TQM 4.0: top management, kulturu kvality 4.0 a integraci udržitelného rozvoje. Studie dále odhalila, že jako nejkritičtější ukazatele modelu TQM 4.0 byly specifikovány: odhodlání vrcholového managementu, všímavost řízená kvalitou a posílení postavení zaměstnanců.

Ve druhé studii autorka zkoumá vztah mezi praktikami TQM 4.0 a Sustainable Excellence (SE tzn. udržitelné excellence) a také roli digitální transformace (DT) a digitálního vedení v této souvislosti. Přitom vychází z teorie stakeholderů, pohledu založeného na přírodních zdrojích teorie (NRBR) a teorie sociotechnického systému (STS). Kromě toho tato studie hodnotí důležitost faktorů TQM 4.0 pro zvýšení udržitelné excelence. Výzkum využívá kvantitativní hybridní metodu SEM-ANN (Structural Equation Model-Artificial Neural

Network) k analýze empirických dat ve zpracovatelském průmyslu ve Vietnamu. Zjištění ukazují, že postupy TQM 4.0 pozitivně ovlivňují jak digitální transformaci, tak SE. V této studii byla potvrzena zprostředkující role digitální transformace a moderující role digitálního vedení ve vztahu mezi postupy TQM 4.0 a SE. Toto šetření poskytuje počáteční snahu o hodnocení důležitosti postupů TQM 4.0 pro zlepšení SE pomocí metody ANN. Výsledky by mohly být cenné jak pro výzkumníky, tak pro odborníky z praxe při posuzování implementace TQM 4.0 ve výrobním sektoru i v budoucnu.

CONTENTS

1 INTRODUCTION

1.1 Research background and research gaps

The 4th Industrial Revolution, called Industry 4.0, has brought a new face to industrial development worldwide by providing a lot of modern and automated technical tools and focusing on CPS (cyber-physical systems), AI (artificial intelligence), ML (machine learning), and big data analysis (Cimini et al., 2020; Chiarini, 2020; Zhou et al., 2020). This revolution significantly impacts various sectors within the business environment, particularly the field of quality management. TQM (Total Quality Management) is a long-standing management method used by many businesses as an effective strategy to achieve success. Traditional TQM usually focuses on managing systems, setting standards, and improving continuously. However, some authors discuss that traditional TQM is cumbersome and bureaucratic (Goetsch and Davis, 2013; Asif, 2020). Focusing on standardisation and stability of typical TQM made adapting to a fast-changing environment challenging. Therefore, organisations need a new TQM model which is leaner and more flexible. Hence, the combined Industry 4.0 and tools models of TQM strategy are currently being explored. Researchers are working on developing the TQM 4.0 model, also known as Quality 4.0, by incorporating Industry 4.0 tools into the existing TQM model (Park et al., 2017; Sony et al., 2020; Chiarini and Kumar, 2022). The application of TQM 4.0 concentrates mainly on the manufacturing industry. Hence, it is essential to have factors and indicators to facilitate the assessment of the accomplishment of TQM 4.0 in manufacturing enterprises. Consequently, it is necessary to focus on developing the main factors and indicators for the application of the TQM 4.0 model. Furthermore, ranking the most essential variables and indicators in implementing the TQM 4.0 model by utilising the AHP technique is important.

Previous models of Quality 4.0 were irrelevant to theories (Chiarini, 2020). One concern is that traditional TQM emphasises standardisation and stability, whereas Industry 4.0 prioritises using technical tools. As a result, the role of human beings in the system appears to be diminished. This problem will be resolved by implementing a framework founded on the principles of STS theory. STS promotes adaptability, a significant level of autonomy, and a wide range of empowerment granted to employees. It serves as a perfect addition to the inflexible traditional TQM system and technological tools used in Industry 4.0. Therefore, it is necessary to examine the TQM 4.0 model through the lens of the STS theory to develop a TQM 4.0 framework that effectively addresses social and technical concerns in a balanced way.

TQM 4.0 model focuses on using new technologies to support quality management to achieve performance. In rapidly changing business environments, firms require a system that gains not only financial performance but also achieves environmental and societal issues (Nguyen et al., 2023). The TQM 4.0 model, including technology tools in Industry 4.0 and social connections, is a business strategy for firms to achieve Sustainable Excellence (Nguyen et al., 2023). Nonetheless, the literature on TQM 4.0 has indicated that there have been a few empirical studies discovering this issue. We recently found some empirical studies on TQM 4.0. For instance, Maganga and Taifa (2022) conducted a study to assess the perceptions of Quality 4.0 among respondents in Tanzanian manufacturing companies. Huang et al. (2022) empirically examine the influence of social and technical Quality 4.0 on Industry 4.0 technologies and circular economic practices in Malaysian small and medium-sized manufacturing businesses. However, those studies have not figured out the connection between TQM 4.0 practices and SE. Consequently, there exists a substantial gap in knowledge concerning this relationship (between TQM 4.0 practices and SE) that scholars should explore.

In addition, the role of the leadership, digital leadership, for example, is essential in driving the effectiveness of TQM 4.0 (Sony et al., 2020; Nguyen et al., 2023). Digital leaders can create networked enterprises and opportunities for employees to understand how to work on the TQM 4.0 system, which can lead to a transformation in digital works (Sony et al., 2020). According to Dun and Kumar (2023), managers have to implement a transformational leadership style for employees that facilitates the adoption of Industry 4.0 technologies. Ardi et al. (2020) examined digital leadership through the lens of transformational leadership and concluded that digital transformational leadership has a positive impact on the innovativeness and performance of organisations. A question is how leadership style impacts TQM 4.0 practices. The roles of digital leadership and DT in the TQM 4.0 context are critical to be investigated. Despite this, few empirical studies clarify this issue.

Moreover, the pandemic has caused widespread disruptions in the manufacturing sector (Piyathanavong et al., 2022; Pansare and Yadav, 2022). Manufacturing enterprises are having difficulties in regenerating activities in their production. Pansare and Yadav (2022) conducted a comprehensive literature review to define the leading Industry 4.0 tools and implementation of reconfigurable manufacturing systems. The results show that quality practices are important criteria for repurposing production operations. Consequently, exploring TQM 4.0 practices for sustainable manufacturing has both theoretical and practical significance in the manufacturing sector.

1.2 Research questions and objectives

This thesis aims to explore main factors and indicators and their ranking of the TQM 4.0 model, as well as investigate the relationship between TQM 4.0 practices and Sustainable Excellence in the manufacturing sector.

From the main objectives, the following research questions and detailed objectives are raised:

(1) Research question 1: What are the main factors and fulfil indicators of TQM 4.0 practices applied in the manufacturing sector?

Research objective 1: To investigate the TQM 4.0's main factors and indicators applied in the manufacturing sector.

(2) Research question 2: How important are the factors of TQM 4.0 practices in the manufacturing sector?

Research objective 2: To rank important factors of TQM 4.0 practices in the manufacturing sector.

(3) Research question 3: How important are the indicators in a factor and in the total indicators of TQM 4.0 practices in the manufacturing sector?

Research objective 3: To rank the important indicators within a factor and in the total indicators of the TQM 4.0 practices in the manufacturing sector.

(4) Research question 4: How do TQM 4.0 practices impact sustainable excellence in the manufacturing sector?

Research objective 4: To test the impact of TQM 4.0 on sustainable excellence in the manufacturing sector.

Research objective 5: To investigate the roles of digital leadership and digital transformation in the relationship between TQM 4.0 and sustainable excellence in the manufacturing sector.

1.3 Research design

This study includes five research objectives: (1) identify the main indicators and factors of TQM 4.0 practices, (2) determine the important factors of TQM 4.0 practices, (3) rank the important indicators within a factor and in the total indicators in the TQM 4.0 practices, (4) test the effect of TQM 4.0 practices on sustainable excellence in manufacturing sector, and (5) explore the mediate and moderate effect in the relationship between TQM 4.0 practices and sustainable excellence in the manufacturing sector. To achieve 1st , 2nd ,and 3rd objectives, this thesis employs both Delphi and AHP approaches. To gain the research's fourth and fifth objectives, the author employs the quantitative Structural Equation Model (SEM) method. Delphi can generate new ideas and valuable confirmations from experts. AHP is a mathematical technique that facilitates pairwise comparisons of multi-criteria and assigns relative weights to measurement items according to their respective importance.

Table 1.1: Research design

Research objectives	Methodology
RO1: Investigating the TQM 4.0's main factors and indicators in the manufacturing sector	Qualitative method: Delphi method
RO2: Ranking the importance of factors of TQM 4.0 practices in the manufacturing sector.	Quantitative method: AHP method

RO3: Ranking the importance of indicators within a factor and in the total indicators of TQM 4.0 practices in the manufacturing sector.	
RO4: Testing the effect of TQM 4.0 practices on sustainable excellence in the manufacturing sector. **RO5:** Examining the roles of digital leadership and digital transformation in the relationship between TQM 4.0 practices and sustainable excellence in the manufacturing sector.	Quantitative method: SEM-ANN approach

To gain the 4th and 5th objectives, the author employs the quantitative Structural Equation Model (SEM) method. Two types of non-random sampling were utilised in the study: purposive and snowball. Purposive sampling focuses on experts with experience in manufacturing companies that have applied TQM practice and Industry 4.0 tools to TQM practice (from above supervisor positions, such as supervisors, managers, and directors). The study also used the snowball sampling technique. Because respondents have unique characteristics, they involve some niche communities, so the study expands the respondents by introducing them from original respondents. Finally, we have the list of 600 employees working in the Vietnam manufacturing sector. We sent them questionnaires in Google form and directly printed questionnaires. Two hundred fifty-eight respondents in Vietnam that are valuable for analysis have been collected.

2 LITERATURE REVIEW

2.1 Theoretical lenses of the research

2.1.1 Socio-technical system theory (STS)

The Socio-Technical Systems (STS) theory is a framework that focuses on the interplay between social and technical aspects within a system (Trist, 1981). Originating in the mid-20th century, it aims to enhance organisational performance and human well-being by considering the combined impact of social and technical elements. STS theory has been applied in industries such as manufacturing, healthcare, and information technology to design work systems that enhance productivity and job satisfaction (Sony and Naik, 2020). It promotes flexibility, autonomy, and employee empowerment, making it a suitable theoretical basis for studying the effects of integrating social and technical aspects on quality and sustainability management. In the TQM field, the principles of STS theory and TQM are combined to create a comprehensive framework for organisational improvement. Both approaches emphasise the importance of involving employees in decision-making, promoting collaboration, and sharing responsibility for quality. By integrating these principles, organisations can effectively address the interdependence of people, processes, and technology in their pursuit of total quality (Trist, 1981; Manz and Stewart, 1997).

Incorporating STS theory into TQM and Industry 4.0 can create a sustainable TQM 4.0 framework that promotes employee empowerment, flexibility, and autonomy. By incorporating these principles, organisations can ensure the effectiveness and relevance of quality management practices.

2.1.2 Stakeholders theory

The stakeholder theory is a widely accepted concept in business and management, emphasising the interactions between organisations and various stakeholders. It emphasises that organisations are responsible to shareholders and diverse groups with a stake in their actions and results. Stakeholder analysts argue that businesses should consider the concerns and requirements of all stakeholders and work hard to provide value for them. The "new stakeholder theory" (NST) emphasises the ethical and financial dimensions of organisations' value creation and appropriation. This reconvergence of stakeholder theory may lead to a greater understanding of the organisation of stakeholders and their role in working together to create value. According to Franco et al. (2020), the stakeholder theory puts social responsibility into practice, which would result in considerable financial advantages while also optimising the overall interests of stakeholders. Examples of stakeholders include customers, suppliers, shareholders, employers, lawmakers, environmental defenders, and social responses. Others are more concerned with organisational rivalry and financial success, while other stakeholders are more concerned with social responsibility.

In conclusion, the stakeholder theory is a valuable framework that emphasises considering the interests and requirements of all stakeholders in decision-making within an organisation.

2.1.3 Natural Resource-based View (NRBR) theory

Hart (1995) introduced the firm's natural resource-based concept, which focuses on a company's natural resources to address ecological issues. The NRBV paradigm of competitive advantage focuses on three strategies: pollution control, product stewardship, and sustainable development. The NRBV theory emphasises the importance of environmental management integration in strategic planning, which improves financial and environmental performance and gives firms a competitive edge. The NRBV theory also values resource orchestration, which involves managers organising, combining, and using company resources for competitive advantage. This approach can be employed across firm, maturity, and organisational levels. The NRBV hypothesis states that environmentally responsible economic behaviour can give companies a long-term competitive advantage by promoting nature-environment harmony.

The NRBV theory is used in quality management and other domains, emphasising the role of natural resources in sustainable competitive advantage. In quality management, the NRBV theory advocates using natural resources to improve products and services. This can be achieved by incorporating environmental considerations into strategic planning, optimising resource allocation, and using sustainable supply chains. The NRBV paradigm helps businesses gain a sustainable competitive advantage through quality management by explaining the link between natural resources and quality results (Agyabeng-Mensah et al., 2021).

2.2 Total Quality Management (TQM) development

Total Quality Management (TQM) is a widely recognised business strategy that focuses on achieving stakeholder satisfaction by implementing principles, tools, and methodologies across all aspects of an organisation. It encompasses all functions and levels, from highest to lowest (Goetsch and Davis, 2013). TQM is often referred to as in line with quality management standards like ISO 9001 and ISO 9004, which emphasise customer satisfaction, process-oriented approaches, and continuous improvement (ISO, 2021). ISO 9004 guides enhancing an organisation's capacity for long-term success and includes a self-assessment tool. TQM is developed through “quality control” , “quality assurance”, and “total quality management” phrases. “Quality control” involves identifying defective items and using statistical control tools, while “quality assurance” ensures high-quality production and manufacturing process stability. Overall, TQM is a managerial ideology encompassing all aspects of product, process, and system quality (Sader et al., 2019)

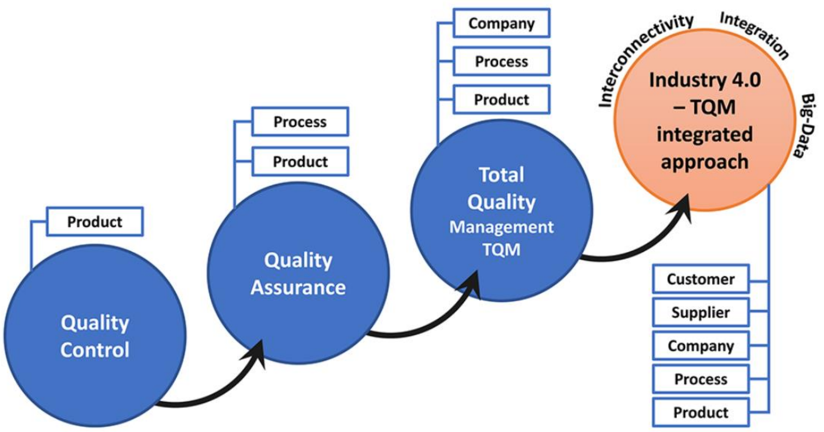

Fig 2.1: The development of TQM

Source: Sader et al. (2019)

2.3 TQM 4.0 and STS theory integration

2.3.1 Social factors

“Top management 4.0”: The involvement, commitment, and support of top management are essential factors for the successful implementation of traditional

TQM (Goetsch and Davis, 2013). Likewise, numerous researchers held the view that the effective execution of a TQM 4.0 framework necessitated the active participation and unwavering dedication of top-level management (Sony et al., 2020; Chiarini and Kumar, 2022). Chiarini and Kumar (2022) proposed that the top management should define explicit strategic goals, objectives, and criteria for TQM 4.0 and communicate them to the employees.

“Quality culture 4.0”: Quality culture is an organisational value system that promotes the establishment and maintenance of quality. Implementing total quality without a quality culture can lead to disastrous results. In Quality 4.0, Quality culture encourages mindfulness, which involves active observation, confirmation, and deliberate actions (Asif, 2020). Managers should encourage employee empowerment, and the Socio-technical System Theory (STS) emphasises flexibility and sustainability in TQM. The STS promotes employee empowerment through enhanced autonomy and a collective understanding of roles in attaining quality objectives, which should be communicated to different kinds of enterprises (Kupper et al, 2019).

“Digital skills for quality staff”: Industry 4.0 focuses on acquiring new skills rather than reducing the workforce, as highlighted by Kupper et al. (2019). Quality 4.0 emphasises the importance of individuals in ensuring quality, requiring workers to use digital tools and communicate data-driven narratives. Quality control employees should develop skills in cyber-physical systems, analytics, and artificial intelligence (Chiarini and Kumar, 2022; Kupper et al., 2019). They should allocate more time to solve problem and prevent activities, delegating less time to operative tasks like inspections. Quality experts with backgrounds in statistical QC and industrial engineering contribute significantly to QM, with data scientists and quality experts potentially merging. Creative thinking is crucial for achieving TQM 4.0.

Intellectual capital management: Asif (2020) introduced TQM 4.0, which specifically emphasises the development of social, human, and intellectual capital. Quality management models focus on human resources but do not explicitly emphasise the development and utilisation of human capital. The TQM 4.0 model prioritises the cultivation of social capital, which pertains to the interpersonal connections and collaborations among individuals inside and outside an enterprise. The TQM 4.0 framework also emphasises management of intellectual capital, including factors such as customer relationships, reputation, company values, employee loyalty, and brand image (Glogovac et al., 2020; Asif, 2020).

“Smart organisation”: Leaders must establish and manage a smart organisation within the TQM 4.0 framework, promoting initiatives, fostering organisational knowledge, and facilitating successful innovations (Fundin et al., 2020). This model offers leaner, more efficient, and responsive processes, enabling quick adaptation to changing environments. TQM 4.0 technologies improve communication, collaboration, innovation, and interconnection within business ecosystems (Asif, 2020). They can engage in exploration and exploitation, enabling effective responses to rapidly evolving environments through external and internal innovation (Fundin et al., 2020)

"Integrating sustainable development": An organisation that is sustainable will prioritise serving society and the planet. It will establish a connection between quality and sustainability and strive for excellence in promoting sustainability (Fundin et al., 2020). Consequently, quality management systems (QMS) should incorporate EMS (Fundin et al., 2020). Hence, the TQM 4.0 framework must include dimensions seamlessly to integrate sustainable development within a dynamic and fluctuating environment.

2.3.2 Technical factors

"Automated document control": According to Chiarini and Kumar (2022), there is a prevailing belief that a paperless approach is now expected for QMS. The TQM 4.0 model incorporates automated and real-time document control, specifically for work instructions. TQM 4.0 will contain digital standard operating procedures (SOPs) to ensure that employees are provided with the latest instructions.

"Automatic data collection": Industry 4.0 tools facilitate data management through the utilisation of ERP modules, such as product life cycle management or the manufacturing execution system (Chiarini and Kumar, 2022). Under the framework of TQM 4.0, various data types, including the statistic of defective or discarded goods, the amount of time spent on reworking by both labour and machines, and the number of customer complaints, product returns, will be automatically collected. It is essential to have an automated system for gathering data relating to customers, including product demands, complaints, and levels of satisfaction (Chiarini and Kumar, 2022).

"Smart Quality Control": In Industry 4.0, the use of smart sensors and inspection technology in real-time will lead to a growing shift from sample inspection to total inspection (Park et al., 2017; Sader et al., 2019). In their study, Chiarini and Kumar (2022) introduced a novel form of SPC that utilises artificial intelligence to predict and identify various defects that may occur during machining. This advanced system also offers real-time feedback to the machine, enabling it to adjust parameters autonomously without requiring human intervention. High-quality data are automatically collected from different processes and managed within ERP modules (Chiarini and Kumar, 2022).

"Smart Quality Assurance": Industry 4.0 technologies, including AI and machine learning, enable proactive measures by predicting and preventing potential issues (Sader et al., 2019; Chiarini and Kumar, 2022). They enhance processes, improve efficiency, and reduce quality issues by using sensors at every production stage. Big-data analysis transforms real-time data into accessible information for business departments. Under TQM 4.0, organisations implement smart improvements by leveraging real-time data and maintaining digital documentation (Asif, 2020).

"Smart product": Big-data analysis and AI can predict market demand and consumption, while smart products use AI-based predictions to meet customer demands. Chiarini and Kumar (2022) demonstrated the potential of smart technology by integrating smart sensors and RFID technology into products and packaging in TQM 4.0. This model incorporates industry 4.0 connectivity, allowing customers to participate actively in manufacturing, thereby enhancing customer satisfaction.

2.4 Sustainable Excellence

The concept of excellence has been a significant part of the quality community since the 1980s, dominating the landscape of quality models and awards globally. Excellence is a valid strategy for enhancing quality and performance, engaging organisations internationally, and producing stable outcomes (Edgeman, 2018). More significant quality-based excellence awards have strong brands and networks, such as the "European Foundation for Quality Management" and the "Malcolm Baldrige Quality Award". Business excellence has emerged as a new trend, elevating TQM implementation frameworks and quality award programs. Sustainable excellence is achieved when key stakeholder segments' competing interests, including social and environmental impacts, are harmonised to enhance the potential of enduring enterprise success and sustainable competitive forces (Edgeman and Eskildsen, 2014). Businesses seeking sustainable excellence should encourage innovative management structures, be supported by effective management tools, and establish a comprehensive knowledge of the driving principles underlying quality management and operational excellence.

The relationship between TQM and excellence has been validated in empirical research and practical cases. To attain organisational excellence, organisations must consistently deliver exceptional value to customers. Total quality is a comprehensive approach encompassing all three outstanding value components, and successful implementation of this approach will likely lead to organisational excellence. Further research is needed to explore how TQM can develop in various contexts, the intersections of QM and sustainability, and how customers and stakeholders can actively advance excellence.

2.5 The research framework and hypothesis development

This research uses stakeholders, natural resource-based view (NRBR), and STS theory to explore direct and indirect relationships among TQM 4.0, digital transformation, digital leadership, and sustainable excellence. According to Franco et al. (2020), based on the stakeholder theory, implementing social responsibility would achieve significant financial gains and optimise stakeholders' overall interests. Customers, suppliers, shareholders, employers, policymakers, environmental defenders, and social respondents are examples of stakeholders. Some stakeholders are primarily concerned with social responsibility, while others are focused on organizational competition and financial performance. To achieve SE, a strategy such as TQM 4.0 must gain balance and satisfy all stakeholders.

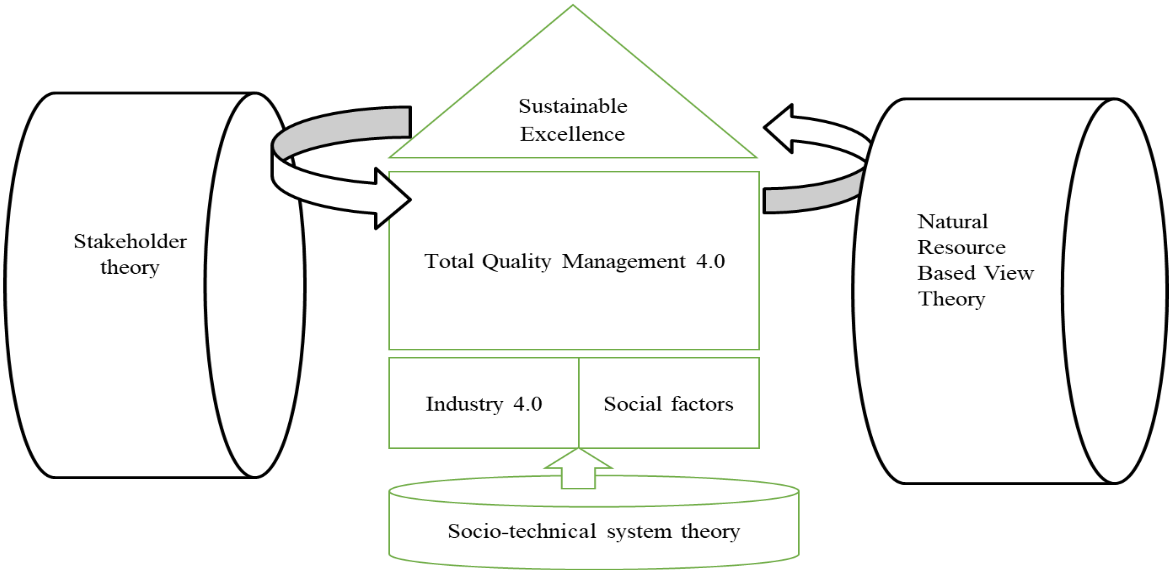

Fig 2.2: Conceptual framework

Source: own research

When researching sustainability, one of the most common ideas employed is the theory of natural resource-based views (social, environmental, and economic aspects). Companies use strategies for continuous improvements, such as TQM, to reduce emissions. Natural resource-based views theory argues that companies with TQM proficiency will be able to amass the resources required for pollution avoidance more quickly than companies without prior capability (Hart et al., 2008). Therefore, NRBR supports the positive effect of TQM 4.0 on SE.

In addition, the STS theory is utilised in the construction of the TQM 4.0 model. This model incorporates not only technological tools but also social connections that will motivate social enterprise (Nguyen et al., 2023). These social connections include a link between quality and sustainability, corporations serving society, and the integration of environmental management systems. As a result, one approach advocated for companies that are interested in achieving SE is to implement a TQM 4.0 framework that is based on STS theory. As a result, the author hypothesises that TQM 4.0 practices have a constructive and immediate impact on SE.

H_1: TQM 4.0 practises positively and directly impact sustainable excellence.

In addition, the use of TQM 4.0 will stimulate the digital transformation (DT) of organisations. TQM 4.0 is a system that emphasises installing tools related to Industry 4.0, so DT will be made faster when organisations apply TQM 4.0. Individuals are stated to play an essential part in the accomplishment of DT in Industry 4.0, as stated by Neumann et al. (2021). In the TQM 4.0 system, human-related variables are brought to the forefront through the promotion of employee empowerment, quality-driven mindfulness, and enhanced skill 4.0, which includes abilities relating to analytics, artificial intelligence, customer relationship management (CRM), digital communication, and the creative capacity of teams. According to Rajput and Singh (2020), individuals participating in TQM 4.0 will make a substantial contribution to the overall success of DT. The author hypothesises that TQM 4.0 practices have a positive and direct effect on DT.

H_2: TQM 4.0 practices positively and directly affect digital transformation (DT).

The manufacturing industries are undergoing digital transformation, paving the way for data-driven and resilient production systems. Rajput and Singh (2020) created a model to reduce the overall cost and energy consumption of equipment in order to promote a circular economy and sustainable production through the use of DT. Thus, DT is more likely to influence sustainable excellence directly and positively. Through DT, TQM 4.0 practises include not only the automatic collection of data via the use of AI software for prediction and prevention but also the development of smart products by predicting market demand and consumption trends. Customisation of the product is one of the companies' primary emphases for differentiating themselves from the competition and generating sustainable competitive advantages Piyathanavong et al. (2022). In order to accomplish SE, businesses practise the TQM 4.0 paradigm via DT. Thus, the author argues that DT directly affects sustainable excellence and plays a mediating role in the relationship between TQM 4.0 practices and SE.

H_3: Digital transformation directly and positively impacts sustainable excellence.

H_4: Digital transformation mediates the relationship between TQM 4.0 and sustainable excellence.

The role of the leader in assuring and driving the transition to TQM 4.0 has been highlighted in the literature (Sony et al., 2020; Nguyen et al., 2023). For DT to be successful, organisations require digital leaders who build collaborative networked enterprises and define digital competencies. Digital leadership is a complex concept encompassing multiple dimensions, including authentic leadership, transactional leadership, and transformational leadership (Prince, 2018). Considering the importance of digital leadership in both the digital age and the TQM 4.0 paradigm, the author proposes that digital leadership moderates the following relationships between TQM 4.0 and SE. Therefore, the following hypothesis is developed from a review of the relevant literature:

H_5: Digital leadership moderates the relationship between TQM 4.0 and sustainable excellence.

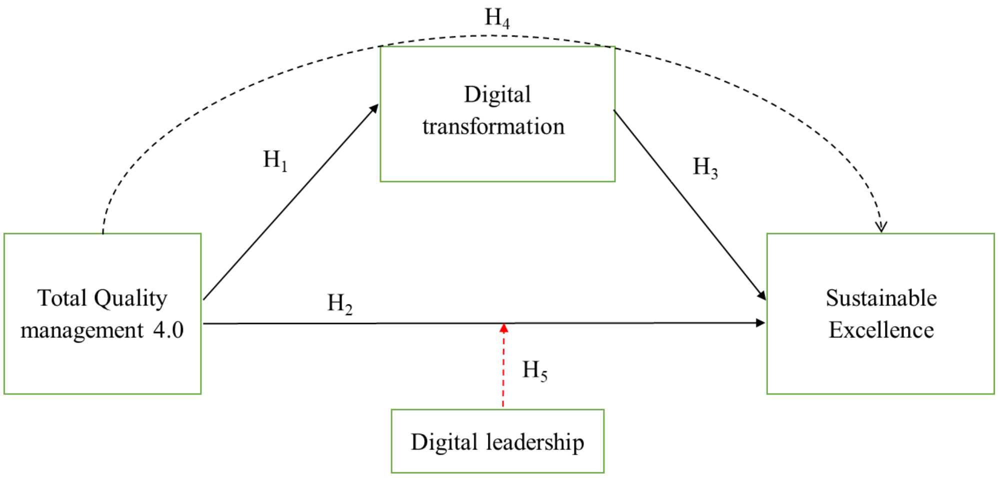

Fig 2.3: Proposed research model.

Source: own research

3 RESEARCH METHODOLOGY

3.1 Delphi and AHP method

The original Delphi method was established by Dalkey and Helmer (1963). It operates as a strategy that methodically gathers the viewpoints of a number of experts regarding a specific problem. According to Dalkey and Helmer (1963), the original Delphi is a broad approach to organising group communication and making it successful enough to allow a group of persons working as a whole to cope with complicated problems. This strategy maximises the benefits of having an expert panel through anonymity while minimising the potential downsides of collaborative decision-making. However, the traditional Delphi is time-consuming and costly because of the need for repetitive surveys to gain converge values. Therefore, Murry and Hammons (1995) introduced the modified Delphi method to overcome the drawbacks. Utilising a structured questionnaire in the modified Delphi method not only aids experts in concentrating on the matter at hand but also results in time and cost savings (Min, 2015). Hence, this research employs a modified Delphi approach to identify the key factors and fulfilment indicators of TQM 4.0 practices.

The Analytic Hierarchy Process (AHP) is frequently combined with the Delphi method to investigate indicators. The AHP, developed by Saaty (1990), is a highly effective methodology for resolving complex problems. Subsequently, many studies employed the AHP combined with the Delphi method, thereby adopting a blended approach for exploratory purposes to examine managerial perspectives on crucial factors (Min, 2015; Delbari et al., 2016; Wong et al., 2020). This research employs the Delphi method to investigate the main factors and fulfilment indicators of the TQM 4.0 application. The AHP technique is utilised to calculate the relative importance of factors and indicators in implementing TQM 4.0 practices.

Step 1: Develop an initial questionnaire.

The first questionnaire was dispatched to the panel of experts. The questionnaire comprises a set of questions derived from the researchers' expertise and insights from the synthesised literature. The respondents comprise consultants, academics, and experts (See *Table 3.1*). Academics were lecturers who taught or did research in TQM. Practitioners, such as production or quality managers and supervisors, were required to possess a minimum of five years of experience in management, along with fundamental proficiency in Industry 4.0 technologies. They are the most knowledgeable individuals regarding TQM and integrating Industry 4.0 tools into TQM to deliver the most accurate and valuable information.

An assessment group reviewed and made corrections to the pilot version of the questionnaire. Following the revision process guided by expert feedback, the author developed the first questionnaire describing the TQM 4.0 model, which comprises eleven factors and forty-four observed indicators.

Table 3.1: Profile of panellists in the Delphi rounds.

No.	Tasks	Academics	Consultants	Supervisors/ Managers	Total numbers
1.	Literature review and deep interview	03	02	02	05
2.	Round-1	03	04	39	46
3.	Round-2	02	03	28	33
4.	Round-3 (AHP)	02	01	08	11

Step 2: The first Delphi round analysis

The questionnaire is divided into four parts. Part 1 introduces TQM 4.0 and asks about the expert's understanding of TQM 4.0. If experts have knowledge about TQM and Industry 4.0, they will continue to part 2. In the second section, the factors and indicators are outlined on a five-point Likert scale ranging from one (indicating low importance) to five (indicating extremely high importance). In the third section, participants will respond to open-ended questions regarding the author's statements on the TQM 4.0 model and provide more information regarding the TQM 4.0 framework. In conclusion, the fourth section gathers general data, including the organization's sector, expert personnel's experience, and position. For the purpose of facilitating the subsequent round of the survey, the author gathered the email addresses of the participants in this round.

Step 3: The second Delphi round analysis

All 46 experts analysed in the first Delphi round were emailed by the author. Thirty-three experts have provided their responses (See Table 3.1). The author also computes the Mean and CRV in this phase. Mean values below 3.5 points or CRV below 0.33 are rejected due to the fact that the minimum acceptable score for CVR, as determined by a panel of 30 experts (Lawshe, 1975), is 0.33.

Step 4: The third Delphi round analysis (AHP approach)

This survey aims to ascertain the importance of each factor and indicator by using comparative judgements in pairwise. Saaty (1990) stated that in this process, panellists are required to make comparisons between two factors or indicators. The participants were able to indicate their preference between each pair of factors and convert these preferences into numerical ratings ranging from 1 to 9, with intermediate values of 2, 4, 6, and 8.

According to the existing literature on AHP applications, there is no minimum sample size requirement for AHP analysis. Some studies employed sample sizes spanning from four to nine participants. As a result, the research collected data from eleven experts (who responded to the two previous rounds) to analyse in the AHP approach is acceptable. The author calculates the average criteria weights and CR of eleven experts for final results.

3.2 Structural Equation Model (SEM) and ANN approach

This study evaluates the proposed model by employing a two-stage analytical methodology that integrates Partial Least Squares Structural Equation Modelling (PLS-SEM) and Artificial Neural Networks (ANN) approaches. PLS-SEM was chosen over CB-SEM because this study was exploratory rather than confirmatory (Hair et al., 2017). The initial model complexity and large number of indicators required the PLS-SEM method (Hair et al., 2017). Nevertheless, it should be noted that PLS-SEM is limited in its ability to investigate non-linear interactions between constructs. When employed, The SEM-ANN approach provides both linear and non-linear relationships between variables and enhances the understanding of the Sustainable Excellence (SE) of manufacturing firms.

Sample size estimation

This sample size is acceptable for structural equation models by calculating formulas from Cohen (1992), Faul et al. (2009), and Kock and Hadaya (2018). Estimating the minimal sample size is one of the most fundamental aspects of PLS-SEM. In PLS-SEM, a widely used method for estimating the minimum sample size is the "10 times rule". The suggested approach is to utilise a sample size that is ten times the number of independent factors in the PLS path model for complex regression. Using this method, the minimum sample size required for this study is 110. Cohen (1992) recommended that 103 should be the minimum sample size for a PLS-SEM analysis. The author employed G*Power software version 3.1.9.7 (Faul et al., 2009) to identify the minimum sample size. The analysis yielded a minimum sample size requirement of 123. Using the inverse square root method developed by Kock and Hadaya (2018) and presuming the minimum expected path coefficient is significant between 0.11 and 0.20, approximately 155 observations would be required to detect a significant effect at a 5% significance level. This criterion is satisfied by the sample size of the present investigation (258 answers). The proposed model was examined using the partial least squares (PLS) method. The SmartPLS software was utilized to determine the measurement and structural model.

Measures

The questionnaire is comprised of three sections. Section 1 consists of two questions to screen interviewees: the first asks whether the respondent's organisation utilises TQM, and the second inquires about the incorporation of Industry 4.0 tools into TQM. The survey will end if respondents indicate that their organisation does not implement TQM or Industry 4.0 tools into TQM practice. In contrast, If their organisations employ TQM practices and integrate Industry 4.0 tools into TQM practices, they will continue to answer section 2.

The second section comprised a total of 67 items, each of which was assessed using a five-point Likert scale ranging from (1 = "strongly disagree" to 5 = "strongly agree"). The scale for TQM 4.0 practices (41 items) is used. The scale used for measuring SE concludes environmental, operational, social performance, and innovation performance. Environmental performance (EP1–EP5), operational performance (OP1–OP3), and social performance (SOP1–SOP4) were adapted from Chavez *et al.* (2022). Innovation performance (IP1–IP4) was adapted from Gök and Peker (2017). The scales of Digital leadership (DL1–DL5) and Digital Transformation (DT1-DT5) constructs were adapted from Abbu *et al.* (2022).

The third section captured the demographic information, including the field of the company, working position, and years of work experience in manufacturing enterprises.

Data collection

The survey was conducted in Vietnam for some causes. Firstly, one notable development in Vietnam is the widespread adoption of TQM 4.0 by organisations, particularly multinational corporations, for example, Mercedes-Benz, Intel, Samsung, Coca-Cola, Hyundai, Fujitsu, etc. They originate from developed nations and introduce Industry 4.0 technological advancements and quality management systems to Vietnam. As a result, gathering data from manufacturing companies that applied TQM 4.0 in Vietnam will provide this research with the data necessary to analyse the model reliably and accurately. Secondly, the objective of the Vietnamese government is to implement a strategy for sustainable development. Specifically, Resolution No. 136/NQ-CP, which was issued by the Vietnamese government, establishes seventeen national sustainable development goals to be accomplished by 2030. This mandate encourages organisations to emphasise strategic planning and pursue sustainable development. While challenging for the nation, these sustainable development objectives are crucial for compelling governments to act and inspiring companies to prioritise sustainable development strategies. Hence, it is imperative for enterprises operating in Vietnam to adopt operational policies that align with the nation's overarching sustainable development strategy. Therefore, researching the TQM 4.0 model (a model of TQM towards sustainability) and sustainable excellence (a concept that includes environmental, operational, social performance, and innovation performance) in Vietnam is appropriate and provides an accurate assessment in the research context.

Table 3.1 Profile of the respondents in the Study 2

Item	Frequency	Percentage (%)
Work experience (years)		
Below 5 years	105	40.7%
5-10 years	102	39.5%
11-15 years	25	9.7%
16-20 years	14	5.4%
Above 20 years	12	4.7%
Position		
Company Director/ Vice-Director	20	7.8%
Quality/Production Managers	66	25.6%
Supply Chain/ Purchasing/Maintenance Managers	48	18.6%
Quality/Production Supervisors	124	48.1%
Industry type		
Beverages and tobacco	10	3.9%
Paper and paper products	11	4.3%
Medicinal and pharmaceutical products	12	4.7%
Food and foodstuff	43	16.7%
Rubber and plastic products	12	4.7%
Textile and leather products	43	16.7%
Wood products	13	5.0%
Metal products, basic metals, and fabricated metal products	19	7.4%
Computer, electronic and optical products, electrical equipment	66	25.6%
Motor vehicles, trailers and semi-trailers, and other transport equipment	11	4.3%
Others	18	7.0%

Source: own research

Measurement model and structural model evaluation

According to Hair et al. (2022), the model estimation process produces empirical estimates of the connections between the indicators and the constructs, which are called measurement models. It also determines the relationships between the constructs, which are known as structural models. The estimates allow for the evaluation of the measures' quality and the assessment of whether the model yields adequate outcomes in terms of explaining and predicting the target constructs. The method of model evaluation consists of two steps: measurement model assessment and the structural model assessment.

In step 1, the author evaluates reliability and validity of constructs and indicators by calculating internal consistency (Cronbach’s alpha and Composite

Reliability), convergent validity (Average Variance Extracted), and discriminant validity (Heterotrait-Monotrait ratio). According to Hair et al. (2022), the criterion threshold of CA and CR values is 0.70. The average variance extracted (AVE) is greater than 0.5 to achieve convergence validity. the Heterotrait-monotrait ratio ≤ 0.9 is acceptance for similar constructs, and ≤0.85 is acceptance for different constructs.

Collinearity between variables was assessed before evaluating the structural model to avoid lateral collinearity (Hair et al., 2022). The author calculates the Variance Inflation Factor (VIF) to identify collinearity. VIF value ≤ 5 is acceptable, and ≤ 3 is preferable. The proposed model's coefficients, standard errors, t-test, effect sizes, and significance values (p) will be determined using the 5000-re-test bootstrap approach. The model's explanatory power is determined through (R^2) and effect size (f^2); The model's predictive power through Predictive relevance (Q^2) value.

Stage 2: ANN method

This study uses ANN because it detects both linear and non-linear relationships better than multiple linear regression, binary logistic regression, and SEM. ANN results for Vietnamese data (90% randomly selected samples for training, 10% for testing). ANN algorithm performs ten models in this stage.

A neural network comprises an input layer, numbers of hidden layers and an output layer. In this study, author used sigmoid function as a stimulating function for the hidden and output layers. The output and input neuron values were constrained to a range from zero to one to enhance the performance of ANN model (Kalinić et al., 2021). In order to minimise the issue of overfitting problems, researchers usually used a technique of ten-fold cross-validation. This procedure uses 90 per cent of the collected data for the training process and allocating the rest of 10 per cent for testing process (Kalinić et al., 2021). The research model contains one endogenous construct (SE) and eleven exogenous constructs in one ANN model. The ANN model has eleven factors of input layers representing exogenous constructs, namely, top management, quality culture 4.0, skill 4.0, smart organisation, integrating sustainable development, automated document control, automatic data collection, smart quality control, smart quality assurance, smart product, digital transformation and one output layer (sustainable excellence).

4 STUDY 1: DEVELOPING TQM 4.0 INDICATORS IN THE MANUFACTURING SECTOR.

This study utilised Delphi and AHP methods to determine key factors and fulfilment indicators for implementing the TQM 4.0 practices in the manufacturing industry. The study used the Delphi method, consisting of two rounds, to gather input from a group of experts from consultants, academics, and top management (supervisors or managers) in production and quality department.

The study successfully identified ten factors and totally 41 indicators. This research also evaluated the important factor and indicators using the AHP method. Based on the findings, social factors are considered to be of greater significance compared to technical factors. The study identified three most important factors of the TQM 4.0 framework: “top management”, “quality culture 4.0”, and the “integration of sustainable development”. Moreover, the research discovered that the TQM 4.0 model's highest importance indicators were “top management commitment, quality-driven mindfulness, and employee empowerment”. The results of this study may provide valuable insights for scholars and professionals in evaluating the application of TQM 4.0 in the industry.

4.1 First Delphi round analysis

In this round, five indicators with a CVR less than 0.29 were removed from the original questionnaire. These items are "Data scientists as quality experts”, “Human capital management”, “Social capital management”, “Intellectual capital management”, and “Managing networked firms in business ecosystems”. Furthermore, two recommendations presented by experts will be incorporated, namely “Application online tools in training, meetings, and work management” and “Machine Learning enhancement”. The revised questionnaire comprises ten factors, consisting of a total of 41 indicators, which will be assessed in the second round of the survey.

4.2 Second Delphi round analysis

The results from round 2 indicate that all indicators have a mean value greater than 3.5 and a CVR greater than 0.33, indicating that the indicators have achieved a high level of concentration. The final TQM 4.0 framework includes ten factors, which are represented by 41 indicators, as illustrated in Table 4.1. Ten factors are Top management (4 indicators), Quality Culture 4.0 (4 indicators), Skill 4.0 (4 indicators), Smart organisation (5 indicators), Integrating sustainable development (4 indicators), Automated document control (4 indicators), Automated data collection (3 indicators), Smart Quality Control (4 indicators), Smart Quality Assurance (5 indicators), and Smart product (4 indicators).

Table 4.1: The results of the second Delphi rounds

	2nd Round		
Factors or Indicators	**Average**	**CVR**	**Results**
“Top management”			
Top management commitment	4.41	0.94	Accepted
Top management involvement	4.38	0.81	Accepted
Top management provides resources	4.59	0.94	Accepted
Top management establishing policy, objectives and indicators	4.16	0.81	Accepted
“Quality Culture 4.0”			
Quality-driven mindfulness	4.25	0.88	Accepted

Employee empowerment	4.34	0.75	Accepted
Individuals' comprehension of their role in attaining quality objectives	4.09	0.69	Accepted
Quality articulation	4.09	0.63	Accepted
“Skill 4.0”			
Skills related to analytics, AI and CPS	4.06	0.69	Accepted
Digital skills for quality staff	4.19	0.69	Accepted
Digital communication skill	4.09	0.75	Accepted
Team creativity skill	4.19	0.69	Accepted
“Smart organisation”			
Top managements support initiatives, spread organisational knowledge	4.16	0.63	Accepted
Lean structure organisation	4.38	0.94	Accepted
Collaboration all stakeholders	4.03	0.63	Accepted
Adaptability in change	4.34	0.75	Accepted
Application of online tools	4.28	0.81	Accepted
“Integrating sustainable development”			
Link quality and sustainability	4.41	0.94	Accepted
Corporations serving society	3.88	0.56	Accepted
Sustainable operations	4.25	0.75	Accepted
Integration of environmental management systems	4.31	0.94	Accepted
“Automated document control”			
Incorporation of documents into ERP and automated revision	4.25	0.75	Accepted
Electronic documentation	4.44	0.94	Accepted
Real-time document control	4.31	0.88	Accepted
Standard operating procedures (SOPs)	4.47	0.88	Accepted
“Automatic data collection”			
Automatic data collection through the lifecycle of the product	4.34	0.94	Accepted
Automatic product-related data collection	4.38	0.81	Accepted
Automatic customer-related data collection	4.34	0.94	Accepted
“Smart Quality Control”			
Real-time quality inspection	4.16	0.75	Accepted
Total inspection	4.13	0.63	Accepted
Machine learning-based SPC	4.28	0.81	Accepted
Data integration in ERP	4.06	0.63	Accepted
“Smart Quality Assurance”			
Using artificial intelligence software for prediction and prevention	4.16	0.75	Accepted
Using smart sensors at each production stage	4.31	0.75	Accepted
Big-data analysis	4.25	0.69	Accepted
Making intelligent adjustments	4.34	0.88	Accepted
Improving machine performance by ML	4.13	0.63	Accepted
“Smart product”			
Predict market demand and consumption trends	4.22	0.69	Accepted
Smart identification and traceability technologies	4.03	0.63	Accepted
RFID technologies and smart sensors	4.25	0.75	Accepted

Involvement of Customers in the production	4.13	0.63	Accepted

Source: own research

4.3 Third Delphi round analysis (AHP technique)

The author employs the AHP approach to calculate the important levels of factors and indicators in implementing the TQM 4.0 framework. Table 4.2 provides a comprehensive overview of the relative important levels of the factors and their ranking in the TQM 4.0 model. The analysis indicates that the "Top management" is the most important factor. The 2nd factor is "Quality culture 4.0", while the less important factor is "Automatic data collection". The CR of 0.092 (shown in Table 4.2) indicates a satisfactory level of consistency.

Table 4.2: Ranking of the key TQM 4.0 factors

Factors in TQM 4.0	Weights of factors	Ranking
Top management	0.2545	1
Quality Culture 4.0	0.2052	2
Integrating sustainable development	0.0886	3
Skill 4.0	0.0719	4
Smart organisation	0.1323	5
Smart Quality Control	0.0376	6
Smart Quality Assurance	0.0631	7
Smart product	0.0567	8
Automated document control	0.0476	9
Automatic data collection	0.0424	10
CR (Consistency Ratio)	*0.092*	

Source: own research

The author also computes the important levels of the indicators in every factor and their corresponding ranks. The findings are displayed in Table 4.9. The responses exhibited consistency, with CR values that ranged from 0.02 to 0.84 in each factor.

Table 4.3: Ranking of the key TQM 4.0 factors

Factors	Indicators	Weights	Rank in factors	CR
“Top management 4.0”	Top management commitment	0.6167	1	0.062
	Top management provides resources	0.1592	2	
	Top management establishes policy, objectives and indicators	0.1591	3	
	Top management involvement	0.0650	4	
“Quality Culture 4.0”	Quality-driven mindfulness	0.4212	1	0.060
	Employee empowerment	0.2388	2	
	Quality articulation	0.2372	3	
	Individuals' comprehension of their role in attaining quality objectives	0.1028	4	
“Skill 4.0”	Skills related to analytics, AI and CPS	0.5175	1	0.077
	Digital skills for quality staff	0.2801	2	
	Digital communication skill	0.1411	3	
	Team creativity skill	0.0614	4	

"Smart organisation"	Lean structure organisation	0.3632	1	0.072
	Adaptability in change	0.3289	2	
	Application of online tools	0.1480	3	
	Top management support initiatives, the spread of organisational knowledge	0.0883	4	
	Collaboration of all stakeholders	0.0715	5	
"Integrating sustainable development"	Integration of environmental management systems	0.3817	1	0.084
	Corporations serving society	0.3258	2	
	Sustainable operations	0.2005	3	
	Link quality and sustainability	0.0920	4	
"Automated document control"	Digital standard operating procedures (SOPs)	0.4077	1	0.041
	Electronic documentation	0.2373	2	
	Real-time document control	0.2303	3	
	Incorporation of documentation into ERP modules and automated revision	0.1247	4	
"Automatic data collection"	Automatic product-related data collection	0.5612	1	0.020
	Automatic customer-related data collection	0.3147	2	
	Automatic data collection throughout the lifecycle of the product	0.1241	3	
"Smart Quality Control"	Real-time quality inspection	0.6181	1	0.077
	Machine learning-based SPC	0.2115	2	
	Total inspection	0.1145	3	
	Data integration in ERP	0.0559	4	
"Smart Quality Assurance"	Using artificial intelligence software for prediction and prevention	0.5156	1	0.056
	Big-data analysis	0.2352	2	
	Improving machine performance by ML	0.0993	3	
	Using smart sensors at each production stage	0.0969	4	
	Making intelligent adjustments	0.0530	5	
"Smart product"	Smart identification and traceability technologies	0.5606	1	0.072
	RFID technologies and smart sensors	0.2700	2	
	Forecast market demand and consumption trends	0.0847	3	
	Customers' involvement in the production process	0.0847	4	

Source: own research

The global weight of the presented indicators was determined by multiplying the weight of the factors with those of the indicators within a factor. Table 4.4 displays global weight and ranking of the 41 indicators. The results show that

"Top management commitment", "Quality-driven mindfulness", "Employee empowerment", "Quality articulation", and "Lean structure organisation" are five highest important indicators of the TQM 4.0 model.

Table 4.4: The rank of the indicators for TQM 4.0

Rank	Indicators	Global weights
1	Top management commitment	0.157
2	Quality-driven mindfulness	0.086
3	Employee empowerment	0.049
4	Quality articulation	0.048
5	Lean structure organisation	0.047
6	Adaptability in the change	0.044
7	Top management provides resources	0.042
8	Top management establishes policy, objectives and indicators	0.041
9	Skills related to analytics, AI and CPS	0.037
10	Integration of environmental management systems	0.034
11	Using artificial intelligence software for prediction and prevention	0.033
12	Smart identification and traceability technologies	0.032
13	Corporations serving society	0.029
14	Automatic product-related data collection	0.024
15	Real-time quality inspection	0.023
16	Individuals' comprehension of their role in attaining quality objectives	0.021
17	Digital skills for quality staff	0.020
18	Application of online tools	0.020
19	Digital standard operating procedures (SOPs)	0.019
20	Sustainable operations	0.017
21	Top management involvement	0.016
22	RFID technologies and smart sensors	0.015
23	Big-data analysis	0.015
24	Automatic customer-related data collection	0.013
25	Top management supports initiatives, spread organisational knowledge	0.012
26	Electronic documentation	0.011
27	Real-time document control	0.011
28	Digital communication skill	0.010
29	Collaboration of all stakeholders	0.009
30	Link quality and sustainability	0.008
31	Machine learning-based SPC	0.008
32	Improving machine performance by ML	0.006
33	Using sensors at each production stage	0.006
34	Incorporation of documentation into ERP modules and automated revision	0.006

35	Automatic data collection throughout the lifecycle of the product	0.005
36	Customers' involvement in the production process	0.005
37	Predict market demand and consumption trends	0.005
38	Team creativity skill	0.004
39	Total inspection	0.004
40	Making intelligent adjustments	0.003
41	Data integration in ERP	0.002

5 STUDY 2: THE IMPACT OF TQM 4.0 PRACTICES ON SUSTAINABLE EXCELLENCE.

In the Industry 4.0 context, it is very important for enterprises to apply a comprehensive and sustainable business model to grow steadily and quickly adapt to the fast-changing environment. Although the existing literature has explored TQM 4.0 framework (or Quality 4.0), which integrates Industry 4.0 tools into the TQM system, the question of how TQM 4.0 drives sustainable excellence (SE) remains unexplored. Therefore, to fill the gap, this investigates the relationship between TQM 4.0 practices and SE as well as the role of digital transformation (DT) and digital leadership in this connection, anchoring on the stakeholder theory, the NRBR (natural resource-based view) theory, and the STS (socio-technical system) theory. Moreover, this study ranks the importance of TQM 4.0 factors to enhance sustainable excellence. The research employs the quantitative hybrid SEM-ANN (Structural Equation Model combining with Artificial Neural Network) method to analyze empirical data in the manufacturing industry in Vietnam. The findings demonstrate that TQM 4.0 practices positively effect both digital transformation and SE. The mediating role of digital transformation and the moderating role of digital leadership in the relationship between TQM 4.0 practices and SE were confirmed in this study. This investigation provides the initial endeavour to rank the importance of TQM 4.0 practices to enhance SE using the ANN method. Future applications of TQM 4.0 practices and digital transformation to improve SE in the manufacturing sector would be aided by the findings of this study.

5.1 Measurement model assessment

To ensure the reliability and validity of constructs and indicators, the author applied the following steps to the assessment measurement model:

In step 1, we determine first-order constructs' scores and consistent correlations by estimating a PLS path model with only first-order constructs. According to Table 5.3, the range of CA values is from 0.791 to 0.969, while the range of CR values is from 0.864 to 0.971. All CA and CR values reached the criterion threshold of 0.70 (Hair et al., 2016), showing that the reliability of the measures is very high. Using indicators’ outer loadings and Average Variance Extracted (AVE), convergent validity was evaluated. The results show that convergent validity is accepted in this research, as the factor loadings and AVE values exceed

0.622 and 0.534, respectively. The outcomes of step 1 are composite scores of second-order construct indicator variables. We export the results of step 1 and import them into a different data file in preparation for step 2 analysis.

In step 2, the author evaluates the measurement model of second-order constructs. Table 5.1 shows that CA values range from 0.868 to 0.947, while CR values range from 0.905 to 0.954. The fact that both the CA and CR values reached the criteria limit of 0.70 (Hair et al., 2017) indicates that the measures are extremely dependable. Convergent validity is assessed by calculating the indicators' outer loadings and the AVE. Table 5.1 illustrates that convergent validity is satisfied in this investigation, as the factor loadings were larger than 0.757 and the AVE values were greater than 0.656.

Table 5.1: Reliability and convergent validity results of second-order constructs

Factors	**Indicators**	**Loadings**	**Cronbach's Alpha**	**CR**	**AVE**
Digital leadership	DT1	0.795	0.891	0.893	0.696
	DT2	0.799			
	DT3	0.861			
	DT4	0.855			
	DT5	0.858			
Digital Transformation	DL1	0.775	0.868	0.870	0.656
	DL2	0.778			
	DL3	0.779			
	DL4	0.882			
	DL5	0.832			
Sustainable Excellence	EP	0.848	0.899	0.903	0.767
	OP	0.84			
	SOP	0.928			
	IP	0.886			
TQM 4.0	TM	0.757	0.949	0.952	0.689
	QC	0.761			
	SK	0.858			
	SO	0.889			
	ISD	0.820			
	ADC	0.823			
	ADAC	0.852			
	SQC	0.816			
	SQA	0.817			
	SP	0.818			

Source: own research

The discriminant validity refers to the extent to which two constructs are separate and distinguishable. This study assessed the discriminant validity by employing the Heterotrait-Monotrait (HTMT) ratio (Henseler et al., 2015). The HTMT criterion was accepted because all values were less than the 0.885 threshold.

5.2 Structural model assessment

Before evaluating the structural model, the collinearity between the variables was evaluated to ensure no lateral collinearity issues (Hair et al., 2017). Collinearity issues could frequently be deceptive, even though the outer model's discriminant validity was confirmed. Thus, an additional inquiry is necessary. According to Table 5.2, there was no collinearity between the predictor components in the structural model (VIF $\leq$ 2.533).

Using 5000-re-test bootstrap, the model's coefficients, standard errors, t-test, effect sizes, and significance values (p) will be determined. The causal linkages among the understudy constructs are evaluated and determined at this analysis stage. The results demonstrate the direct and indirect effects of TQM 4.0 on SE in manufacturing enterprises.

As shown in Table 5.2, all of the proposed hypotheses were accepted. TQM 4.0 practices predicted digital transformation (H_1: β = 0.771, t = 29.101), whereas sustainable excellence is explained by TQM 4.0 practices (H_2: β = 0.717, t = 17.495) and digital transformation (H_3: β = 0.555, t = 7.969). Digital transformation has a mediation role on the relationship between TQM 4.0 practices and SE (H_4: β = 0.428, t = 8.376). Additionally, digital leadership moderates the connection between TQM 4.0 practices and SE (H_5: β = 0.093, t = 2.809)

The data presented in Table 5.2 demonstrates that the proposed model is statistically significant. This is indicated by the coefficients of determination (R^2) for the two endogenous constructs, which explain a substantial amount of the total variance (R^2 = 0.595 for digital transformation and R^2 = 0.665 for sustainable excellence). In addition, the effect sizes (f^2) were computed, as shown in Table 5.6; TQM 4.0 practices have a large effect size on DT (f^2 =1.468), while DT has a large effect size on SE (f^2=0.364). In addition, the findings indicate a medium effect size of TQM 4.0 practices on SE (f^2= 0.100). Otherwise, digital leadership has a small effect size on the relationship between TQM 4.0 practices and SE, with a value of 0.029.

Predictive relevance (Q^2) was also attained in the structural model (based on the blindfolding procedure with an omission distance of 7). According to Table 5.2, all Q^2 values were more than 0.25 (Digital Transformation: Q^2 = 0.384 and SE: Q^2 = 0.498), so the models have medium predictive power.

Table 5.2: Hypothesis testing results

Hypothesis		**Path coefficient**	**t-value**	**p-value**	**f^2**	**R^2**	**Q^2**	**VIF**
H_1	TQM 4.0 → Digital Transformation	0.771	29.101	0.000	1.468	0.595	0.384	1.000
H_2	TQM 4.0 → Sustainable Excellence	0.717	17.495	0.000	0.100	0.665	0.498	2.487
H_3	Digital Transformation →	0.555	7.969	0.000	0.364			2.533

	Sustainable Excellence							
H_4	TQM 4.0 → Digital Transformation → Sustainable Excellence	0.428	8.376	0.000				
H_5	TQM 4.0*Digital Leadership → Sustainable Excellence	0.093	2.809	0.005	0.029			1.031

Source: own research

5.3 ANN analysis

In the first stage of this research, PLS-SEM was utilised to test the hypothesised relationships and identify the factors that influence SE. In the second phase, ANN analysis ranks the importance of factors impacting SE.

From the data analysis, the average RMSE of the neural network models was relatively small: 0.259 for the training data and 0.271 for the testing data. These results indicate that the model's ability to predict endogenous construct, SE, is highly accurate. Consequently, it is widely accepted that the Artificial Neural Network (ANN) model created in this research yielded reliable and accurate findings.

The model sensitivity analysis calculates the variations in the endogenous construct by considering the modifications in the exogenous constructs linked to the model. Using sensitivity analysis, the contribution of each predictor to SE was determined in this study. The author calculated the relative importance of the factors and their normalised importance (NI). The sensitivity analysis results show that digital transformation (NI = 100%) is the most influencing exogenous construct in predicting SE, followed by integrating sustainable development (NI = 84.3%), top management (NI = 81%), automatic data collection (78.1%), smart organisation (NI = 76.2%), quality culture 4.0 (NI = 75.5%), smart product (NI = 72,4%), smart quality control (NI = 70.9%), smart quality assurance (NI = 70.9%), automated document control (NI = 70%), and skill 4.0 (NI = 65.1%).

6 DISCUSSIONS

My thesis investigates two main studies: the first focuses on exploring factors and indicators of the TQM 4.0 model practices in manufacturing enterprises, and the second focuses on investigating the relationship between TQM 4.0 practices and Sustainable Excellence.

6.1 Discussions in Study 1

The first study uses the STS theory as a framework to investigate the ten factors of TQM 4.0 practices and their indicators by employing three survey rounds. The research has identified forty-one indicators corresponding to ten factors (five social factors and five technical factors). The ten factors include Top management (consisting of 4 indicators), Quality Culture 4.0 (consisting of 4 indicators), Skill 4.0 (consisting of 4 indicators), Smart organisation (consisting of 5 indicators), Integrating sustainable development (consisting of 4 indicators), Automated document control (consisting of 4 indicators), Automated data collection (consisting of 3 indicators), Smart Quality Control (consisting of 4 indicators), Smart Quality Assurance (consisting of 5 indicators), and Smart product (consisting of 4 indicators). Several factors, including top management, smart organization, skills 4.0, sustainable development integration, Smart Quality Control, Automated document control, and Automatic data collection, have similarities in previous studies (Sader et al., 2019; Fundin, 2020; Chiarini and Kumar, 2022). However, prior research only mentioned the central theme and failed to develop the indicators to the same extent as my investigation. Furthermore, this study gives insight into social factors that have escaped the attention of previous research. In previous studies, quality culture 4.0, for instance, was disregarded. Conversely, organisations must prioritise developing and disseminating the quality culture 4.0 in TQM 4.0. It facilitates employees' readiness to adopt new technologies and readily accept new tools in Industry 4.0.

The author used the AHP technique to rank the importance of TQM 4.0's indicators and factors. The findings reveal three distinct rankings, which consist of (1) ranking of factors in the TQM 4.0 framework based on their importance, (2) ranking of the indicators within each factor, and (3) ranking of the indicators in the whole indicators in the TQM 4.0.

In particular, "top management" factor was most important among the ten factors assessed when investigating the TQM 4.0 implementation. Therefore, when evaluating the implementation of TQM 4.0, the scale should incorporate indicators that belong to top management involvement. This result is marginally consistent with the findings of Chiarini and Kumar (2022), who suggest that top management is a crucial component of the Quality 4.0 model in Italian manufacturing firms. "Quality Culture 4.0" is the second most important factor, while "Integrating sustainable development" is positioned as the third largest factor out of ten. Additionally, in the "Quality 2030: quality management for the future" study, Fundin (2020) emphasised the importance of incorporating sustainable development. Society must be the focus of TQM 4.0, which connects quality and sustainability (Ramanathan, 2019; Fundin, 2020). Smart Organisation and Skill 4.0, the two factors that comprise the social approach, are positioned 4^{th} and 5^{th}, respectively, among the ten factors. Chiarini and Kumar (2022) and Kupper et al. (2019) corroborate this result, which demonstrates that "Skill 4.0" is required for TQM 4.0 implementation. The TQM 4.0 framework also specifies "smart organisation" as a social factor, with "lean structure organisation" and "adaptability in a fast-changing environment" being the two indicators that carry the most significant weight.

Furthermore, experts consider five technical factors less important but essential components of a TQM 4.0 system. This research validates the aspects that have been underscored by numerous authors in prior investigations. Nevertheless, this study provides additional contribution by ranking the comparative importance of every factor and indicator. Smart Quality Control is the most significant technical factor, with "Real-time quality inspection" and "A new kind of SPC based on machine learning" carrying the highest weightings as indicators. The TQM 4.0 model enables quality department to inspect the quality of products or services in real-time (Sader et al., 2019) and introduces a new type of statistical process control (SPC) that utilises artificial intelligence to anticipate various machining defects and provide feedback to the machine. This feedback automatically adjusts the machine's parameters in real-time without requiring human involvement (Chiarini and Kumar, 2022). The following factor is “Smart Quality Assurance”, where the two most important weighted indicators are “Using AI software for prediction and prevention” and “Big-data analysis”. The TQM 4.0 framework will incorporate machine learning to conduct maintenance proactively and implement preventive measures to prevent downtime or system failure (Chiarini and Kumar, 2022). The TQM 4.0 framework incorporates big-data analysis to gather data produced from production processes and convert it into user-friendly interface to support decision making (Sader et al., 2019; Sader et al., 2021). Next, the factor of "Smart product" is ranked 8th among the factors investigated. It explains the way smart technologies can help enterprises identify and track products. In TQM 4.0 framework, smart sensors in products, packaging and RFID technologies can be utilised for monitoring and identifying product conditions (Chiarini and Kumar, 2022). The factors of "Automated document control" and "Automatic data collection" are the least significant. The TQM 4.0 framework automates the collection of various forms of product-related data. The findings of this thesis are corroborated by Chiarini and Kumar (2022), who assert the utilisation of automatic documentation for the Quality Management System. Finally, TQM 4.0 will additionally offer SOPs to guarantee that the employees in enterprises follow the most current instructions and procedures (Kupper et al., 2019).

6.2 Discussions in Study 2

The second study investigates the correlation between TQM 4.0 practices and SE as well as the influence of DT as a mediator and digital leadership as a moderator on this relationship in the manufacturing industry based on the stakeholder, NRBR, and STS theories. The results indicated that the implementation of TQM 4.0 practices has a positive impact on both DT (Digital Transformation) and SE (Sustainable Excellence). TQM 4.0 practices additionally impact SE indirectly through DT, in addition to their direct effects. In this study, the mediating function of DT between TQM 4.0 practices and SE was validated. The significance of the discovery within the framework of Industry 4.0 is to equip the organisation with a comprehensive and sustainable model. TQM 4.0 implementation has facilitated the DT of organisations and enhanced SE outcomes. Industry 4.0 technologies are suitable for businesses that want to achieve sustainable growth and quickly adapt to an unstable environment. This study's findings are consistent with previous research (Sanders et al., 2016; Sordan et al., 2022; Piyathanavong et al., 2022). Moreover, the findings indicate the importance of digital leadership by demonstrating that when TQM 4.0 is implemented in an organisation with more digital leaders, the achievement of SE is enhanced.

Using the ANN method, the second study ranks the importance of TQM 4.0 practice factors that enhance SE. The most influential exogenous constructs for predicting SE, according to the key results, are digital transformation, integrating sustainable development, smart organisation, and top management 4.0. As a result, future research examining methods to improve SE in manufacturing companies should not assume that each factor contributes equally but rather assess the relative significance of the components. It is surprising that, according to ANN results, the most significant elements of TQM 4.0 practices to improve SE are social aspects rather than technical aspects, which have received the most scholarly attention, despite the fact that TQM 4.0 is an integration of TQM and numerous tools of Industry 4.0. There are sustainable development, intelligent organisation, and top management 4.0. The findings of this study are consistent with those of previous research on TQM 4.0/ Quality 4.0 practises. In the study titled "Quality 2030: quality management for the future," Fundin et al. (2020) emphasised combining sustainable development. While serving society, TQM 4.0 must integrate quality and sustainability (Fundin et al., 2020). Moreover, Nguyen et al. (2023) proposed that a smart organisation is distinguished by its lean structure and its ability to adapt to a swiftly changing environment. There, upper management supports initiatives, disseminates organisational knowledge, and scales up effective innovations. To accomplish SE, the concept must include not only operational performance but also environmental, social, and innovative performance; ISD and SO are essential predictors of a consistent outcome. Expert evaluation of the TQM 4.0 application ranked top management as the most essential of the ten domains (Nguyen et al., 2023). Top management 4.0 is also an important factor in achieving SE. Chiarini and Kumar's (2022) research also revealed that top management is a crucial aspect of the Quality 4.0 paradigm in Italian manufacturing companies.

7 CONTRIBUTIONS

7.1 Theoretical contributions

My thesis makes valuable contributions to the existing body of knowledge on quality management in general, as well as the specific research on the movement of TQM 4.0 framework in several ways. Firstly, the thesis is an initial attempt to identify TQM 4.0's indicators and factors in manufacturing organisations through the utilisation of the Delphi technique in three rounds. Forty-one indicators have been identified for ten key factors in the study, which concludes with five social and five technical factors. Furthermore, this brings light on social factors that have failed the attention of previous research. In prior research, quality culture 4.0, for instance, was disregarded. Therefore, organisations must prioritise the development and dissemination of the new quality culture 4.0 outlined in TQM 4.0. It facilitates the acceptance of new tools by employees and prepares them to adapt to emerging technologies in the 4th Industrial Revolution.

Secondly, this thesis is the initial endeavour to rank the weighted significance of factors and indicators within the TQM 4.0 framework. The results of the AHP analysis reveal three rankings: (1) the importance of factors, (2) the importance of the indicators in each factor, and (3) the importance of the indicators in total indicators in the TQM 4.0 model. This significant finding demonstrates that crucial indicators or factors should carry greater weight, while less significant indicators or factors should carry lesser weight. Hence, it is imperative for forthcoming researchers to carefully evaluate the varying significance of TQM 4.0 factors and avoid making the assumption that every factor is equally important when investigating the TQM 4.0 framework in production companies. Surprisingly, the most important features of TQM 4.0 are the social aspects rather than the technological aspects, which have received a lot of attention from many different academics. This is despite the fact that TQM 4.0 is an integration of TQM and a variety of tools that are part of Industry 4.0.

Thirdly, this thesis examines the TQM 4.0 model by integrating the concepts of the STS theory and attaining an ideal equilibrium between social and technological elements. The STS theory tackles the constraints of conventional TQM and Industry 4.0 by presenting a TQM 4.0 framework that provides improved adaptation, flexibility, and sustainability. This discovery partially aligns with an earlier study conducted by Sony and Naik (2020), which suggested incorporating STS theory into the design of Industry 4.0 implementation. However, this thesis represents the initial effort to improve the current QM literature by including STS theory into the TQM 4.0 framework. Traditional TQM generally focuses on external management, whereas Industry 4.0 lays a stronger emphasis on technological instruments. On the other hand, the STS theory promotes the idea that businesses should give more importance to internal management by increasing employee empowerment, promoting productivity, and nurturing creativity and innovation. By incorporating the STS theory into TQM 4.0, a framework is established that successfully harmonises internal and external management, leading to the attainment of a lasting competitive advantage.

Fourthly, this thesis is an initial effort to provide a comprehensive and empirical analysis of TQM 4.0 practices and SE in the manufacturing sector by anchoring on the stakeholder, NRBR, and STS theory. This study not only analyses the connection between TQM 4.0 practices and SE but also explores the mediating role of DT and the moderating role of digital leadership in the relationship between TQM 4.0 practices and SE. TQM 4.0 practices, including ten factors and 41 indicators, were incorporated into the model in order to examine their effect on SE. The results indicated that implementing TQM 4.0 practices has a positive impact on both digital transformation and sustainable excellence. In addition, TQM 4.0 practices not only directly impact SE but also indirectly influence it through DT. The mediated role of DT in the relationship between TQM 4.0 practices and SE was confirmed in this study. In the context of Industry 4.0, the discovery's significance is creating a comprehensive and sustainable model for the company. The implementation of TQM 4.0 has promoted the DT of businesses and improved SE outcomes.

Finally, this is the first attempt to rank the significance of TQM 4.0 practises factors to improve SE using the ANN technique. According to the significant findings, the most influential exogenous constructs for predicting SE are digital transformation, integrating sustainable development, smart organisation, and top management 4.0. Therefore, future research examining methods to improve SE in manufacturing companies should evaluate the relative significance of the components and not assume that each factor contributes equally. Despite the fact that TQM 4.0 model is a combination of TQM and many Industry 4.0’s tools, it is surprising that, according to ANN results, the most significant elements of TQM 4.0 practises to improve SE are social factors rather than technical factors, which received the most attention from researchers.

7.2 Managerial contributions

My research indicates that production companies implementing the TQM 4.0 framework should utilise social and technical factors. The computation of indicator weight has facilitated the prioritisation of forty-one indicators, revealing that indicators related to social factors hold greater significance compared to those associated with technical factors. This outcome is noteworthy for business practitioners who want to implement TQM 4.0 in their companies. This thesis suggests that the key factors for success are “Top management commitment, Quality-driven mindfulness, and Employee empowerment”. Hence, it is imperative for top executives in manufacturing organisations to demonstrate unwavering dedication to the implementation of TQM 4.0 in order to achieve success. In addition, managers should promote a culture of mindfulness focused on quality and empower employees by fostering self-leadership. They should also take proactive measures to address problems instead of relying solely on regular processes, with the aim of achieving success on the first attempt, minimising waste, and reducing costs associated with failures.

Moreover, the findings reveal that indicators or factors are different at important levels. Managers in the manufacturing industry should prioritise specific factors or indicators when applying and evaluating TQM 4.0. It is important not to assume that all factors have an equal impact. This enhances the precision and efficiency of implementing and evaluating TQM 4.0 in the enterprise.

Furthermore, it is essential for managers to be aware that the TQM 4.0 model not only fulfils the expectations of consumers, improves performance, and satisfies shareholders, but it also works towards sustainable growth by addressing the demands of society. Consequently, it is imperative for manufacturing enterprises to adopt a more sustainable approach and incorporate environmental management systems. In addition, the incorporation of various Industry 4.0 tools necessitates that employees acquire new proficiencies, particularly in the domains of analytics, artificial intelligence, machine learning, cyber-physical systems (CPS), and digital skills for problem-solving and proactive measures are essential for quality staff. Therefore, it is imperative for manufacturing organisations to promote and facilitate employee skill development through training programmes. Utilising online courses can particularly enhance their digital skills conveniently.

Moreover, this empirical investigation revealed that TQM 4.0 practices significantly affect SE. Furthermore, there are different important TQM 4.0 activities in order to gain SE. In order to implement TQM 4.0 in the manufacturing business, managers should prioritise factors that have the most role in enhancing the accomplishment of SE, such as integrating sustainable development, smart organisation, and top management 4.0. Managers should connect quality and sustainability and develop more sustainable operations. Manufacturing businesses need lean structures for operational efficiencies and quicker decision-making facilitated by AI-based systems. This lean organisation will be capable of adjusting to a rapidly changing environment. Managers should promote a culture of quality-focused awareness and empowerment by fostering employee self-leadership and proactively addressing issues rather than relying solely on routine procedures to minimise inefficiencies and decrease the costs associated with failures.

Finally, the application of TQM 4.0 promotes DT in businesses, which leads to the achievement of SE. This result is remarkable for manufacturing industry practitioners. Applying TQM 4.0 practices in an environment where DT is being aggressively promoted not only assists businesses in achieving SE but also improves their digital performance. Therefore, the application of the TQM 4.0 model, which combines the social approach and tools of Industry 4.0, should be considered a comprehensive and sustainable model for businesses. Managers should inspire all employees with the DT plans of the organisation and encourage all employees to consider DT ideas.

8 CONCLUSIONS

8.1 Conclusions of the thesis

This thesis contributes to exploring the TQM 4.0's indicators and factors based on STS theory. The study analysed data from three survey rounds and found results that included ten factors and 41 indicators. The results also indicate the important levels of indicators and factors. This thesis also investigates the relationship between TQM 4.0 practices and SE in the manufacturing sector. The results demonstrated that TQM 4.0 practices positively influence both digital transformation and sustainable excellence. The mediate role of digital transformation and the moderate role of digital leadership in the relationship between TQM 4.0 practices and SE were authenticated. This result provides valuable insights for researchers and practitioners who can utilise it to implement and evaluate TQM 4.0 in manufacturing organisations.

8.2 Limitations and future research

Despite the significant contributions that this thesis makes to the field of QM, it acknowledges specific limitations. Firstly, there is low participation in Study 1 because of the practical challenge of requiring participants to join in many Delphi-AHP survey rounds. Secondly, it is important to mention that some indicators or factors of TQM 4.0 have not been identified in the conceptual framework of this study. Despite the study's comprehensive approach, which includes a literature review and three rounds of Delphi sessions, this limitation cannot be avoided. Therefore, it is suggested that future researchers make an effort to identify any additional indicators that may have been overlooked in this study. Thirdly, comprehending the effects that TQM 4.0 practises have on SE is predominately dependent on the information obtained from closed questionnaire surveys. That caused the research to ignore profound opinions that the closed questionnaire could not collect. Therefore, in-depth interviews with industry professionals might provide more in-depth explanations of the correlations between the elements. Moreover, scholars can research typical TQM 4.0 application case studies that are robust enough for a significant amount of time to be used in upcoming research. Fourth, the results of the survey provided by a single respondent do not accurately reflect the real implementation. In the future, a questionnaire should be distributed to a large number of appropriate individuals. For instance, managers will provide more correct answers to problems connected to performance, whereas an engineer may provide more accurate answers to questions linked to skills. Fifth, despite attempts to examine the TQM 4.0 - SE framework, the research may still disregard numerous factors associated with the model. Due to the recent development of this field of study, the successful implementation of TQM 4.0 will necessitate further empirical investigation to understand better the factors that determine SE. Finally, it is important to acknowledge that the research was carried out in a developing nation where awareness and understanding of TQM 4.0 are still in their early stages. Therefore, it is necessary to obtain validation from other regions. Future research should, therefore, aim to investigate TQM 4.0 in various areas or countries, as this would enable a comparison of TQM 4.0 based on experts' perspectives in different geographical areas.

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LIST OF PUBLICATIONS

Jimp/ Scopus articles: ***(published)***

1. **Thi Anh Van Nguyen**, David Tucek, Nhat Tan Pham (2023): Indicators for TQM 4.0 model: Delphi Method and Analytic Hierarchy Process (AHP) analysis, *Total Quality Management & Business Excellence, 34(1-2), 220-234,* DOI: 10.1080/14783363.2022.2039062 *(SSCI; IF=3.9)*
2. **Thi Anh Van Nguyen**, Khac Hieu Nguyen, David Tucek (2023): Total Quality Management 4.0 Framework: Present and Future. *Operations and Supply Chain Management: An International Journal*, 16(3), 311-322. DOI: http://doi.org/10.31387/oscm0540391 *(Scopus Q2)*
3. Nu Nguyen, Chuong Nguyen, Hieu Nguyen, **Van Nguyen** (2021); The Impact of Quality Management on Business Performance of Manufacturing Firms: The Moderated Effect of Industry 4.0; *Quality Innovation Prosperity*; 25/3-2021; 120-135, DOI: 10.12776/QIP.V25I3.1623 *(Scopus Q2)*

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Thi Anh Van Nguyen, David Tucek, Khac Hieu Nguyen, Nhat Tan Pham (2023): Total Quality Management 4.0 practices and sustainable excellence in the manufacturing sector: the role of digital transformation and digital leadership, *Oeconomia Copernicana*. *(SSCI)*

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1. **Thi Anh Van Nguyen**; David Tuček; Khac-Hieu Nguyen (2021); *Do quality management system standards affect firm innovation? Results from an empirical research*; International Bata Conference for Ph.D. Students and Young Researchers (DOKBAT), 2021, 332-341.
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4. **Thi Anh Van Nguyen**, David Tuček; Thi Thu Huong Nguyen (2022); *Total Quality Management in the context of Industry 4.0: a theoretical framework*; International Doctoral Seminar (IDS) 2022, 218-230

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