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Doctoral Thesis

Total Quality Management 4.0 and Sustainable Excellence in Manufacturing Sector

Totální řízení kvality 4.0 a udržitelná excelence ve výrobním sektoru

Author Thi Anh Van Nguyen
Degree Program P0413D050013 Economics and Management
Supervisor prof. Ing. David Tuček, Ph.D.
Consultant Pham Tan Nhat, Ph.D

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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.

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LIST OF SYMBOLS, ACRONYMS, ABBREVIATIONS

AHP: analytic hierarchy process

AI: Artificial Intelligence

ANN: Artificial Neural Networks

CB-SEM: Covariance-Based Structural Equation Modelling

CI: Consistency Index

CPS: cyber-physical systems

CR: Consistency Ratio

CSR: corporate social responsibility

CVR: Content Validity Ratio

DT: Digital Transformation

EMS: Environment Management System

ERP: Enterprise Resource Planning

ISO: International Organization for Standardization

LSS: Lean Six Sigma

MES: manufacturing execution system

ML: Machine Learning

NRBR: Natural Resource-Based View

PLS-SEM: Partial Least Squares Structural Equation Modelling

QC: Quality Control

QM: Quality Management

QMS: Quality Management System

RBV: Resource-Based View

RFID: Radio Frequency Identification

SE: Sustainable Excellence

SEM: Structural Equation Model

SOP: standard operating procedures

SPC: Statistical Process Control

STS: Socio-technical system theory

TQM 4.0: Total Quality Management in Industry 4.0

TQM: Total Quality Management

VIF: Variance inflation factor

1 INTRODUCTION

1.1 Research background

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).

TQM 4.0 operations might encounter a heightened level of complexity and uncertainty. In 2019, the Covid-19 pandemic served as a prime example of the volatility and unpredictability that present and future organisations must manage (Fundin et al., 2020). Globally, the economy has been profoundly affected by the Covid-19 pandemic, with manufacturing enterprises in particular. Consequently, enterprises are seeking a management system that can effectively and promptly adapt to these challenges. Enterprises can address obstacles that have arisen due to the effect of the Covid-19 outbreak because of the implementation of TQM 4.0, which offers a lean framework and the capacity to respond to unanticipated external conditions. Manufacturing is the primary sector that is focusing on the implementation of TQM 4.0. However, there is a lack of indications that may be used to evaluate the application of TQM 4.0 in businesses. As a result, it is of the utmost importance to possess indications and factors that will make it easier to evaluate the level of success that TQM 4.0 techniques have achieved in manufacturing businesses. As a consequence of this, it is essential to concentrate on the development of the primary indicators and factors for the implementation of TQM 4.0 practices. Furthermore, it is crucial to rank variables and indicators in the process of implementing TQM 4.0 using AHP method.

TQM 4.0 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 SMEs. 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. Digital leadership, defined by De Waal et al. (2016), is an integration of digital technology and the transformational leadership style. 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 gaps

Although some authors attempt to research TQM in the context of Industry 4.0, some issues need to be investigated.

Firstly, most studies give general topics without fulfilling factors and indicators for the TQM 4.0 framework and employ the literature review methodology (Park et al., 2017; Asif, 2020; Sony et al., 2020; Sader et al., 2021). There is a scarcity of studies that have employed a quantitative approach to investigate Quality 4.0. For example, Glogovac et al. (2020) evaluated Quality 4.0 implementation based on 9004:2008. The study is limited by the fact that it is not adaptable in terms of updating the model. This is because the model is dependent only on the initial ISO scheme, and the research that was carried out is applicable to all production and service companies. Glogovac et al. (2020) suggested that further research on this topic should explore all the indicators within factors and consider different contexts. Moreover, Chiarini and Kumar (2022) conducted a study using sequential mixed methods to investigate the main concept of Quality 4.0. On the other hand, this study only focused on the most important components, and it did not give a comprehensive list of indications that were pertinent to each different factor. As a result, the absence of a complete collection of indicators and factors is a significant shortcoming that has to be addressed. Researchers and businesses are able to execute and evaluate the use of TQM 4.0 in the industrial sector more successfully with the assistance of these indicators and factors.

Secondly, previous models of Quality 4.0 were irrelevant to theories (Chiarini, 2020). Traditional TQM places a greater emphasis on standardisation and stability, whereas Industry 4.0 emphasises the use of technology instruments. Because of this, it would appear that humans' function inside the system is becoming less significant. The solution to this issue will be discovered through the implementation of a framework that is based on the concepts of STS theory. The STS encourages adaptation, provides employees with a substantial amount of autonomy, and provides them with a wide range of empowerment opportunities. When combined with the rigid old TQM approach and the technical tools utilised in Industry 4.0, it is an ideal complement to both of these environments. Additionally, in order to attain both organisational stability and flexibility, Manz and Stewart (1997) suggested combining TQM and STS simultaneously. Chaudhuri and Jayaram (2019) also proposed that STS may be utilised as an appropriate theory for the purpose of investigating the effect of integrating social and technological components on QM and sustainability management. As a result of its progress, the combination of STS with Industry 4.0 for the goal of achieving sustainable development has emerged as a realistic answer for academics. During the process of developing the application of Industry 4.0, Sony and Naik (2020) proposed the STS theory. As a result, it is appropriate to use STS theory in order to construct the TQM 4.0 framework, which successfully handles both social and technological problems in a balanced manner. Additionally, this is a crucial kind of repair for earlier research about Quality 4.0 models that were devoid of any value to theories (Chiarini, 2020). The STS promotes employee empowerment through the enhancement of individual and team autonomy. Consequently, it fosters the development of flexibility, adaptability, and innovation. STS prioritises the enhancement of employees' productivity and the development of an organisational culture that fosters creativity and innovation.

Thirdly, when implementing the TQM 4.0 framework, it is essential to provide a ranking of the significant factors and indicators. Within the framework of the TQM 4.0 paradigm, not all factors and indicators have the same amount of influence. When analysing the TQM 4.0, it is necessary to give more weight to the indications that are considered more critical while giving less weight to those considered less relevant. Further inquiry is necessary to determine the significance of particular elements on other dimensions within the TQM 4.0 model, according to Glogovac et al. (2020), which also suggests that extra research is required. Given the importance of this particular domain, it is of the utmost importance to carry out research on the ranking of the major factors and indicators that are included in the TQM 4.0 model.

Fourthly, some studies have illustrated that TQM is key important strategy for enterprises to achieve successful performance (Alič, 2014; Kafetzopoulos et al., 2015), and investigating the effect of TQM 4.0 practices on firms performance remains unexplored. In the context of Industry 4.0, it is essential to develop a comprehensive and sustainable business model aimed at quickly adapting to an unstable environment and achieving sustainable development goals. There have been efforts to define Quality 4.0 or TQM 4.0 based on the determined method (Nguyen et al., 2023; Chiarini and Kumar, 2022). Nevertheless, TQM 4.0 research is in its early stages, with the majority of studies concentrating on the conceptualization of TQM 4.0. As a result, providing a comprehensive model of TQM 4.0 practices and organisational factors, sustainable performance, for instance, is needed. This discovery is in the initial stages, as enterprises may be just beginning to adopt TQM 4.0 practices. In general, from the standpoint of the STS theory, it is suggested that TQM 4.0, which is geared towards a sustainable business model, has the potential to be an essential component that drives sustainable excellence (SE) in companies. In spite of this, the existing literature has not clarified this issue. Consequently, it is important to take into consideration the topic of how and why TQM 4.0 might actually enhance SE. It is absolutely necessary to do research and practice in order to investigate the linkages that exist between TQM 4.0 techniques and other factors. TQM and Excellence are two concepts that usually co-exist in enterprises. The concept of business excellence has arisen globally as a new trend that elevates TQM implementation frameworks and quality award programs. Therefore, exploring the direct and indirect effect of TQM 4.0 on SE is theoretically and practically significant. Furthermore, it is necessary to research the roles of digital leadership and DT in the TQM 4.0 and SE framework. The role of a leader is essential in driving the effectiveness of TQM 4.0 (Sony et al., 2020; Nguyen et al., 2023). Because digital leaders have the ability to create collaborative networked enterprises and provide opportunities for employees to understand how to work on the TQM 4.0 system, this can lead to a transformation in the way digital works are performed (Sony et al., 2020). The influence of leadership style on the practices of TQM 4.0 is an interesting question. However, the roles of digital leadership and DT in the framework of TQM 4.0 and SE are unexplored.

Finally, the pandemic has caused many problems in the manufacturing sector (Piyathanavong et al., 2022; Pansare and Yadav, 2022). Companies that make things are having trouble getting their production activities to start up again. Pansare and Yadav (2022) thoroughly reviewed the literature to identify the most important Industry 4.0 technologies and practices for reconfigurable manufacturing systems. The results show that quality practices are essential in repurposing production operations. So, looking into TQM 4.0 practises for sustainable manufacturing is important from both a theoretical and a practical standpoint. However, manufacturing enterprises have not investigated the connection between TQM 4.0 practices and SE. Using the stakeholder, NRBR, and STS theories as a foundation, this thesis aims to examine the associations between TQM 4.0 practises and sustainable excellence in the manufacturing sector, as well as rank the importance of factors to enhance SE in manufacturing enterprises.

1.3 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.

1.4 Research design

This study includes five research objectives. The first objective is to identify the main indicators and factors of TQM 4.0 practices. The second objective is to determine the importance of TQM 4.0's factors in practice. The third objective is to rank the indicators' importance in a factor and in the total indicators in the TQM 4.0 practices. The fourth objective is to test the effect of TQM 4.0 practices on sustainable excellence in manufacturing sector, and the final objective is to explore the mediate and moderate effect of digital transformation and digital leadership in the relationship between TQM 4.0 practices and sustainable excellence in the manufacturing sector. To achieve 1st, 2nd, 3rd objectives, this thesis employs both Delphi and AHP approaches. To gain the research's 4th and 5th 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. **RO3:** Ranking the importance of indicators within a factor and in the total indicators of TQM 4.0 practices in the manufacturing sector.	Quantitative method: AHP method
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

Source: own research

According to Saunders et al. (2019), combining quantitative and qualitative is designed in many business and management research. While employing a questionnaire may be a component of a research design, there are specific justifications for incorporating "open" questions that require respondents to express themselves using their own words instead of simply selecting the appropriate checkbox (Saunders et al., 2019). This study has used a mix of research approaches consisting of both qualitative and quantitative methods. The qualitative approach is demonstrated through the Delphi method to identify the fulfilment indicators and factors of the TQM 4.0 practices. The experts from enterprises will be given in-depth interviews to generate the questionnaire based on the literature review. In round 1, the experts will answer the closed-opened questionnaire. Besides ticking the appropriate box, participants will provide responses to open-ended questions regarding the author's comments on the TQM 4.0 model, as well as offer additional insights and opinions based on their knowledge and experiences. The quantitative approach is demonstrated by using numerical data collection method in Likert scale and data analysis (for example, calculating Mean and Content Validity Ratio in the first and second rounds, Normalized Pair-wise comparison matrix, criteria weights, global weights, consistency ratio in the AHP technique).

To gain the fourth and fifth 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. 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 (Barclay et al., 1995). 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 utilised to determine the measurement and structural model.

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 emerged in organisational studies and centres on the interplay between social and technical aspects within a system. Originating in the mid-20th century, specifically at the Tavistock Institute in the United Kingdom, this theory seeks to enhance organisational performance and human well-being by considering the combined impact of social and technical elements (Trist, 1981). The STS theory promotes a comprehensive perspective on organisations, considering them interconnected systems in which social and technological elements rely on each other. The social system encompasses individuals, interpersonal connections, roles, and the prevailing organisational culture. It recognises the influence of human factors on the performance of an organisation. A technical system collects tools, technology, and processes that enable and support work activities. It acknowledges the significance of developing efficient technical systems that align with human requirements and capacities (Trist, 1981; Manz and Stewart, 1997; Davis et al., 2014).

STS theory has been applied in many industries, such as manufacturing, healthcare, and information technology, to design work systems that enhance productivity and job satisfaction (Chaudhuri and Jayaram, 2019; Cimini et al., 2020; Sony and Naik, 2020). Chaudhuri and Jayaram (2019) proposed that STS has the potential to function as an appropriate theoretical foundation for the investigation of the impacts of integrating social and technological components on QM and sustainability management. The majority of the gains that have been made because of Industry 4.0 have been in the technological realm, and they do not immediately connect to the social components of the organisation (Kupper et al., 2019). The consequence of this is that there is an imbalance between the social and technical parts of the circumstance. Tools developed for Industry 4.0 fail to take into account the human aspect, and quality models do not address this problem. STS promotes flexibility, significant autonomy, and a wide range of employee empowerment. Therefore, it is an appropriate addition to the rigorous traditional TQM and of Industry 4.0's resources. Sony and Naik (2020) propose the consideration of STS theory in designing and implementing Industry 4.0 for sustainable management. Sony and Naik (2020) propose a method for integrating the perspective of STS theory into the architectural design for combination during the implementation of Industry 4.0. Effective execution of Industry 4.0 necessitates the integration of various aspects, including vertical, horizontal, and end-to-end integration. The result proposes a development strategy for systems in Industry 4.0 by integrating STS on various aspects such as men, infrastructure, technology, processes, culture, procedure and goals.

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 shared responsibility for quality. They share systems thinking perspective, identifying and addressing root causes of quality issues and promoting continuous improvement and skill development (Manz and Stewart, 1997).

For the purpose of achieving both organisational stability and flexibility, Manz and Stewart (1997) incorporated both STS and TQM. Integrating the principles of STS and TQM creates a comprehensive framework for improving organisations. STS theory promotes a comprehensive organisational perspective, encompassing both technical and social dimensions. In addition, TQM strives for a holistic approach to quality improvement. By integrating these various perspectives, organisations can effectively address the interdependence of people, processes, and technology in their pursuit of total quality. TQM and STS theory both place significant emphasis on the criticality of employee participation in decision-making procedures. Employee participation is vital to TQM's commitment to continuous improvement. This is supported by STS theory, which acknowledges that the efficacy of technical systems is contingent upon the individuals operating them. Incorporating these ideas fosters a culture of collaboration and shared accountability for quality. The STS theory promotes the integration of technical and social systems in their optimisation. TQM aims to optimise operations in terms of quality. By aligning these objectives, organisations can develop systems that not only optimise efficiency and quality but also consider the welfare and capabilities of their personnel. The STS theory's emphasis on flexibility and adaptability is congruent with the TQM's commitment to continuous improvement. Both approaches recognise that organisations must adapt to technological developments, processes, and market conditions. By incorporating these principles, one can guarantee quality management practices' continued effectiveness and relevance.

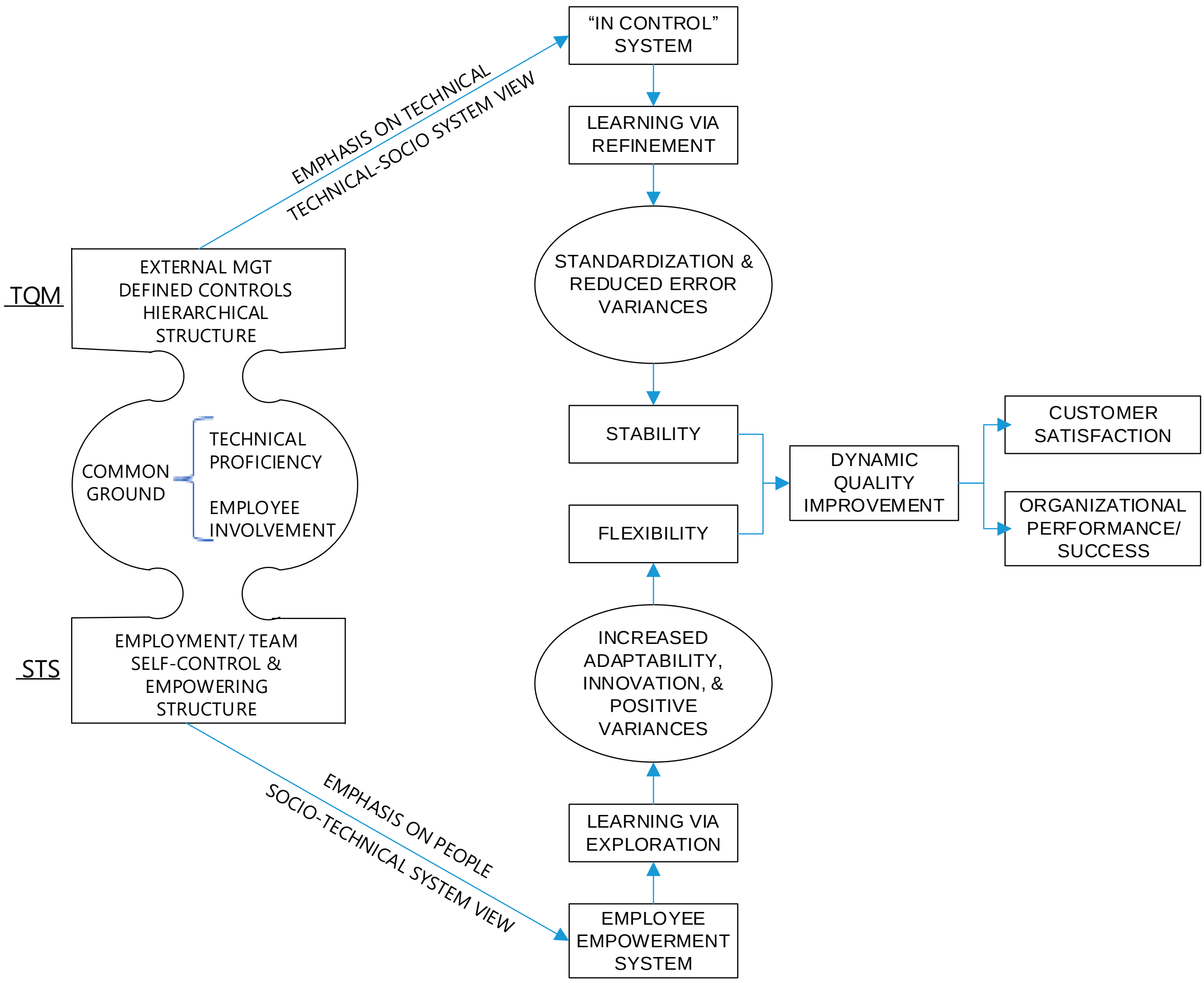

Fig 2.1: TQM and STS integration.

Source: Manz and Stewart, 1997

Traditional TQM emphasises establishing standards and maintaining stability, whereas Industry 4.0 emphasises utilising advanced technical tools. The STS theory framework is a comprehensive solution for integrating social aspects into both TQM and Industry 4.0. STS cultivates an atmosphere that encourages employee autonomy, flexibility, and a substantial degree of self-governance. It is the ideal complement to the technological instruments of Industry 4.0 and the rigidity of conventional TQM. Therefore, it will be suitable to implement a sustainable TQM 4.0 framework by constructing the TQM 4.0 model in accordance with STS theory.

2.1.2 Stakeholders theory

The stakeholder theory is a popular concept in business and management. Its primary emphasis is on the interactions between organisations and the many groups of people interested in those organisations. It recognises that organisations are responsible not just to their shareholders but also to a diverse variety of persons and groups that have a stake in the actions and results of the organisation.

In addition, organisations have to hold their shareholders accountable. According to the principle, businesses should consider the concerns and requirements of all of their stakeholders and work hard to provide value for those individuals (Flammer, 2013).

Donaldson and Preston (1995) showed that the input-output paradigm is opposed to the stakeholder theory, which emphasises the significance of stakeholders' perspectives. Stakeholder analysts argue that all individuals and organisations with genuine interests participate in a business to receive benefits. Consequently, communication occurs between the corporation and the numerous constituencies considered stakeholders. All stakeholder connections are depicted in the same size and shape and are evenly dispersed from the "black box" representing the organisation in the centre of the diagram. As they continue their investigation, the unique characteristics of this concept in comparison to more conventional input-output theories will become apparent.

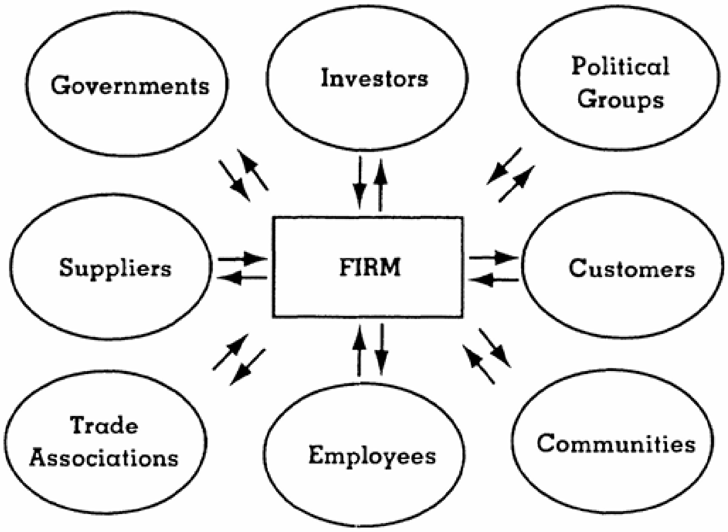

Fig 2.2: The Stakeholder theory

Source: Donaldson and Preston (1995)

Instrumental stakeholder theory is an extension of stakeholder theory that considers corporate social responsibility (CSR) initiatives as a method to gain required resources or stakeholder support. This theory views CSR efforts as achieving essential resources or stakeholder support. According to Flammer (2013), introducing a new recycling programme may boost a company's brand and bring in consumers and stakeholders who are environmentally sensitive. The genuine entity theory is an alternative interpretation of stakeholder theory. This interpretation views the corporation as an independent and distinct entity whose function is predetermined by the organisation that seeks to incorporate it. According to Claassen (2023), it is vital to thoroughly comprehend the goals and functions that corporations serve within our society. The notion of stakeholders has developed over time, and there have been further attempts to integrate it with the academic study of strategic management. The "new stakeholder theory" (NST) strongly emphasises the ethical and financial dimensions involved in organisations' value creation and value 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 (Bridoux and Stoelhorst, 2022).

A number of different theories and conceptual frameworks, such as corporate social disclosure and corporate social responsibility (often abbreviated as CSR), have been connected to stakeholder theory. Arguments and discussions have concerned the connection between stakeholder theory and corporate social responsibility (CSR). While some academics consider them to be alternative conceptual frameworks, others consider them to be almost interchangeable. On the other hand, a thorough understanding of the connection between stakeholder theory and CSR has not yet been thoroughly investigated (Dmytriyev et al., 2021). 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 how important it is to take into account the interests and requirements of all stakeholders in making decisions inside an organisation. It has been expanded upon and combined with some different conceptual frameworks and theoretical frameworks, such as the instrumental stakeholder theory, the fundamental entity theory, and strategic management research. Stakeholder theory has seen an increase in popularity, but at the same time, it has been subjected to criticism and requests for additional clarity.

2.1.3 Natural Resource-based View (NRBR) theory

Hart (1995) established the natural-resource-based concept of the firm, which embraces the natural environment, to address firms' mounting ecological issues. Future strategy and competitive advantage will likely be based on characteristics that enable ecologically friendly economic activities (Hart, 1995). The author created a three-part NRBV framework: pollution control, product stewardship, and sustainable development.

The NRBV paradigm of competitive advantage focuses on a company's natural resources, according to Barney (2001). The resource-based view (RBV) hypothesis underlines how firms generate economic rents from scarce, valuable, and expensive resources and skills (Barney, 2001). The NRBV theory includes the natural environment to meet firms' growing ecological challenges because the RBV hypothesis ignores environmental limits (Markley and Davis, 2007). NRBV theory states that strategy and competitive advantage will be built on abilities that enable eco-friendly economic activities. It advises NRBV on pollution avoidance, product stewardship, and sustainable development (Markley and Davis, 2007). Environmental management integration in strategic planning improves financial and environmental performance and gives firms a competitive edge (Judge and Douglas, 1998). The NRBV theory also values resource orchestration managers' efforts to organise, bundle, and use company resources (Sirmon et al., 2011). Resource orchestration illustrates RBV theory by emphasising managers' resource use for competitive advantage. It can be employed across the firm, maturity, and organisational levels (Sirmon et al., 2011). The NRBV theory also values natural resources for sustained competitive advantage (Pan et al., 2020). The NRBV hypothesis states that environmentally responsible economic behaviour can give companies a long-term competitive advantage by promoting nature-environment harmony (Pan et al., 2020). The Natural Resource-Based View theory incorporates nature. It supports strategic planning that includes environmental issues and uses natural resources for business. According to the hypothesis, resource orchestration and eco-friendly economic behaviour can create lasting competitive advantage. By managing their natural resources, firms can increase performance and sustainability.

Table 2.1: Conceptual Framework of Natural Resource-based View

Strategic Capability	*Pollution Prevention*	*Product Stewardship*	*Sustainable Development*
Key Resource	Continuous improvement	Stakeholder integration	Shared vision
Environmental Driving Force	Minimise emissions, effluents, and waste	Minimise life-cycle cost of products	Reduce the ecological impact of the expansion and progress of the company
Competitive Advantage	Lower costs	Preempt competitors	Future position

Source: Hart (1995)

The theory of Natural Resource-Based View (NRBV) finds application in various fields, including quality management. The importance of natural resources to sustainable competitive advantage is emphasised by the NRBV theory. (Agyabeng-Mensah et al., 2021). In quality management, the NRBV theory advocates using natural resources to improve products and services (Vasudevan, 2021). NRBV theory can be used for quality management by incorporating environmental considerations into strategic planning. Research shows that including environmental management concerns in strategic planning improves financial and environmental performance (Judge and Douglas, 1998). Businesses can improve performance by considering natural resource impacts on quality and incorporating environmental concerns into quality management. Resource orchestration and efficient resource management are also stressed in the NRBV theory. Businesses can use resource orchestration to improve quality management by optimising resource allocation. This may involve using sustainable procurement or eco-friendly production methods to improve quality. NRBV theory can also help build sustainable quality management and supply chain practises. Businesses can improve product quality and sustainability by considering environmental supply chain and social factors (Agyabeng-Mensah et al., 2020). This may entail green supply chain practises, including waste reduction, energy conservation, and ethical sourcing, which can improve quality. In conclusion, the NRBV paradigm helps increase organisational performance through quality management. Businesses can improve product quality by incorporating environmental issues into strategic planning, maximising resource allocation, and using sustainable supply chains. The NRBV theory helps firms gain a sustainable competitive advantage through quality management by explaining the link between natural resources and quality results.

2.2 Industry 4.0 definition

The Fourth Industrial Revolution, commonly referred to as Industry 4.0, is characterised by the adoption of intelligent digitalisation and the integration of information technology in order to establish a smart factory. It is possible for humans, machines, and goods to communicate with one another in this factory through both physical and virtual channels. The implementation of this innovation has the potential to improve sustainability (Zhou et al., 2020; Neumann et al., 2021). Four industrial revolutions underwent a lengthy development process, as depicted in Figure 2.3.

The First Industrial Revolution took place between 1760 and 1820, during which individuals recognised the potential of utilising water and steam power to transition from manual production to mechanised processes, thus called “mechanisation”. The term "Second Industrial Revolution" refers to the period of rapid industrialisation from the late 1800s to the 1900s. During that period, our society began utilising electric power for large-scale manufacturing and assembly lines powered by electricity, a process commonly referred to as "electrification". The Third Industrial Revolution commenced in the 1950s and was subsequently succeeded by the phenomenon known as "digitisation" until the 1970s. Individuals began using artificial digital logic circuits, computers, cellular phones, and the internet to generate output independently. The most recent advancements in the Fourth Industrial Revolution involve the utilisation of cyber-physical systems, big data analytics, cybersecurity, simulation, autonomous robots, vertical and horizontal system integration, additive manufacturing, the cloud, the internet of things, artificial intelligence, machine learning, and augmented reality. (Chiarini, 2020; Zhou et al., 2020).

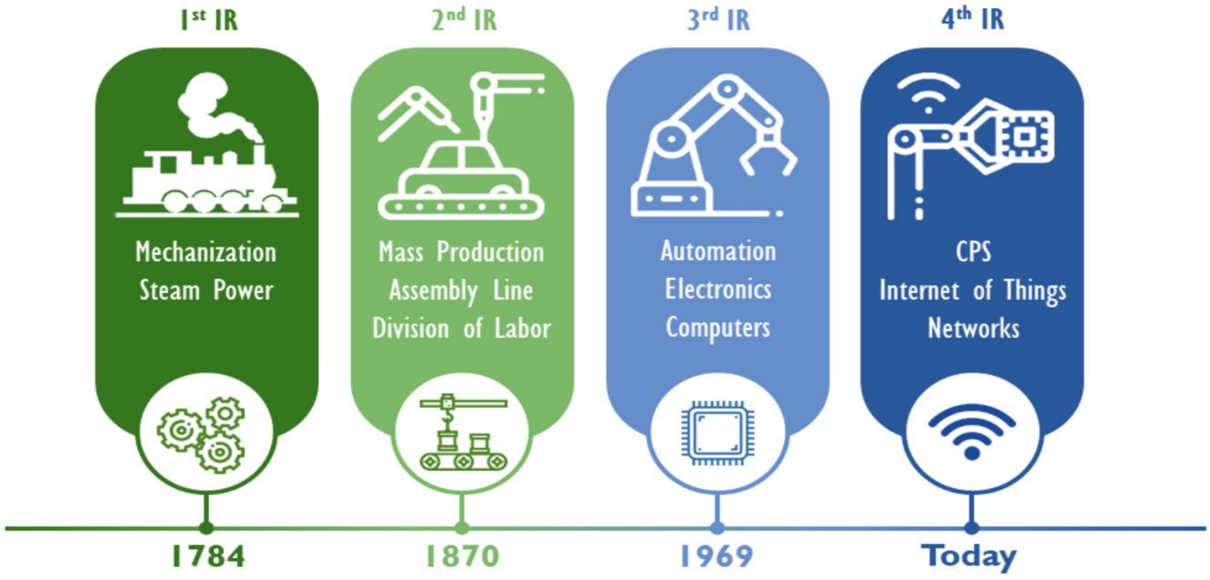

Fig 2.3: The four "Industrial Revolutions"

Source: Speringer (2019)

2.3 Total Quality Management (TQM) development

Total Quality Management (TQM) is a popular strategy applied in doing business in the industry sector (Miller, 1996; Goetsch and Davis, 2013; Zhang et al., 2020). TQM comprises a collection of principles, tools, and methodologies that facilitate stakeholder satisfaction for both executives and staff. Additionally, TQM encompasses all organisational components rather than concentrating merely on the systems involved in the design, production, and deployment of the organization's products and services. This system encompasses all auxiliary systems, such as finance, human resources, and marketing. TQM is an organization-wide concept that incorporates every function and level, from the highest to the lowest (Goetsch and Davis, 2013).

While certain academics characterise TQM as aligned with quality management standards like ISO 9001 and ISO 9004, alternative perspectives integrate TQM into business excellence frameworks, including Baldrige, EFQM, and Deming Prize. ISO 9001 defines the criteria that govern quality management systems. The fundamental principles of this standard are centred around quality management, including the optimisation of customer satisfaction, active participation and engagement of senior management, implementation of a process-oriented methodology, and ongoing progress. The ISO 9004 standard offers recommendations for enhancing an organization's ability to attain sustained prosperity. It also comprises a self-evaluation instrument that gauges the degree to which the standard has been incorporated (ISO, 2021).

Sader et al. (2019) stated that the quality management development process consists of the following components: quality assurance, quality control, and total quality management. Furthermore, as illustrated in Figure 2.4, the TQM was integrated into Industry 4.0. In this process, quality control is an item-centric procedure that utilises a variety of statistical control tools and inspection techniques to detect any defective products. In addition to guaranteeing the output of superior products, quality assurance enhances the manufacturing process's stability. Quality Management (TQM) is an all-encompassing managerial ideology that concerns itself with the quality of systems, processes, and products.

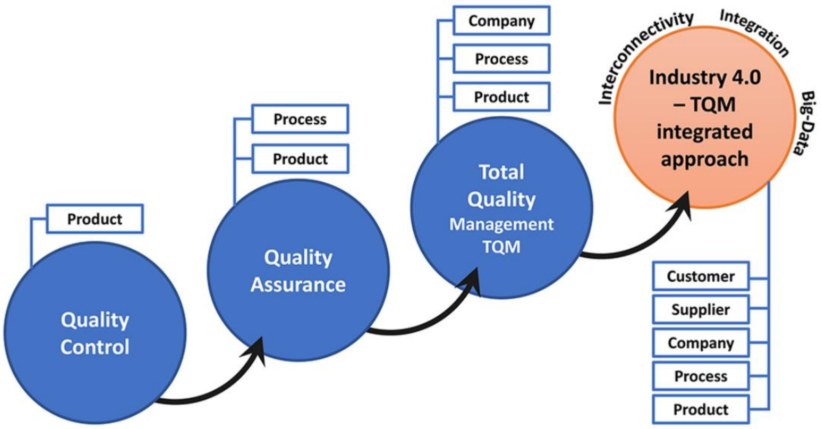

Fig 2.4: The development of TQM

Source: Sader et al. (2019)

2.4 Quality Management implementation in Four Industrial Revolutions

Throughout the history of four industrial revolutions, quality management (QM) implementation in organisations has undergone significant transformations. The inspection of the finished product throughout the First and Second Industrial Revolutions gave rise to the QM methodology. Following that, the scope of the inspection was expanded to include the evaluation of outputs (including semi-finished and final products), processes, and inputs (including materials and machinery). At this juncture, statistical process control (SPC) was implemented. A variety of instruments are employed by engineers in their work, such as control charts, scatter diagrams, checklists, flowcharts, fishbone diagrams, Pareto charts, histograms, stratification charts, and run charts. These tools were employed with the intention of resolving issues and improving procedures through the collection and analysis of data that would form the basis for making decisions. Significant advancements were made in the field of SPC techniques during the course of the Third Industrial Revolution. These methodologies laid the groundwork for the creation of numerous others, such as the Design of Experiments (DOE) and Robust Design Methodology. Although SPC has the capability to regulate a multitude of variables, which particular variable necessitates regulation? The methodology of DOE is utilised in order to investigate this matter. An unprecedented approach to improving a procedure through the identification of cause-and-effect connections. In the 1980s, Genichi Taguchi made the significant realisation that the design of a product or process could be deemed responsible for the preponderance of issues. Taguchi successfully implemented the DOE in order to construct the Robust Design methodology. Implementing the "do it right the first time" principle, the method enhanced the product/process design in order to achieve a superior outcome.

The Quality Management System (QMS) was firmly established in the 1990s. It is acknowledged that the notion of QMS encompasses an extensive philosophy. 1987 marked the introduction of the initial ISO 9001 standard by the International Organisation for Standardisation (ISO). This standard provides a structured approach to establishing and overseeing a system that guarantees consistent customer contentment by improving the quality of products and services. The ISO 14001 standard was implemented for environmental management systems in 1996. This criterion requires the implementation of practical tools in order to manage their environmental responsibilities efficiently. However, QMS offers a structural framework devoid of any tools or statistical methodologies. Introduced in 1995, the Six Sigma method is a breakthrough improvement approach that utilises advanced statistical techniques. The Six Sigma methodology offers a range of technical tools to enhance the effectiveness of processes. Improving performance and reducing process variation contribute to decreased defects and increased profits, staff satisfaction, and product or service quality.

In the Fourth Industrial Revolution context, Total Quality Management (TQM) incorporated Industry 4.0 technologies into a unified system known as "TQM 4.0". Industry 4.0 encompasses advanced technologies, including cyber-physical systems, simulation, big data analytics, autonomous robots, the Internet of Things, and AI. TQM 4.0 possesses distinct attributes that differentiate it from previous QM models. TQM 4.0 employs advanced information technology (IT) and efficient inspection tools to inspect the whole item rather than relying on sampling carefully. In addition, businesses have the option to procure quality assurance, quality control, and real-time inspections. Patrons possess the capacity to design merchandise that can be modified to accommodate their particular inclinations. As a result of the convergence of quality expertise and data science within the context of Industry 4.0, the combined profession known as "data & quality scientist" is formed.

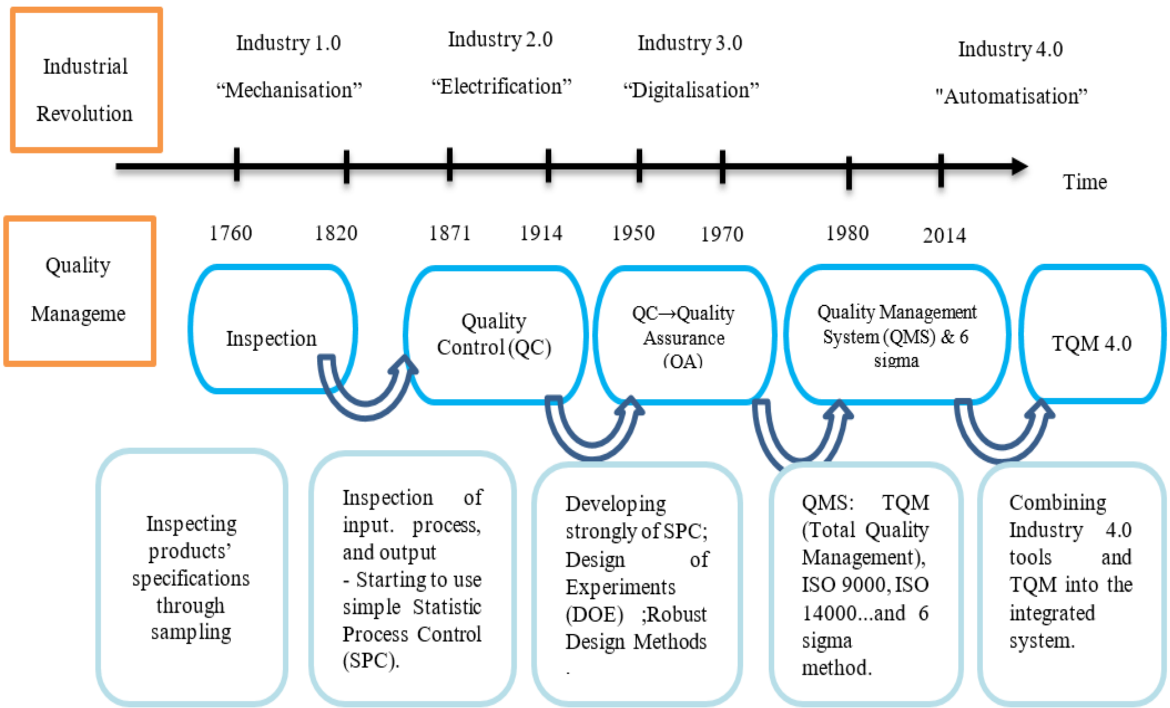

Fig 2.5: Quality management implementation in Four Industrial Revolutions

Source: own research

2.5 TQM 4.0 and STS theory integration

In this study, supported by STS, we emphasise both social and technical approaches in TQM 4.0.

2.5.1 Social factors

"Top management 4.0": The engagement, dedication, and support of top management are crucial components that must be present in order to execute traditional TQM successfully (Goetsch and Davis, 2013; Jaca and Psomas, 2015). 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) suggested that in order to implement TQM 4.0, upper management should establish and disseminate explicit strategic goals, objectives, and criteria to all employees. This will facilitate the effective execution of these objectives through the provision of essential resources and the assessment of results attained.

"Quality culture 4.0": According to Goetsch and Davis (2013), "Quality culture is an organisational value system that results in an environment that promotes the establishment and maintenance of quality". As Goetsch and Davis (2013) demonstrate, comprehensive quality implementation in the absence of a quality culture can result in catastrophic outcomes. Asif (2020) emphasises the significance of encouraging mindfulness in Quality 4.0 while investigating

QM models that are in line with Industry 4.0. This approach differs from traditional quality management routines as it involves actively observing rather than passively seeing, confirming rather than simply conforming, and taking deliberate actions instead of relying on automaticity. Managers should encourage employee empowerment in a quality culture 4.0 (Kupper et al., 2019). The Socio-technical system theory (STS) emphasises the importance of focusing on sustainability and flexibility in TQM. Besides, the STS encourages employee empowerment by fostering increased levels of autonomy on both the individual and individual team levels. TQM 4.0 should promote a collective understanding among individuals throughout the organisation regarding their respective roles in attaining quality objectives, which should be communicated to different kinds of enterprises (Kupper et al., 2019).

"Digital skills for quality staff": As stated by Kupper et al. (2019), the objective of Industry 4.0 is not labour force reduction; instead, it requires the development of novel skill sets. It is evident from this study that Quality 4.0 does not diminish the significance of individuals in the process of ensuring quality. By equipping employees with the requisite knowledge and skills to proficiently employ digital tools and deliver data-driven narratives, future manufacturing facilities can be ensured to be of the highest quality. As part of the TQM 4.0 framework, quality control employees ought to develop greater skills in cyber-physical systems, analytics, and artificial intelligence (Chiarini and Kumar, 2022; Kupper et al., 2019). In light of the TQM 4.0 framework, quality personnel will devote a reduced amount of time to operational duties such as inspections and increase their focus on problem-solving and preventive activities. Significant contributions to QM have been made by quality experts with backgrounds in statistical QC and industrial engineering; in the near future, data scientists and quality experts will eventually get to form a single profession. In addition, Park et al. (2017) emphasised that the ability to think creatively during team activities is the most crucial skill for achieving the overall achievement of TQM 4.0.

"Intellectual capital management": TQM 4.0, which Asif (2020) introduced, places particular emphasis on the growth and advancement of intellectual, human, and social capital. While quality management models do place emphasis on human resources, they do not overtly prioritise the growth and application of human capital. In this thesis, the TQM 4.0 framework places emphasis on the development of social capital, which refers to the interpersonal relationships and partnerships among personnel, both internal and external in an organisation. (Glogovac et al., 2020). The TQM 4.0 framework places an additional emphasis on the management of intellectual capital, which encompasses a variety of elements, including customer connections, reputation, business values, staff loyalty, and brand image (Glogovac et al., 2020; Asif, 2020).

"Smart organisation": According to Fundin et al. (2020), leaders are required to create and oversee an intelligent organisation inside the TQM 4.0 framework.

The senior leadership will endorse projects, cultivate organisational expertise, and assist in the development of successful innovations. The TQM 4.0 paradigm enables businesses to streamline their processes, making them more efficient and responsive, allowing for rapid adaptation to a dynamic environment (Asif, 2020). Furthermore, Sader et al. (2019) highlighted the manner in which the implementation of TQM 4.0 technologies will improve collaboration and communication by enabling connectivity and social networking. Furthermore, these technologies will promote innovation and streamline the sharing of ideas across manufacturing stakeholders and partners. Moreover, Asif (2020) supposed that TQM 4.0 would facilitate the integration of enterprises throughout business ecosystems. TQM 4.0 has the potential to successfully adapt to a quickly changing environment by actively participating in both exploration (external innovation) and exploitation (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 (Isaksson, 2019; Fundin et al., 2020). Therefore, it is essential for quality management systems (QMS) to include environment management systems (Fundin et al., 2020). Then, the TQM 4.0 framework should have elements that effectively integrate sustainable growth within a dynamic and unpredictable context.

2.5.2 Technical factors

Besides focusing on the social approach, the TQM 4.0 framework also emphasises technical aspects, including five factors below.

"Automated document control": According to Chiarini and Kumar (2022), there is a prevailing belief that a paperless approach is now expected for Quality Management Systems (QMS). The TQM 4.0 model incorporates automated and real-time document control, specifically for designs and work instructions. In this thesis, TQM 4.0 will contain digital SOPs to ensure that employees are provided with the latest instructions (Kupper et al., 2019).

"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": The implementation of Industry 4.0, including Internet of Things, artificial intelligence (AI) and machine learning (ML), would empower the production system to take proactive measures by predicting and preventing potential issues (Sader et al., 2019; Chiarini and Kumar, 2022). In addition, Sader et al. (2019) demonstrate that 4^{th} Industrial Revolution will enhance processes, improve efficiency of resource allocation, and minimise the effort needed for quality issues by utilising sensors at every production stage. The process of big-data analysis involves gathering real-time data generated during production and transforming it into meaningful and accessible information that can be comprehended and utilised by various business departments (Sader et al., 2019). Under the framework of TQM 4.0, organisations will implement smart improvements by leveraging real-time data and maintaining digital documentation (Asif, 2020).

"Smart product": Sader et al. (2019) stated that the utilisation of big-data analysis has the potential to predict market demand and consumption. According to Asif (2020), the use of artificial intelligence enables accurate forecasting of clients' preferences. Smart products utilise AI-based predictions to meet customer demands and provide the ability to identify and track items. In their study, Chiarini and Kumar (2022) demonstrated the significant potential of smart technology in facilitating the identification and tracking of TQM 4.0's tools and items. This was achieved through the utilisation of sensors and RFID technology integrated into products. The TQM 4.0 framework incorporates industry 4.0, enabling customers to actively participate in the manufacturing process instead of being passive recipients.

The detailed factors of the TQM 4.0 model are presented in *Table 2.2.*

Table 2.2 Explanation of key factors of TQM 4.0 model

1			**Top management**	
	1	Top management commitment	Top management needs to commit to TQM 4.0 development in the TQM 4.0 model.	Chiarini and Kumar (2022);Glogovac et al. (2020).
	2	Top management involvement	Top management needs to be involved in TQM 4.0 development in the TQM 4.0 model.	Chiarini and Kumar (2022);Glogovac et al. (2020).

	3	Top management provides resources.	Top management needs to provide resources for TQM 4.0 development in the TQM 4.0 model.	Chiarini and Kumar (2022);Glogovac et al. (2020).
	4	Top management establishes policy, objectives.	Top management needs to establish policy, strategic, and objectives for TQM 4.0 in the TQM 4.0 model.	Chiarini and Kumar (2022);Glogovac et al. (2020).
2			**Quality culture 4.0**	
	1	Quality-driven mindfulness	TQM 4.0 should promote employee self-leadership and proactive problem-solving rather than relying on standard procedures.	Asif (2020)
	2	Employee empowerment	The TQM 4.0 model should foster the empowerment of employees within the enterprise.	Kupper et al. (2019); Xu et al. (2020)
	3	Individuals' comprehension of their role in attaining quality objectives	TQM 4.0 should encourage a culture where individuals throughout the organisation comprehend their responsibilities in attaining quality objectives.	Kupper et al. (2019)
	4	Quality articulation	In TQM 4.0 model, organisations will employ digital media to clearly communicate quality goals and objectives to all levels of the organisation.	Kupper et al. (2019)
3			**Skill 4.0**	
	1	Skills related to data analytics, AI	In TQM 4.0 model, it is important for quality control employees to improve their skills in data analytics.	Chiarini and Kumar (2022); Kupper et al. (2019)
	2	Digital skills for quality staff	In TQM 4.0 model, quality employees will allocate less time to operational duties like inspections and more time to resolving issues and engaging in proactive measures.	Chiarini and Kumar (2022); Kupper et al. (2019)
	3	Digital communication skill	TQM 4.0 model requires employees to apply digital tools and can tell data-driven stories	Kupper et al. (2019)
	4	Data scientists as quality experts	Data scientists are regarded as quality experts in the TQM 4.0 model.	Park et al. (2017)
	5	Team creativity	In TQM 4.0 model, creative thinking emphasizes team activities in the design stage and QM activities.	Park et al. (2017)
4			**Intellectual capital management**	
	1	Human capital management	In addition to managing human resources, the TQM 4.0 model should prioritise cultivating and utilising human	Asif (2020); Glogovac et al. (2020).

			capital, including the expertise and competencies of employees.	
	2	Social capital management	The TQM 4.0 model should prioritise the growth of social capital, which includes the interpersonal connections among individuals inside and outside an enterprise.	Asif (2020); Glogovac et al. (2020).
	3	Intellectual capital management	TQM 4.0 should prioritise intellectual capital management, encompassing elements such as reputation, employee allegiance, customer connections, corporate values, and brand perception.	Asif (2020)
5			**Smart organisation**	
	1	Top management supports initiatives, spreads organisational knowledge	Top management will promote initiatives, disseminate organisational knowledge, and expand successful innovations in TQM 4.0.	Fundin et al. (2020)
	2	Lean structure organisation	TQM 4.0 will lead to the implementation of lean organisational structures, resulting in improved operational efficiencies and expedited decision-making through the utilisation of AI-based systems.	Asif (2020); Fundin et al. (2020)
	3	Collaboration all stakeholders	TQM 4.0 technologies will improve communication and creativity by using connectivity and social media, facilitating innovation and fostering the exchange of ideas among various production entities and stakeholders, including suppliers, patterners, customers, and investors.	Sader et al. (2019)
	4	Networked firm management within business ecosystems	Companies provide a digital platform for buyers and sellers in TQM 4.0. Companies and logistics providers utilise the same platform to offer services smoothly and uninterruptedly.	Asif (2020)
	5	Adaptability in change	TQM 4.0 model will adapt to the fluctuating environment with exploration (external innovation) and exploitation (internal innovation)	Fundin et al. (2020)
6			**Integrating sustainable development**	
	1	Link quality and sustainability	TQM 4.0 model requires a connection between quality and sustainability.	Fundin et al. (2020); Ramanathan (2019)
	2	Corporations serving society	TQM 4.0 model prioritises quality-focused management to serve society.	Fundin et al. (2020); Ramanathan (2019)

	3	Sustainable operations	TQM 4.0 model should focus on enhancing operations to be more sustainable.	Fundin et al. (2020)
	4	Integration of environmental management systems	TQM 4.0 model requires the integration of EMS.	Fundin et al. (2020)
	Technical factors			
7			**Automated document control**	
	1	Incorporation of documentation into ERP modules and automated revision	Organisations should incorporate quality management documents into ERP modules and implement automatic revision when there are changes in products or processes in TQM 4.0.	Chiarini and Kumar (2022)
	2	Electronic documentation	In TQM 4.0 model, utilising electronic documentation for QMS is necessary.	Chiarini and Kumar (2022)
	3	Real-time document control	Work instructions are subjected to automation and real-time control in TQM 4.0.	Chiarini and Kumar (2022)
	4	Digital standard operating procedures (SOPs)	SOPs are provided to ensure that workers possess the latest instructions in TQM 4.0.	Kupper et al. (2019)
8			**Automatic data collection**	
	1	Automatic data collection throughout the lifecycle of the product.	Throughout the product lifecycle, data will be collected autonomously in TQM 4.0 via CPSs, sensors, and the IoT.	Chiarini and Kumar (2022)
	2	Automatic product-related data collection	In TQM 4.0 model, various forms of product-related data are gathered automatically, such as the quantity of defective or discarded products, the amount of time spent on reworks by both labour and machines, and the quantity of returned items and complaints.	Chiarini and Kumar (2022)
	3	Automatic customer-related data collection	Customer-related data, including product requirements, complaints, and satisfaction levels, is automatically collected in TQM 4.0.	Chiarini and Kumar (2022)
9			**Smart Quality Control**	
	1	Real-time quality inspection	Real-time quality inspection is applied in the TQM 4.0.	Sader et al. (2019); Sader et al. (2021)
	2	Total inspection	TQM 4.0 will permit total inspection as an alternative to sample inspection.	Sader et al. (2019); Park et al. (2017)
	3	Machine learning-based SPC	In TQM 4.0 model, a novel form of statistical process control (SPC) that utilises machine learning to forecast various types of defects that may occur during the machining process provides	Chiarini and Kumar (2022)

			feedback to the machine, enabling it to autonomously adjust its parameters without requiring human intervention.	
	4	Data integration in ERP	Automatic quality data collection from various processes is incorporated into enterprise resource planning (ERP) modules in TQM 4.0.	Chiarini and Kumar (2022)
10			**Smart Quality Assurance**	
	1	Using artificial intelligence software for prediction and prevention	Preventive intervention for avoiding downtime or system failure and predictive maintenance in advance will be implemented via AI software in TQM 4.0.	Chiarini and Kumar (2022); Sader et al. (2019)
	2	Using sensors at each production stage	TQM 4.0 model will facilitate the optimisation of processes, enhance resource allocation and efficiency through the use of sensors at every stage of production, and offer mechanisms to support quality activities to reduce rework and scrap.	Sader et al. (2019)
	3	Big-data analysis	Big-data analysis will gather and transform all real-time data generated during manufacturing into useful, actionable information in the TQM 4.0.	Sader et al. (2019)
	4	Making intelligent adjustments	TQM 4.0 will make informed modifications using real-time data and uphold digital files.	Asif (2020)
11			**Smart product**	
	1	Predict market demand and consumption trends	TQM 4.0 tools will facilitate early prediction of market demand and changes in consumption trends accurately.	Asif (2020); Sader et al. (2019).
	2	Smart identification and traceability technologies	Smart technologies can substantially aid organisations in the identification and monitoring of products in TQM 4.0.	Chiarini and Kumar (2022)
	3	RFID technologies and smart sensors	The TQM 4.0 model identifies and traces products through the use of RFID technologies and intelligent sensors on packaging and products.	Chiarini and Kumar (2022)
	4	Customers' involvement in the production process	The connectivity features of Industry 4.0 will enable customers to participate in the manufacturing process instead of only receiving goods in TQM 4.0.	Sader et al. (2019) Fundin et al. (2020)

2.6 Sustainable Excellence

The quality community has witnessed the conception and development of excellence since the early 1980s; at this point, it has come to dominate the landscape of quality models and awards. According to Talwar (2011), excellence is implemented through a variety of frameworks and activities, spanning from less structured approaches to models, programmes, and awards that are meticulously structured. Excellence is a legitimate approach to improving performance and quality, involving organisations on a global scale, and producing unquestionably stable results (Edgeman, 2018). Larger quality-based excellence awards seem to have well-established, strong brands and networks (Carvalho et al., 2021). For example, the European Foundation for QM renamed its honour the "European Quality Award" to the "European Excellence Award" (EFQM, 2017), while the Malcolm Baldrige Quality Award shifted its focus to the acknowledgement of "performance excellence" (ASQ, 2017).

Globally, the concept of business excellence has emerged as a new trend that elevates TQM implementation frameworks and quality award programs. However, the corporate excellence trend has largely ignored the environmental and societal components (Edgeman and Eskildsen, 2014).

Sustainable excellence is achieved when key stakeholder segments' competing and complementary interests, including social and environmental impacts, are harmonised to enhance the potential of enduring enterprise success and sustainable competitive forces (Edgeman and Eskildsen, 2014). According to Carvalho et al. (2021), businesses seeking sustainable excellence should encourage an innovative and effective management structure, be backed by similarly effective management tools, and establish a comprehensive knowledge of the driving principles underlying QM and operational excellence. Sustainable excellence is attained by utilising an integrated organisational design and function strategy that prioritises exceptional performance across domains, including customer-focused, financial, operational, supply chain, human resources, marketplace, environmental, and business intelligence and analytics (Edgeman and Eskildsen, 2014).

The relationship between TQM and excellence has been validated in empirical research and practical cases. The majority of studies demonstrate that TQM and Excellence operate collaboratively. According to Goetsch and Davis (2013), to attain organisational excellence, which is essential for sustained success in a global context, it is imperative to deliver exceptional value to customers consistently. Total quality is a comprehensive approach encompassing all three exceptional value components. Total quality refers to enhancing the quality of products, processes, services, and costs. The organisations that successfully implement the TQM approach will most likely attain organisational excellence. Eriksson et al. (2016) analyse and examine significant quality-related obstacles organisations encounter and investigate integrating these challenges into existing excellence models. According to the study, QM is still in the process of adopting and adjusting to a dynamic business environment. The study highlights the need for further research in several significant domains, including how TQM can develop in various contexts, with varying demands for exploratory and adaptive capabilities, the intersections of QM and sustainability, and how customers and stakeholders can actively advance excellence. A case study by Srinivasan, Sarulkar and Yadav (2023) employed the widely recognised quality methodology known as Lean Six Sigma (LLS) to achieve operational excellence in the steel sector. This research demonstrated the efficacy of using Lean Six Sigma (LSS) in the steel manufacturing industry to remove inefficiencies, improve process performance, and attain operational excellence. Overall, case studies and empirical research demonstrate the implementation of TQM principles and tools that produce advantageous performances which exemplify business excellence (Goetsch and Davis, 2013; Carvalho et al., 2021; Srinivasan et al., 2023).

2.7 The research framework and hypothesis development

TQM and Excellence are two concepts that usually co-exist in enterprises. While some scholars believe them to be the same conception (Wade, 2000), others contend that they are distinct concepts that might and should coexist (Dale et al., 2000). Thus, the argument around the relationship between excellence and TQM may be extrapolated to other quality initiatives and utilized to predict the future of excellence (Carvalho et al., 2021). In this study, the author mentions the TQM 4.0 model that integrates TQM principles, tools of industry 4.0, and social components, which is expected to be a complete model for sustainable excellence. According to Carvalho et al. (2021), sustainable excellence requires a new age in business and manufacturing and solves the many difficulties that corporate environments and societies are now confronting. This approach must be adaptable to rapidly changing markets and environments while re-centring the notion of excellence on its quality fundamentals. With the deployment of industry 4.0 technologies, TQM 4.0 should adapt to rapidly changing markets and surroundings, enabling enterprises to achieve sustainable excellence.

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 optimize 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. For achieving SE, a strategy such as TQM 4.0 must gain a balance and satisfy all stakeholders.

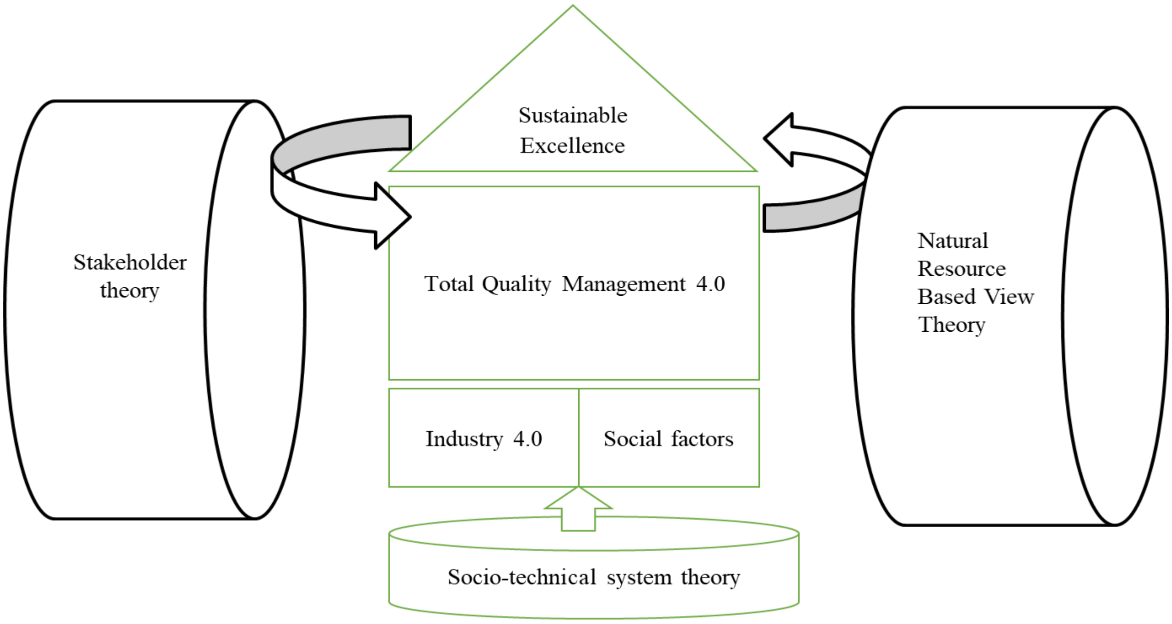

Fig 2.6: Conceptual framework

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). This theory was created from the resource-based concept, which has emerged as a key theory in strategic management (Barney et al., 2001). The traditional resource-based view, which fails to acknowledge the competitive capacities that result from environmental preservation, energy conservation, a decrease in resource utilization and waste, and an increase in quality, led to the development of the natural resource-based theory (Agyabeng-mensah et al., 2020). According to Hart et al. (2008), the natural resource-based approach indicates that a firm's three main strategic capability goals are product stewardship, sustainable development, and pollution prevention. Pollution prevention's primary goal is to reduce emissions, while product stewardship directs the choice of raw materials and design disciplines to reduce the environmental impact of product systems. Additionally, the definition of sustainability broadens its focus to include social, economic, and environmental issues. 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, which 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. DT is a deliberate process of implementing strategic changes based on modern technology (Bresciani et al., 2021). DT is also defined as a means of adapting business processes, cultures, and organisational aspects to align with evolving market demands resulting from advancements in digital technologies (Nasiri et al., 2020). DT has multiple ramifications that alter business models, influence employment for executives, staff, and knowledge workers, and affect organisational cultures (AlNuaimi et al., 2022; Abbu et al., 2022).

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 of this study put forth the hypothesis 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, intelligent, networked, 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). According to Alnuaimi et al. (2022), digital leadership is a combination of transformative leadership and digital technologies. Several studies show that digital leadership positively influences DT (Abbu et al., 2022; Alnuaimi et al., 2022). Abbu et al. (2022) found that digital transformational leadership and organisational agility have a positive effect on DT in the public sector. According to Alnuaimi et al. (2022), digital leaders are essential to the success of DT because they can instil organisational and employee confidence in these disruptive and often hazardous endeavours. 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.

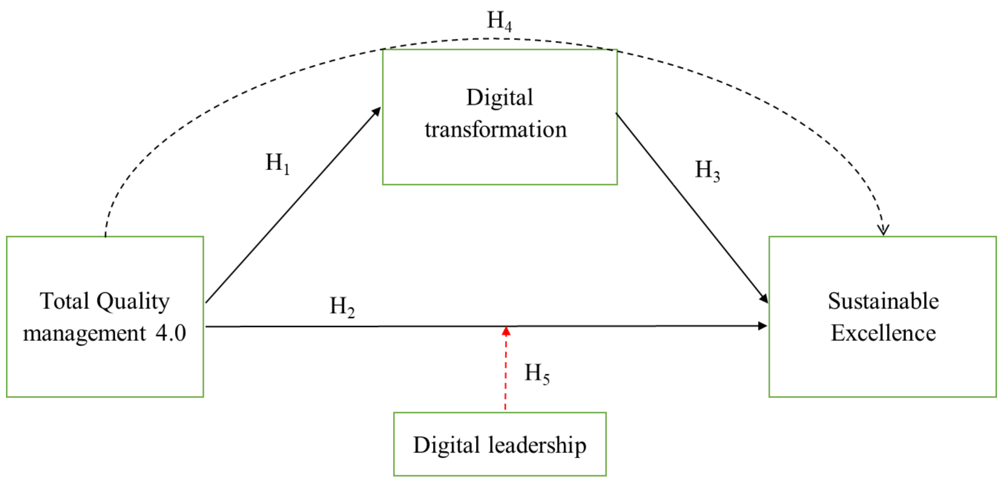

Fig 2.7: Proposed research model.

Source: own research

3 RESEARCH METHODOLOGY

3.1 Research process

Figure 3.1 shows the proposed process for exploring the indicators and key factors of the TQM 4.0 practices and testing the hypotheses around the relationship between TQM 4.0 practices and Sustainable Excellence. The process starts with the identification of factors based on the existing literature and suggestions from business and academic experts. Then, the confirmation of the indicators and factors are analysed using the Delphi and AHP techniques. The questionnaire is provided to experienced practitioners and academic experts in the field. The questionnaires were circulated until group consensus was high. In this study, the final factors and indicators are found after two rounds. Achieving objective three, the author determines the important weight among factors and indicators of TQM 4.0 practices by deploying the AHP method. Finally, the study focuses on exploring the relationship between TQM 4.0 and sustainable excellence. The research employed two forms of non-random sampling: purposive and snowball. Purposive sampling focuses on experts with experience in manufacturing companies that have applied TQM practice and Industry 4.0 tools into 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 experts.

In study 2, the author also used two types of non-random sampling: purposive and snowball. Purposive sampling targets individuals who possess expertise in the field of manufacturing and have practical experience in implementing TQM practises, specifically in companies that have also utilised Industry 4.0 tools in conjunction with TQM. In addition, the study employed the snowball sampling technique. Due to the distinct attributes of the respondents, who are part of specific niche communities, the study broadens its participant pool by adding more experts. Finally, the author has a list of 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.

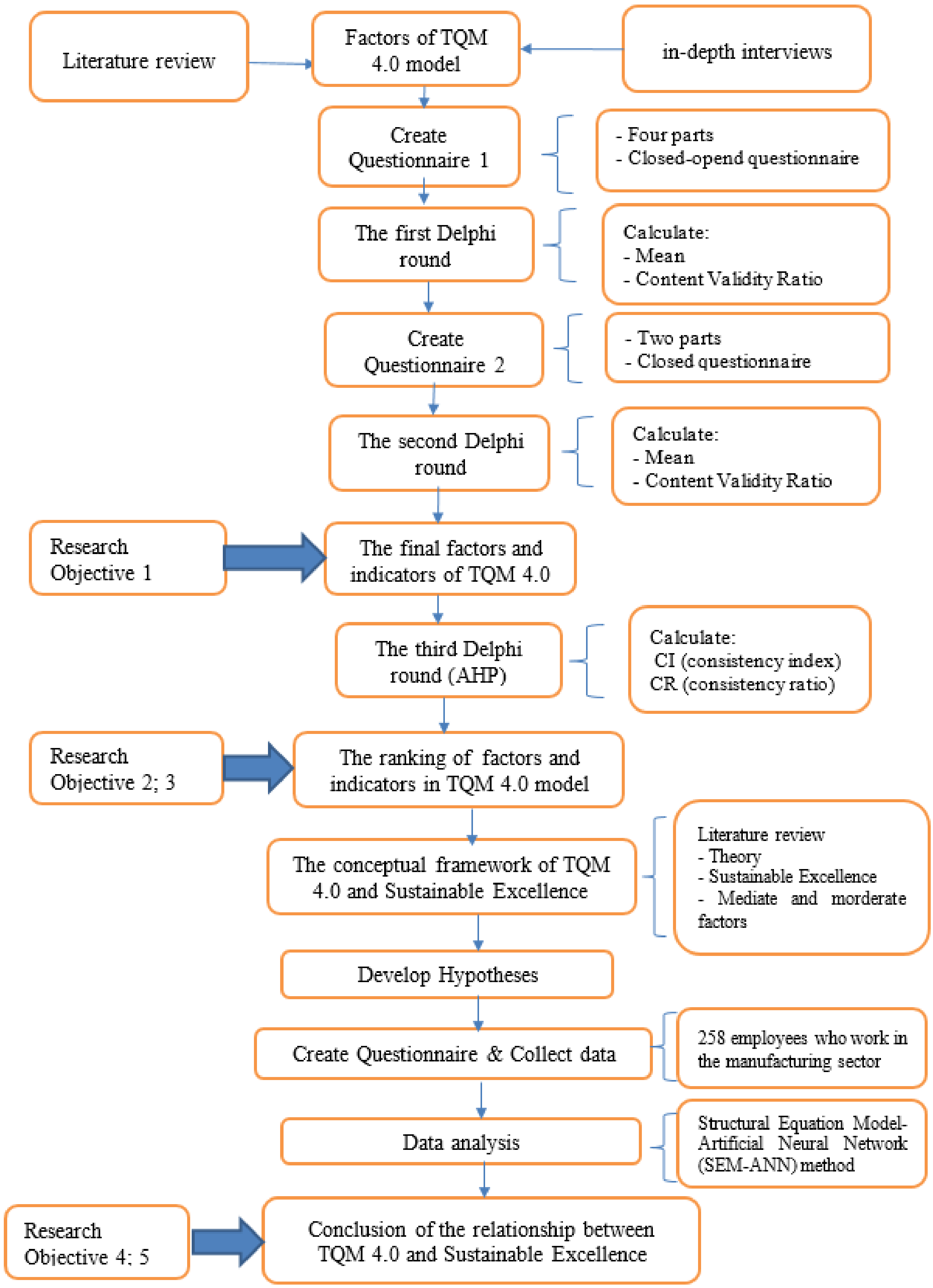

Fig 3.1: Research process

Source: own research

3.2 Research Methods

3.2.1 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 important 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 key 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 the first questionnaire.

The first questionnaire was dispatched to the panel of experts. The questionnaire includes a set of questions derived from the researchers' expertise and insights gathered 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 round of Delphi analysis

The author divided questionnaire into 4 parts (*See Appendix 1*). Part 1 includes questions about TQM 4.0 and 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 Likert scale ranging from 1 (indicating low importance) to 5 (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.

For the first analysis round, 46 observations were utilised. Mean and content validity ratio (CVR) are computed by the author; values of CRV < 0.29 or Mean < 3.5 points are rejected. As Lawshe (1975) stated, the minimum acceptable score for CVR with a panel of forty experts is 0.29. The CVR for every indicator is computed as follows:

$$(CVR)\ Content\ Validity\ Ratio = \frac{(n_e - \frac{N}{2})}{N/2}$$

In this formula, n_e is the panellists' number indicating "essential", and N represents the number of panellists in total (Lawshe, 1975).

The three opinions established by Lawshe (1975) for every item were essential, not essential but useful, and not necessary. This study has to match two scales, as it employs a Likert scale. Correspondingly, we consider extremely important and very important to be equivalent to essential. In contrast, we consider moderately important to be equivalent to not essential but useful, slightly important and not important and not necessary to be equivalent to equal to not necessary, respectively.

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. *Appendix 2* represents the second questionnaire.

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

This step aims to ascertain the importance of every 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 numbers from 1 to 9, with intermediate values of 2, 4, 6, and 8.

The participants will compare the relative importance of factor A and factor B in the TQM 4.0 framework to determine factors holding greater importance. Suppose factor A has the same importance as factor B; select 1 value. If factor A holds greater importance than factor B, select a numerical value ranging from 2 to 9 points on the left side. Otherwise, select option B on the right side. Grade 9 holds the greatest importance.

A Options	9. Extremly	8	7. Very strongly	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very strongly	8	9. Extremly	B Options
Top management	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	**Quality Culture 4.0**

Such an example means that in the TQM 4.0, the “Quality Culture 4.0” is less important than “Top management” factor. The fulfilled questionnaire answer example is presented in *Appendix 3,4.*

According to Saaty (1987), a Consistency ratio (CR) value from 0.1 to 0.2 is accepted, whereas those below 0.1 represent a good consistency of the results. The CR value was analysed to integrate the weights of indicators and factors, resulting in the development of a final weighted score for measuring the implementation of the TQM 4.0 framework in production companies.

The author checks the reliability and consistency of collected data by calculating consistency ratio (CR). The consistency ratio is calculated as:

$$CR\ (consistency\ ratio) = \frac{CI\ (consistency\ index)}{RI\ (random\ index)}$$

RI is presented in detail in *Table 3.2*.

CI(Consistency index) is defined as:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Table 3.2: Random index values

n	**Random Index**	**n**	**Random Index**	**n**	**Random Index**
02	0.00	05	1.11	08	1.40
03	0.52	06	1.15	09	1.45
04	0.89	07	1.35	10	1.49

Note: n is number of criteria

Source: Saaty (1987)

According to the existing literature on AHP applications in construction management, there is no minimum sample size requirement for AHP analysis (Darko et al., 2019). 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 (See *Table 3.1*). The author calculates the average criteria weights and CR of eleven experts for final results.

3.2.2 Structural Equation Model (SEM) and ANN approach

This study evaluates the proposed model by employing an analytical methodology that integrates PLS-SEM and ANN (Artificial Neural Networks) approaches. The author chose PLS-SEM 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. Raut et al. (2018) and Al-Sharafi et al. (2022) employ ANN and PLS-SEM to assess the relative importance of independent variables after normalisation. When employed, the

SEM-ANN approach provides both non-linear and linear relationships among variables and enhances the understanding of the Sustainable Excellence (SE) of manufacturing firms.

Sample size estimation

To ensure that the PLS_SEM analysis yields statistically significant results, it is necessary to calculate the sample size. In doing research, there are numerous methods for determining the sample size; this thesis will examine a few of them in order to calculate the appropriate sample size for the study.

According to Hair et al. (2022), analysis results will be questionable if the basic sampling theory guidelines are disregarded. Ensuring compliance with the recommended minimum sample size instructions makes sure that the outcomes of a statistical technique, such as PLS-SEM, possess sufficient statistical power. Insufficient sample size can lead to a type II error, as it may fail to identify an existing effect in the overall population. Furthermore, conducting statistical analyses in accordance with the recommended instructions of minimum sample size will guarantee the reliability of the statistical process's outcomes and the generalizability of the model to another sample drawn from the population. Following is a discussion of the PLS-SEM and its minimum sample size requirements.

Several early investigations conducted a systematic evaluation of the efficacy of PLS-SEM using small sample size, and the results indicate that this method works well. Furthermore, Hair et al. (2017) indicated that PLS-SEM is the preferred method when the sample size is not large. Nonetheless, PLS-SEM also performs exceptionally well with the large amount of observations (Hair et al., 2022).

The 10-minute rule is a common method for calculating sample size. This concept suggests that the sample size for the regression in the PLS path model should be ten times the number of independent variables (Barclay et al., 1995). Using this method, the minimum sample size required in this study is 110. However, according to Hair (2022), the 10-times rule is an unreliable approach for determining sample size requirements in PLS analysis. According to Hair (2022), statistical power analysis provides a more accurate estimate of the sample size, while the inverse square root methodology is a more conservative method for determining the minimum sample size. To evaluate statistical power, scholars may use power tables (Cohen, 1992) or power analyses with software like G*Power (Faul et al., 2009). In this study, the author use G*Power software version 3.1.9.7 to calculate the minimum sample size requirement. The author chose “F tests”; statistical test is “linear multiple regression: fixed model, R^2 deviation from zero”; and type of power analysis is “ A priori: Compute require sample size given α, power and effect size". The detailed input and output parameters are presented in Figure 3.2. The result shows that the minimum sample size requirement of 123.

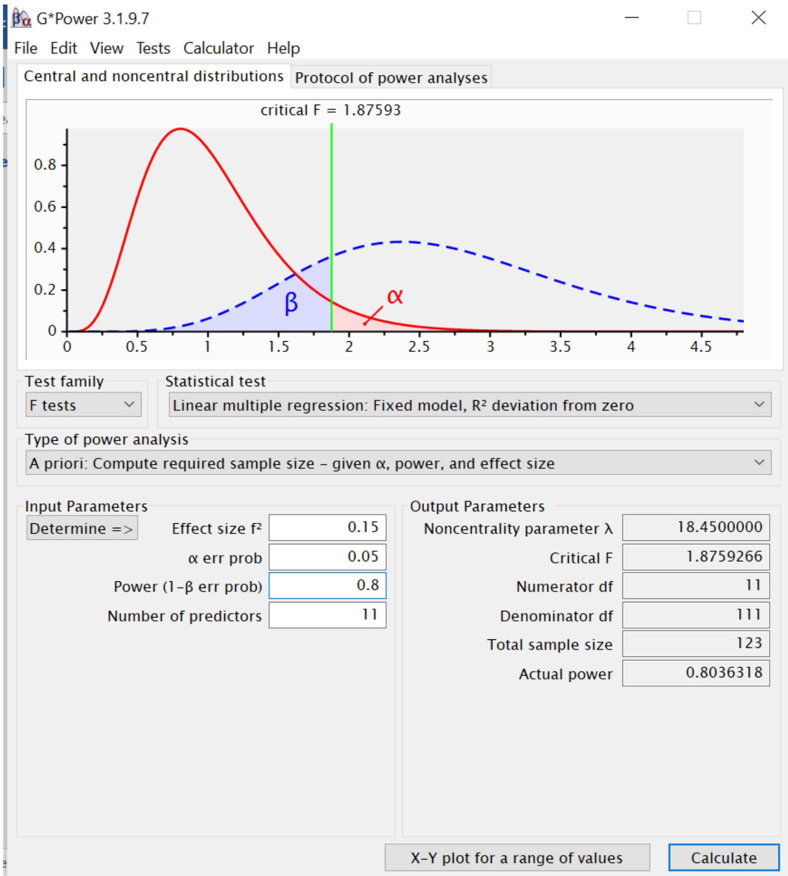

*Fig 3.2: Calculating sample size from G*Power*

Source: own research

The minimum sample size obtained from these estimations might still be insufficient despite the fact that power analysis employs the most complex regression and researchers typically aim to achieve 80% of power level (Kock and Hadaya, 2018). For example, the minimum sample size requirement in this study is only 123. In addressing these issues, Kock and Hadaya (2018) presented the inverse square root technique, which examines the likelihood that a route coefficient's ratio and standard error would exceed a test statistic's critical value for a certain significance level. Hair et al. (2017) supposed that a significance of 5 per cent is usually used in management. So, in this study, the author chooses a significance of 5 per cent in testing the hypothesis. Determined a typical power level of 80 per cent and significance level of 5 per cent; the minimum sample size (n_{min}) is calculated by the following formula:

$$\text{Significance level} = 5\% : n_{min} > \left(\frac{2.486}{|p_{min}|} \right)^2$$

Where p_{min} represents the path coefficient with the minimum magnitude in the PLS path model, table 3.3 illustrates the minimum number of sample size requirements for various significance levels and p_{min} ranges. For instance, assuming the minimum expected path coefficient is significant between 11 per cent and 20 per cent, one would require approximately 155 respondents to detect a significance at a 5% significance level.

Table 3.3: Minimum sample size according to inverse square root technique

p_{min}	Significance levels		
	1%	5%	10%
0.05-0.1	1,004	619	451
0.11-0.2	251	155	113
0.21-0.3	112	69	51
0.31-0.4	63	39	29
0.41-0.5	41	25	19

Source: Hair et al. (2022)

In this study, the author collected data from 258 respondents to achieve the requirement of minimum sample size. The questionnaire is presented in *Appendix 5*.

Structural model and Measurement model evaluation

According to the results of Hair et al. (2022), the 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, as shown in Table 3.4. This table shows key criteria and threshold values for evaluating measurement models (step 1) and the structural model (step 2).

Table 3.4: Key criteria for evaluating measurement and structural model.

Step 1: Measurement model evaluation		
	Criteria	Threshold value
Indicator reliability	Indicator's outer loadings	≥0.7: Accept 0.4 – 0.7: Consider <0.4: Delete
Internal consistency	Cronbach's alpha	≥0.7: Accept 0.6 – 0.7: Consider

Convergent validity analysis	AVE: Average variance extracted	≥0.5: Accept
Discriminant validity analysis	HTMT: Heterotrait-monotrait ratio	≤0.9: Accept for similar constructs ≤0.85: Accept for different constructs
Step 2: Structural model evaluation		
Collinearity	VIF	≤ 5 : Acceptable ≤ 3 : Preferable
Significant and relevance of structural model relationship	The Path coefficients	Nearly to +1: strong positive relationships Nearly to 0: no relationships Nearly to -1: strong negative relationships
	P value	p=1%→10%: depend on study
The model's explanatory power	R^2: Coefficient of Determination	R^2 = 0 →1: higher number indicating higher power of explanatory
	f^2: effect size	>= 0.02 means small size value >= 0.15 means medium size value >= 0.35 means large effect sizes
The model's predictive power	Q^2: Predictive relevance	0→0.25 means small relevance value

		0.25→0.50 means medium relevance value >=0.50 means large relevance value

Source: Hair et al. (2022)

Stage 2: ANN method

This study uses ANN because it detects both non-linear and linear relationships better than multivariate linear regression, 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, the 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; Sharma et al., 2021). In order to minimise the issue of overfitting problem, 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 allocates 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. Figure 3.3 depicts that 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).

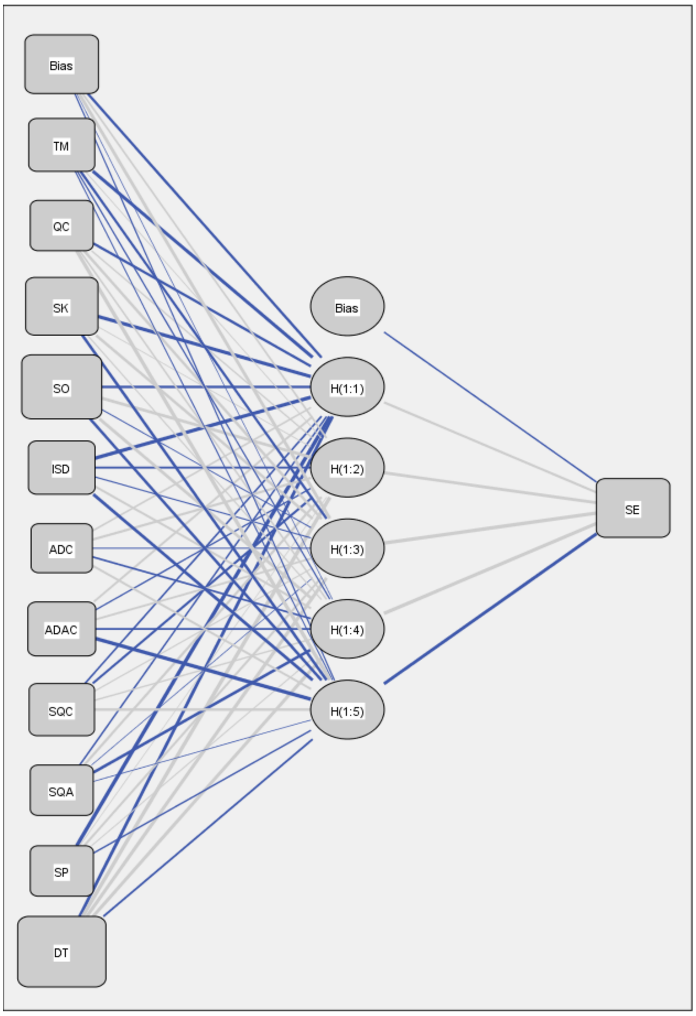

Fig 3.3: ANN model (SE as Dependent Variable)

Source: own research

After calculating the parameters, Artificial Neural Network (ANN) was validated by computing the RMSE (Root Mean Square Error). This parameter is widely used to check the accuracy of constructing the model (Raut et al., 2018; Al-Sharafi et al., 2022). The value of RMSE can represent the errors in the testing and training process.

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 factors 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 Research process

Step 1: Construct the first questionnaire

In this step, a first questionnaire was dispatched to the panel of experts. The survey comprises a set of open-ended questions derived from the researchers' expertise and insights gathered from the synthesised literature. The experts comprise consultants, academics, and mid-level leaders (See Table 3.1). Academics are lecturers who have research in TQM or teach TQM. Mid-level leaders are managers or supervisors in production or quality departments. The respondents were required to possess at least five years of practical experience in quality management or production 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 questionnaire. Following the revision process guided by the feedback from the group of experts, the author has developed a first questionnaire that describes the TQM 4.0, which comprises eleven factors and forty-four observed indicators.

Step 2: The first round of Delphi:

In this study, the questionnaire is divided into 4 parts (See Appendix 1). 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 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. For the first analysis round, 46 observations were utilised. Mean and content validity ratio (CVR) are computed by the author;

values of CRV < 0.29 or Mean < 3.5 points are rejected. As Lawshe (1975) stated, the minimum acceptable score for CVR with a panel of forty experts is 0.29. The CVR is calculated for each indicator utilising the below formula:

$$CVR\ (Content\ Validity\ Ratio) = \frac{n_e - N/2}{N/2}$$

In this formula, n_e is the amount of panellists representing "essential", and the value N represents the total amount of panellists (Lawshe, 1975).

The three opinions established by Lawshe (1975) were essential, useful but not essential, and not necessary. This work has to match two scales, as it employs a five-point Likert scale. Correspondingly, we consider extremely important and very important to be equivalent to essential. In contrast, we consider moderately important to be equivalent to useful but not essential, slightly important and not important and not necessary to be equivalent to equal to not necessary, respectively.

Table 4.1: Minimum Values of CVR

No. of experts	Min value	No. of experts	Min value	No. of experts	Min value
05	0.99	09	0.78	25	0.37
06	0.99	10	0.62	30	0.33
07	0.99	15	0.49	35	0.31
08	0.75	20	0.42	40	0.29

Source: Lawshe (1975)

Step 3: The second Delphi round

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. The 2nd questionnaire example is provided in Appendix 2.

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

This study aims to ascertain the relative importance of every indicator and factor by using pairwise comparative judgements. 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 answers into numbers from 1 to 9.

According to Saaty (1987), responses with consistency ratios (CR) between 0.1 and 0.2 are considered acceptable, while those falling below 0.1 indicate a high degree of response consistency. Once the CR value had been analysed, the final weighted score for evaluating the implementation of the TQM 4.0 framework in production firms was calculated by integrating the relative weights of indicators and factors.

Statistical analysis process:

Step 1: Establish matrix of Pair-wise comparison

The author establishes matrix of Pair-wise comparison from the answer sheet of respondents. The fulfilled questionnaire answer example is presented in *Appendix 3,4.*

Table 4.2: Example of the answer sheet of Respondent A

A Options	9. Extremly	8	7. Very strongly	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very strongly	8	9. Extremly	B Options
Top management	☐	☐	☐	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Quality Culture 4.0
Top management	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Skill 4.0
Top management	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Smart organisation
Top management	☐	☐	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Integrating sustainable development
Top management	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Automated document control
Top management	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Automatic data collection
Top management	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Smart Quality Control
Top management	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Smart Quality Assurance
Top management	☐	☑	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	Smart product

Source: own research

The importance of factor *i* compared to factor *j* can be defined as S_{ij}. The author completes Pair-wise comparison matrix by using the formula below:

$$S_{ji} = \frac{1}{S_{ij}}$$

Table 4.3: Pair-wise comparison matrix.

	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
Top management	1	3	6	7	6	9	9	9	9	8
Quality Culture 4.0	1/3	1	6	5	7	8	7	7	6	9
Skill 4.0	1/6	1/6	1	1	1/2	5	5	4	4	4
Smart organisation	1/7	1/5	1	1	1/2	4	4	2	2	3
Integrating sustainable development	1/6	1/7	2	2	1	5	6	4	3	5
Automated document control	1/9	1/8	1/5	1/4	1/5	1	1	1/3	1/4	1/6
Automatic data collection	1/9	1/7	1/5	1/4	1/6	1	1	1/4	1/5	1/2
Smart Quality Control	1/9	1/7	1/4	1/2	1/4	3	4	1	1/5	1
Smart Quality Assurance	1/9	1/6	1/4	1/2	1/3	4	5	5	1	2
Smart product	1/8	1/9	1/4	1/3	1/5	6	2	1	1/2	1
Sum of columns	2.3790	5.1980	17.1500	17.8333	16.1500	46.0000	44.0000	33.5833	26.1500	33.6667

Source: own research

Step 2: Calculate matrix of Normalised Pair-wise comparison and weights of criteria

In the next step, the author finds criteria weight of each factor in the Normalised matrix of Pair-wise comparison and divides them by the total criteria to obtain the mean value. The mean values of the weights assigned to the first-order criteria (factors) assessed by expert A are presented in Table 4.4.

w_{ij} is criteria weights of factor i compared with sum of column j in the Normalised Pair-wise comparison matrix. And w_i is criteria weights of factor *i* in the whole factors in the matrix of Normalised Pair-wise comparison.

$$w_{ij} = \frac{s_{ij}}{\sum_{i=1}^{n} \sum_{j=1}^{n} s_{ij}}$$

$$w_i = \frac{\sum_{j=1}^{n} w_{ij}}{n}$$

For example:

$$w_{11} = \frac{s_{11}}{\sum_{j=1}^{n} s_{1j}} = \frac{1}{2.379} = 0.4204$$

$$w_1 = \frac{\sum_{j=1}^{n} w_{1j}}{n} = \frac{0.4204 + 0.5771 + 0.3499 + 0.3925 + 0.3715 + 0.1957 + 0.2045 + 0.268 + 0.3442 + 0.2376}{10} = 0.3361$$

Table 4.4: Normalised Pair-wise comparison matrix and criteria weights for factors

	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	**Criteria weights**
Top management	0.4204	0.5771	0.3499	0.3925	0.3715	0.1957	0.2045	0.2680	0.3442	0.2376	0.3361
Quality Culture 4.0	0.1401	0.1924	0.3499	0.2804	0.4334	0.1739	0.1591	0.2084	0.2294	0.2673	0.2434
Skill 4.0	0.0701	0.0321	0.0583	0.0561	0.0310	0.1087	0.1136	0.1191	0.1530	0.1188	0.0861
Smart organisation	0.0601	0.0385	0.0583	0.0561	0.0310	0.0870	0.0909	0.0596	0.0765	0.0891	0.0647
Integrating sustainable development	0.0701	0.0275	0.1166	0.1121	0.0619	0.1087	0.1364	0.1191	0.1147	0.1485	0.1016
Automated document control	0.0467	0.0240	0.0117	0.0140	0.0124	0.0217	0.0227	0.0099	0.0096	0.0050	0.0178
Automatic data collection	0.0467	0.0275	0.0117	0.0140	0.0103	0.0217	0.0227	0.0074	0.0076	0.0149	0.0185
Smart Quality Control	0.0467	0.0275	0.0146	0.0280	0.0155	0.0652	0.0909	0.0298	0.0076	0.0297	0.0356
Smart Quality Assurance	0.0467	0.0321	0.0146	0.0280	0.0206	0.0870	0.1136	0.1489	0.0382	0.0594	0.0589
Smart product	0.0525	0.0214	0.0146	0.0187	0.0124	0.1304	0.0455	0.0298	0.0191	0.0297	0.0374

Source: own research

The author calculates an average of criteria weights of eleven experts in AHP round to give the result in Table 4.8.

Likewise, the author calculates the criteria weight for each indicator within a factor. Table 4.5 shows calculating results of the criteria weight for each indicator within a factor “Top management” of expert A. The final weights of TQM 4.0 indicators in each factor results are presented in Table 4.9.

Table 4.5: Normalised Pair-wise comparison matrix and criteria weights for indicators.

	TM1	TM2	TM3	TM4	Criteria weights
Top management commitment (TM1)	0.5966	0.5385	0.5263	0.6429	0.5761
Top management involvement (TM2)	0.0852	0.0769	0.0526	0.0714	0.0716
Top management provides resources (TM3)	0.1193	0.1538	0.1053	0.0714	0.1125
Top management establishes policy, objectives and indicators (TM4)	0.1989	0.2308	0.3158	0.2143	0.2399

Source: own research

The author calculates global weight to rank the importance of an indicator in the whole indicators. The global weights are computed using the following formula:

$$Global\ weight\ of\ indicator\ r = w_i * w_{ir}$$

In which, w_i is criteria weight of factor i in the whole factors; w_{ir} is criteria weight of indicator *r* within factor *i*.

The results are presented in Table 4.10.

Step 3: Calculate Consistency Index

The author investigate the reliability and consistency of collected data by calculating consistency ratio (CR). The consistency ratio is calculated as following formula:

$$CR\ (consistency\ ratio) = \frac{CI\ (consistency\ index)}{RI\ (random\ index)}$$

RI numbers are shown in *Table 3.2*.

CI is defined as:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

According to Saaty (1987), Responses with consistency ratios (CR) between 0.1 and 0.2 are considered acceptable, while those falling below 0.1 indicate a high degree of response consistency. After calculating the CR value, the final weighted score was derived by calculating the relative weights of indicators and factors. This score was utilised to assess the implementation of the TQM 4.0 framework in production companies.

The C.I. can be utilised to ascertain the AHP model's tolerance for inconsistency and the judgment's dependability. The matrix weights (MW) are computed utilising the weights of the criteria (W) and the comparison matrix (M) and so as to validate the judgment's dependability.

$$MW = \begin{bmatrix} 0.4204 & 0.5771 & 0.3499 & 0.3925 & 0.3715 & 0.1957 & 0.2045 & 0.2680 & 0.3442 & 0.2376 \\ 0.1401 & 0.1924 & 0.3499 & 0.2804 & 0.4334 & 0.1739 & 0.1591 & 0.2084 & 0.2294 & 0.2673 \\ 0.0701 & 0.0321 & 0.0583 & 0.0561 & 0.0310 & 0.1087 & 0.1136 & 0.1191 & 0.1530 & 0.1188 \\ 0.0601 & 0.0385 & 0.0583 & 0.0561 & 0.0310 & 0.0870 & 0.0909 & 0.0596 & 0.0765 & 0.0891 \\ 0.0701 & 0.0275 & 0.1166 & 0.1121 & 0.0619 & 0.1087 & 0.1364 & 0.1191 & 0.1147 & 0.1485 \\ 0.0467 & 0.0240 & 0.0117 & 0.0140 & 0.0124 & 0.0217 & 0.0227 & 0.0099 & 0.0096 & 0.0050 \\ 0.0467 & 0.0275 & 0.0117 & 0.0140 & 0.0103 & 0.0217 & 0.0227 & 0.0074 & 0.0076 & 0.0149 \\ 0.0467 & 0.0275 & 0.0146 & 0.0280 & 0.0155 & 0.0652 & 0.0909 & 0.0298 & 0.0076 & 0.0297 \\ 0.0467 & 0.0321 & 0.0146 & 0.0280 & 0.0206 & 0.0870 & 0.1136 & 0.1489 & 0.0382 & 0.0594 \\ 0.0525 & 0.0214 & 0.0146 & 0.0187 & 0.0124 & 0.1304 & 0.0455 & 0.0298 & 0.0191 & 0.0297 \end{bmatrix} \text{X} \begin{bmatrix} 0.3361 \\ 0.2434 \\ 0.0861 \\ 0.0647 \\ 0.1016 \\ 0.0178 \\ 0.0185 \\ 0.0356 \\ 0.0589 \\ 0.0374 \end{bmatrix}$$

$$= \begin{bmatrix} 4.1206 \\ 3.1167 \\ 1.0068 \\ 0.7443 \\ 1.1995 \\ 0.1905 \\ 0.1980 \\ 0.3633 \\ 0.6405 \\ 0.3784 \end{bmatrix}$$

In next phase, the author calculate λ_{max}, which represents total of MW divided by the weight of each criterion.

$$\lambda_{max} = \frac{1}{10}\left(\frac{4.1206}{0.3361} + \frac{3.1167}{0.2434} + \frac{1.0068}{0.0861} + \frac{0.7443}{0.0647} + \frac{1.1995}{0.1016} + \frac{0.1905}{0.0178} + \frac{0.1980}{0.0185} + \frac{0.3633}{0.0356} + \frac{0.6405}{0.0589} + \frac{0.3487}{0.0374}\right) = 11.273$$

Then, λ_{max}, is used to calculate the CI value in the in next step (where n is number of all criteria):

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{11.273 - 10}{10 - 1} = 0.1414$$

In this case, RI (Random index) = 1.49 with n=10 (See *Table 3.2*). Therefore, the Consistency ratio (CR) value is estimated as follows:

$$CR = \frac{0.1414}{1.49} = 0.095$$

According to Lin et al. (2009), a suitable number of surveyed experts to complete AHP questionnaires is between five and fifteen, as the number should not be excessive. Consequently, the research compiled the opinions of eleven experts who responded to the initial two surveys to analyse by AHP technique. The author calculates the average criteria weights and CR of eleven experts for final results.

4.2 Results

4.2.1 First Delphi round analysis

In this step, 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" (as displayed in Table 4.6). 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 10 factors, consisting of a total of 41 indicators, which will be assessed in the second round.

Table 4.6: The first Delphi round result

Factors/ Indicators	**Average**	**CVR**	**Result**
"Top management"			
Top management commitment	4.70	0.96	Accepted
Top management provides resources	4.52	0.87	Accepted
Top management establishing policy, objectives	4.61	0.91	Accepted
Top management involvement	4.39	0.70	Accepted
"Quality Culture 4.0"			

Quality-driven mindfulness	4.43	0.83	Accepted
Employee empowerment	4.24	0.61	Accepted
Individuals' comprehension of their role in attaining quality objectives	4.48	0.78	Accepted
Quality articulation	4.22	0.65	Accepted
"Skill 4.0"			
Skills related to analytics, AI and CPS	4.41	0.78	Accepted
Digital skills for quality staff	4.30	0.74	Accepted
Digital communication skill	4.24	0.74	Accepted
Data scientists as quality experts	3.65	0.26	*Rejected*
Team creativity skill	4.35	0.87	Accepted
"Intellectual capital management"			
Human capital management	3.87	0.22	*Rejected*
Intellectual capital management	3.83	0.26	*Rejected*
Social capital management	3.67	0.17	*Rejected*
"Smart organisation"			
Top management supports initiatives, spread organisational knowledge	4.37	0.87	Accepted
Lean structure organisation	4.39	0.83	Accepted
Collaboration all stakeholders	4.33	0.74	Accepted
Networked firm management within business ecosystems	3.63	0.17	*Rejected*
Adaptability in change	4.33	0.83	Accepted
"Integrating sustainable development"			
Link quality and sustainability	4.57	0.91	Accepted
Corporations serving society	4.24	0.83	Accepted
Sustainable operations	4.46	0.78	Accepted
Integration of environmental management systems	4.33	0.65	Accepted
"Automated document control"			
Incorporation of documents into ERP and automated revision	4.31	0.57	Accepted
Electronic documentation	4.43	0.78	Accepted
Real-time document control	4.30	0.74	Accepted
Standard operating procedures (SOPs)	4.41	0.87	Accepted
"Automatic collection of data"			
Automatic data collection through the lifecycle of product	4.50	0.83	Accepted
Automatic product-related data collection	4.37	0.74	Accepted
Automatic customer-related data collection	4.35	0.83	Accepted
"Smart Quality Control"			
Real-time quality inspection	4.35	0.83	Accepted

Total inspection	4.24	0.74	Accepted
Machine learning-based SPC	4.17	0.61	Accepted
Data integration in ERP	4.43	0.78	Accepted
“Smart Quality Assurance”			
Using artificial intelligence for prediction and prevention	4.35	0.74	Accepted
Using smart sensors in each production process	4.39	0.83	Accepted
Big-data analysis	4.35	0.74	Accepted
Making intelligent adjustments	4.26	0.65	Accepted
“Smart product”			
Forecast market demands, consumption trends	4.22	0.74	Accepted
Smart identification and traceability technologies	4.35	0.74	Accepted
RFID technologies and smart sensors	4.37	0.70	Accepted
Involvement of customers in the production	4.11	0.61	Accepted

Source: own research

4.2.2 Second Delphi round analysis

In this step, the results from round 2 indicate that every indicator has 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. Then, the final TQM 4.0 framework includes ten factors, which are represented by 41 indicators, as illustrated in Table 4.7. 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 4.7: The results of the second Delphi round

	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 document 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

4.2.3 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 4.8 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 4.8) indicates a satisfactory level of consistency.

Table 4.8: 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 4.9: The importance of TQM 4.0 indicators within each factor

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 factors’ weight with those of the indicators within a factor. Table 4.10 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 importance indicators of the TQM 4.0 model.

Table 4.10: Ranking of the indicators in 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

Source: own research

5 STUDY 2: THE RELATIONSHIP BETWEEN TQM 4.0 PRACTICES AND 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 the 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 combined with Artificial Neural Network) method to analyse empirical data in the manufacturing industry in Vietnam. The findings demonstrate that TQM 4.0 practices positively affect 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 Research process

5.1.1 Data collection

Before doing the real survey, the pretesting step was implemented. Face and content-related validities are important and can be confirmed by academic and industrial professionals. A panel of five experts, consisting of both academic and industry experts, was invited to assess and confirm the validity of the indicators for each factor. In order to develop a questionnaire for use in Vietnamese, we utilised a back-translation technique. A proficient linguist, fluent in both English and Vietnamese, translated the original survey. Subsequently, to guarantee the comprehensibility of the questionnaire, a focus group consisting of four TQM experts employed in the manufacturing industry deliberated upon the Vietnamese rendition. The author, proficient in both Vietnamese and English, thoroughly examined and fixed any inconsistencies and mistakes. Ultimately, a proficient English-speaking specialist with a high level of fluency in Vietnamese rendered the translation back into English. Subsequently, we dispatched invitations via email and sent hard copies to prospective participants, utilising our established connections.

The study employed two forms of non-random sampling: purposive and snowball. Purposive sampling targets individuals who possess expertise in the field of manufacturing and have practical experience in implementing TQM practices and Industry 4.0 tools within manufacturing companies. These individuals typically hold supervisory positions, such as supervisors, managers, and directors. In addition, the study employed the snowball sampling technique. Due to the distinct characteristics of the respondents, who are part of specific specialised communities, the study broadens its participant pool by introducing other experts. At last, we obtained a database of individuals employed in Vietnam's manufacturing industry. 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 (see the profile of the respondents in Table 5.1). This sample size is acceptable for structural equation models by calculating formulas from Cohen (1988) and Westland (2010).

The sample questionnaire is presented in *Appendix 5*.

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 5.1 Profile of the respondents in Study 2

Item	**Frequency**	**Percentage (%)**
Work experience (years)		
Below 5	105	40.7%
[5 →10]	102	39.5%
[11 → 15]	25	9.7%
[16 →20]	14	5.4%
Above 20	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

5.1.2 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 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).

Table 5.2: Constructs explanation

Constructs		**Number of items**	**References**
TQM 4.0 (41 items)	Top management 4.0	4	Chiarini and Kumar (2022); Glogovac et al. (2020); Nguyen et al. (2023).
	Quality Culture 4.0	4	Asif (2020); Kupper et al. (2019); Nguyen et al. (2023).
	Skill 4.0	4	Chiarini and Kumar (2022); Kupper et al. (2019); Park et al. (2017); Nguyen et al. (2023).
	Smart organisation	5	Asif (2020); Fundin et al. (2020); Sader et al. (2019); Nguyen et al. (2023).
	Integrating sustainable development	4	Fundin et al. (2020); Ramanathan (2019); Nguyen et al. (2023).

	Automated document control	3	Chiarini and Kumar (2022); Nguyen et al. (2023).
	Automatic data collection	3	Chiarini and Kumar (2022); Nguyen et al. (2023).
	Smart Quality Control	4	Chiarini and Kumar (2022); Sader et al. (2019); Nguyen et al. (2023).
	Smart Quality Assurance	5	Chiarini and Kumar (2022); Sader et al. (2019); Nguyen et al. (2023).
	Smart product	4	Chiarini and Kumar (2022); Sader et al. (2019); Nguyen et al. (2023).
Sustainable Excellence (16 items)	Environmental performance	5	Chavez et al. (2022); Zhu and Sarkis (2004)
	Operational performance	3	Chavez et al. (2022); Chavez et al. (2015)
	Social performance	4	Chavez et al. (2022); Nikolaou, et al. (2013)
	Innovation performance	4	Gök and Peker (2017); Prajogo (2006)
Digital leadership (5 items)		5	Abbu et al. (2022); AlNuaimi et al. (2022)
Digital Transformation (5 items)		5	Li (2022); Abbu et al. (2022).

Source: own research

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

5.1.3 Data analysis

In this section, the author utilises a two-stage analytical process that integrates the partial least squares-structural equation modelling (PLS-SEM) with ANN to evaluate the proposed model. Given the nature of this study, which is more focused on exploration than confirmation, the PLS-SEM method was selected instead of the Covariance-based Structural Equation Modelling (CB-SEM) method (Hsu et al., 2006; Hair et al., 2017). In the first stage, the PLS-SEM method was necessary because of the complex model development and the large number of indicators (Hair et al., 2017). However, PLS-SEM is incapable of analysing non-linear relationships between constructs. Raut et al. (2018) and Al-Sharafi et al. (2022) address this issue by integrating the ANN method with PLS-SEM to rank the normalised importance of the significant variables. The SEM-

ANN method permits the use of both non-linear and linear correlations between variables to explain of the SE of manufacturing enterprises.

Stage 1: PLS-SEM

In this stage, the author conducts an assessment of both measurement model and structural model. According to Hair et al. (2011), The measuring model was established to assess the precision and reliability of constructs and indicators. The assessment involved evaluating the dependability of internal consistency, as well as the validity of convergence and discrimination. The internal consistency reliability of the constructs is assessed by computing composite reliability and Cronbach's alpha. Because this study has second-order constructs, the assessment measurement model includes two steps by applying the process from Riel et al. (2017).

In step 1, the author employs a PLS path model that exclusively includes first-order constructs. The primary goal of the initial phase is to calculate the latent variables' scores and reliable correlations of first-order constructs. For the construction of composited factors to be significant, it is necessary to ensure the validity and reliability of the first-order construct.

In step 2, second-order constructs are used to evaluate the measurement model. The objective of the second step is to obtain estimates that are consistent with the structural model. We use the approximated composite scores from step 1 as indicators for the second-order constructs.

In both steps, CA and CR values have to reach the criterion threshold of 0.70 (Hair et al., 2017). The convergent validity of the reflective latent variable was measured by the average variance extracted (AVE) and must be greater than 0.5. (Henseler, Ringle, and Sarstedt, 2015). We relied on the Heterotrait-Monotrait ratio of correlations (HTMT) between all reflective constructs to evaluate discriminant validity.

Stage 2: ANN technique

This study utilises the ANN method because of its superior efficacy in identifying both non-linear and linear relationships, as compared to other statistical techniques such as multiple linear regression, binary logistic regression, and SEM. ANN results for Vietnamese data (90 % of randomly selected samples were used as training data and the remaining 10 % as testing data). In this step, ten models are performed by the ANN algorithm.

5.2 Results

5.2.1 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. Table 5.3 shows 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.

Table 5.3: Reliability and convergent validity results of first-order constructs

Factors	**Indicators**	**Loadings**	**Cronbach's Alpha**	**CR**	**AVE**
Total Quality Management 4.0 (TQM 4.0)					
"Top management"	TM1	0.909	0.919	0.943	0.805
	TM2	0.894			
	TM3	0.893			
	TM4	0.893			
"Quality Culture 4.0"	QC1	0.747	0.795	0.866	0.619
	QC2	0.799			
	QC3	0.825			
	QC4	0.774			
"Skill 4.0"	SK1	0.839	0.799	0.864	0.615
	SK2	0.859			
	SK3	0.713			
	SK4	0.713			
"Smart organisation"	SO1	0.742	0.842	0.888	0.617
	SO2	0.773			
	SO3	0.857			
	SO4	0.868			
	SO5	0.668			
"Integrating sustainable development"	ISD1	0.842	0.885	0.921	0.745
	ISD2	0.899			
	ISD3	0.893			

	IDS4	0.815			
"Automated document control"	ADC1	0.717	0.875	0.901	0.534
	ADC2	0.728			
	ADC3	0.673			
	ADC4	0.704			
"Automatic data collection"	ADAC1	0.844	0.811	0.888	0.726
	ADAC2	0.872			
	ADAC3	0.840			
"Smart Quality Control"	SQC1	0.867	0.854	0.901	0.694
	SQC2	0.776			
	SQC3	0.850			
	SQC4	0.836			
"Smart Quality Assurance"	SQA1	0.871	0.882	0.913	0.678
	SQA2	0.804			
	SQA3	0.826			
	SQA4	0.805			
	SQA5	0.811			
"Smart product"	SP1	0.873	0.845	0.896	0.683
	SP2	0.832			
	SP3	0.796			
	SP4	0.802			
Sustainable Excellence					
Environmental performance	EP1	0.870	0.924	0.942	0.766
	EP2	0.908			
	EP3	0.858			
	EP4	0.859			
	EP5	0.881			
Operational performance	OP1	0.845	0.817	0.891	0.732
	OP2	0.864			
	OP3	0.858			
Social performance	SOP1	0.829	0.791	0.866	0.621
	SOP2	0.622			

	SOP3	0.857			
	SOP4	0.821			
Innovation performance	IP1	0.898	0.890	0.924	0.753
	IP2	0.870			
	IP3	0.843			
	IP4	0.858			
Digital leadership	DT1	0.796	0.891	0.920	0.696
	DT2	0.800			
	DT3	0.861			
	DT4	0.856			
	DT5	0.857			
Digital Transformation	DL1	0.774	0.868	0.905	0.656
	DL2	0.778			
	DL3	0.779			
	DL4	0.882			
	DL5	0.832			

Source: own research

In step 2, the author evaluates the measurement model of second-order constructs. Table 5.4 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 5.4 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 5.4: 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 represents the extent to which two constructs are separate and distinguishable. The author assessed this value by employing the HTMT ratio (Henseler et al., 2015). Following Table 5.5, the HTMT values were accepted because all values were less than the 0.885 threshold.

Table 5.5: HTMT results

	DL	DT	SE	TQM 4.0
DL				
DT	0.375			
SE	0.354	0.885		
TQM 4.0	0.328	0.847	0.774	

Source: own research

5.2.2 Structural model assessment

Before evaluating the structural model, the collinearity between the variables is evaluated to make sure that there are no lateral collinearity problems (Hair et al., 2011). 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 5.6, there was no collinearity among the predictor components in the structural model (VIF $\leq$ 2.533).

The proposed model's coefficients, standard errors, t-test, effect sizes, p-value will be determined using the 5000-re-test bootstrap approach. 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 production companies.

As shown in Table 5.6, 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 5.6 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.

The structural model achieved predictive relevance (Q^2) through the blindfolding technique, with an omission distance of 7. According to Table 5.6, 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 5.6: 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 → Sustainable Excellence	0.555	7.969	0.000	0.364			2.533
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

5.2.3 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 in Table 5.7, 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 ANN model created in this research yielded reliable and accurate findings.

Table 5.7: RMSE values (SE as Dependent Variable)

RMSE Values (SE as Dependent Variable)					
	Training		Testing		
Model	N	RMSE	N	RMSE	Total sample
1	228	0.203	30	0.225	258
2	229	0.220	29	0.205	258
3	227	0.205	31	0.209	258
4	237	0.273	21	0.337	258
5	232	0.265	26	0.281	258
6	226	0.360	32	0.245	258

7	234	0.256	24	0.365	258
8	236	0.269	22	0.395	258
9	235	0.235	23	0.205	258
10	226	0.305	32	0.244	258
Mean	0.259		0.271		

Source: own research

The sensitivity analysis calculates the variations in the endogenous construct by considering the modifications in the exogenous constructs linked to the model. Using this analysis, the contribution of each predictor to SE was determined in this study. The author calculated the important levels of the factors and their normalised importance (NI). Table 5.8 shows sensitivity analysis results where digital transformation (NI = 100%) is the most affecting 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%).

Table 5.8: Sensitivity analysis

Neural Networks	TM	QC	SK	SO	ISD	ADC	ADAC	SQC	SQA	SP	DT
Model 1	0.842	1.000	0.730	0.688	0.820	0.741	0.871	0.793	0.557	0.611	0.879
Model 2	0.676	0.709	0.643	0.632	1.000	0.764	0.289	0.378	0.640	0.651	0.810
Model 3	0.414	0.497	0.355	0.637	0.545	0.580	0.554	0.569	0.396	0.656	1.000
Model 4	0.827	0.847	0.507	0.515	0.744	0.717	1.000	0.675	0.351	0.816	0.699
Model 5	0.709	0.804	0.882	0.673	0.984	0.676	0.731	0.605	1.000	0.800	0.917
Model 6	0.713	0.947	0.699	0.831	0.819	1.000	0.716	0.690	0.772	0.730	0.955
Model 7	0.195	0.284	0.601	0.916	0.495	0.187	0.849	1.000	0.598	0.395	0.680
Model 8	1.000	0.310	0.275	0.414	0.604	0.388	0.348	0.171	0.446	0.389	0.534
Model 9	1.000	0.851	0.513	0.548	0.711	0.587	0.777	0.674	0.517	0.657	0.896
Model 10	0.637	0.765	0.564	0.685	0.568	0.646	0.475	0.522	0.664	0.560	1.000
Mean Importance	0.096	0.089	0.077	0.090	0.100	0.083	0.092	0.084	0.084	0.086	0.118
Normalised Importance	81.0%	75.5%	65.1%	76.2%	84.3%	70.0%	78.1%	70.9%	70.9%	72.4%	100.0%
Rank	3	6	11	5	2	10	4	8	9	7	1

Source: own research

6 DISCUSSIONS

My thesis investigates two main studies: the first focuses on exploring TQM 4.0's indicators and factors of the practices in manufacturing companies, 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 4th and 5th, 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 4^{th} 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, as outlined below: 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). The findings also indicate the importance of indicators or factors, which consist of (1) ranking of factors in the TQM 4.0 practices based on their importance, (2) ranking of the indicators within each factor, and (3) ranking of the indicators in the whole indicators in TQM 4.0 practices. This result provides valuable insights for researchers and professionals who can utilise it to implement and evaluate TQM 4.0 in production companies.

This thesis also investigates the relationship between TQM 4.0 practices and SE in the production 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. The investigation also ranks the importance of TQM 4.0 practice factors for enhancing 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.

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 respondents to join in all Delphi-AHP survey rounds. Secondly, it is important to mention that some TQM 4.0's indicators have not been identified in the conceptual model of this study. Despite the study's comprehensive approach, which includes a careful literature review and three rounds of Delphi method, to thoroughly investigate all the indicators of TQM 4.0, this limitation cannot be avoided. Therefore, it is recommended 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 framework based on perspectives of experts in variety of geographical areas.

REFERENCES

Abbu, H., Mugge, P., Gudergan, G., Hoeborn, G., & Kwiatkowski, A. (2022). Measuring the Human Dimensions of Digital Leadership for Successful Digital Transformation. *Research-Technology Management*, *65*(3), 39–49. https://doi.org/10.1080/08956308.2022.2048588

Agyabeng-Mensah, Y., Afum, E., Agnikpe, C., Cai, J., Ahenkorah, E., & Dacosta, E. (2021). Exploring the mediating influences of total quality management and just in time between green supply chain practices and performance. *Journal of Manufacturing Technology Management*, *32*(1), 156–175. https://doi.org/10.1108/JMTM-03-2020-0086

Al-Sharafi, M. A., Al-Emran, M., Iranmanesh, M., Al-Qaysi, N., Iahad, N. A., & Arpaci, I. (2022). Understanding the impact of knowledge management factors on the sustainable use of AI-based chatbots for educational purposes using a hybrid SEM-ANN approach. *Interactive Learning Environments*, 1–20. https://doi.org/10.1080/10494820.2022.2075014

Alič, M. (2014). Impact of ISO 9001 certification cancellation on business performance: a case study in Slovenian organisations. *Total Quality Management & Business Excellence*, *25*(7–8), 790–811. https://doi.org/10.1080/14783363.2014.906107

AlNuaimi, B. K., Kumar Singh, S., Ren, S., Budhwar, P., & Vorobyev, D. (2022). Mastering digital transformation: The nexus between leadership, agility, and digital strategy. *Journal of Business Research*, *145*(March), 636–648. https://doi.org/10.1016/j.jbusres.2022.03.038

American Society for Quality. (2017). Malcolm Baldrige National Quality Award (MBNQA). Retrieved from http://asq.org/learn-about-quality/malcolm-baldrige-award/overview/over%0Aview.html

Ardi, Djati, S. P., Bernarto, I., Sudibjo, N., Yulianeu, A., Nanda, H. A., & Nanda, K. A. (2020). The relationship between digital transformational leadership styles and knowledge-based empowering interaction for increasing organisational innovativeness. *International Journal of Innovation, Creativity and Change*, *11*(3), 259–277.

Asif, M. (2020). Are QM models aligned with Industry 4.0? A perspective on current practices. *Journal of Cleaner Production*, *258*, 120820. https://doi.org/10.1016/j.jclepro.2020.120820

Barclay, D., Thompson, R., dan Higgins, C. (1995). The Partial Least Squares (PLS) Approach to Causal Modeling: Personal Computer Adoption and Use an Illustration. *Technology Studies*, *2*(2), 285–309.

Barney, J. B. (2001). Resource-based theories of competitive advantage: A ten-year retrospective on the resource-based view. *Journal of Management*, *27*(6), 643–650. https://doi.org/10.1177/014920630102700602

Barney, J., Wright, M., & Ketchen, D. J. (2001). The resource-based view of the firm: Ten years after 1991. *Journal of Management*, *27*(6), 625–641. https://doi.org/10.1177/014920630102700601

Bresciani, S., Ferraris, A., Romano, M., & Santoro, G. (2021). Digital Leadership. In *Digital Transformation Management for Agile Organizations: A Compass to Sail the Digital World* (pp. 97–115). Emerald Publishing Limited. https://doi.org/10.1108/978-1-80043-171-320211006

Bridoux, F., & Stoelhorst, J. (2022). Stakeholder theory, strategy, and organization: Past, present, and future. *Strategic Organization*, *20*(4), 797–809. https://doi.org/10.1177/14761270221127628

Carvalho, A. M., Sampaio, P., Rebentisch, E., & Saraiva, P. (2021). 35 Years of Excellence, and Perspectives Ahead for Excellence 4.0. *Total Quality Management and Business Excellence*, *32*(11–12), 1215–1248. https://doi.org/10.1080/14783363.2019.1691915

Chaudhuri, A., & Jayaram, J. (2019). A socio-technical view of performance impact of integrated quality and sustainability strategies. *International Journal of Production Research*, *57*(5), 1478–1496. https://doi.org/10.1080/00207543.2018.1492162

Chavez, R., Yu, W., Jacobs, M., Fynes, B., Wiengarten, F., & Lecuna, A. (2015). Internal lean practices and performance: The role of technological turbulence. *International Journal of Production Economics*, *160*, 157–171. https://doi.org/10.1016/j.ijpe.2014.10.005

Chavez, R., Yu, W., Jajja, M. S. S., Song, Y., & Nakara, W. (2022). The relationship between internal lean practices and sustainable performance: exploring the mediating role of social performance. *Production Planning and Control*, *33*(11), 1025–1042. https://doi.org/10.1080/09537287.2020.1839139

Chiarini, A. (2020). Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research. *TQM Journal*, *32*(4), 603–616. https://doi.org/10.1108/TQM-04-2020-0082

Chiarini, A., & Kumar, M. (2022). What is Quality 4.0? An exploratory sequential mixed methods study of Italian manufacturing companies. *International Journal of Production Research*, *60*(16), 4890–4910. https://doi.org/10.1080/00207543.2021.1942285

Cimini, C., Boffelli, A., Lagorio, A., Kalchschmidt, M., & Pinto, R. (2020). How do industry 4.0 technologies influence organisational change? An empirical analysis of Italian SMEs. *Journal of Manufacturing Technology Management*, *32*(3), 695–721. https://doi.org/10.1108/JMTM-04-2019-0135

Claassen, R. (2023). Political theories of the business corporation. *Philosophy Compass*, *18*(1). https://doi.org/10.1111/phc3.12892

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences* (2nd ed.). Hillsdale, NJ: Lawrence Earlbaum Associates.

Cohen, Jacob. (1992). A power primer. *Psychological Bulletin*, *112*(1), 155–159. https://doi.org/10.1037/0033-2909.112.1.155

Dale, B. G., Zairi, M., Van der Wiele, A., & Williams, A. R. T. (2000). Quality is dead in Europe – long live excellence - true or false? *Measuring Business Excellence*, *4*(3), 4–10. https://doi.org/10.1108/13683040010377737

Dalkey, N., & Helmer, O. (1963). An Experimental Application of the DELPHI Method to the Use of Experts. *Management Science*, *9*(3), 458–467. https://doi.org/10.1287/mnsc.9.3.458

Darko, A., Chan, A. P. C., Ameyaw, E. E., Owusu, E. K., Pärn, E., & Edwards, D. J. (2019). Review of application of analytic hierarchy process (AHP) in construction. *International Journal of Construction Management*, *19*(5), 436–452. https://doi.org/10.1080/15623599.2018.1452098

De Waal, B., & van Outvorst, F. Ravesteyn, P. (2016). Digital leadership: The objective-subjective dichotomy of technology revisited. In *The 12th European Conference on Management, Leadership and Governance ECMLG 2016*.

Delbari, S. A., Ng, S. I., Aziz, Y. A., & Ho, J. A. (2016). An investigation of key competitiveness indicators and drivers of full-service airlines using Delphi and AHP techniques. *Journal of Air Transport Management*, *52*(April), 23–34. https://doi.org/10.1016/j.jairtraman.2015.12.004

Dmytriyev, S. D., Freeman, R. E., & Hörisch, J. (2021). The Relationship between Stakeholder Theory and Corporate Social Responsibility: Differences, Similarities, and Implications for Social Issues in Management. *Journal of Management Studies*, *58*(6), 1441–1470. https://doi.org/10.1111/joms.12684

Donaldson, T., & Preston, L. E. (1995). The Stakeholder Theory of the Corporation: Concepts, Evidence, and Implications. *The Academy of Management Review*, *20*(1), 65. https://doi.org/10.2307/258887

Edgeman, R. (2018). Excellence models as complex management systems. *Business Process Management Journal*, *24*(6), 1321–1338. https://doi.org/10.1108/BPMJ-02-2018-0049

Edgeman, R., & Eskildsen, J. (2014). Modeling and Assessing Sustainable Enterprise Excellence. *Business Strategy and the Environment*, *23*(3), 173–187. https://doi.org/10.1002/bse.1779

Eriksson, H., Gremyr, I., Bergquist, B., Garvare, R., Fundin, A., Wiklund, H., … Sörqvist, L. (2016). Exploring quality challenges and the validity of excellence models. *International Journal of Operations and Production Management*, *36*(10), 1201–1221. https://doi.org/10.1108/IJOPM-12-2014-0610

European Foundation for Quality Management. (2017). Journey to excellence. Retrieved from www.%0Aefqm.org/journey-to-excellence

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*(4), 1149–1160. https://doi.org/10.3758/BRM.41.4.1149

Flammer, C. (2013). Corporate Social Responsibility and Shareholder Reaction: The Environmental Awareness of Investors. *Academy of Management Journal*, *56*(3), 758–781. https://doi.org/10.5465/amj.2011.0744

Franco, S., Caroli, M. G., Cappa, F., & Del Chiappa, G. (2020). Are you good enough? CSR, quality management and corporate financial performance in the hospitality industry. *International Journal of Hospitality Management*, *88*(November 2019), 102395. https://doi.org/10.1016/j.ijhm.2019.102395

Fundin, A., Lilja, J., Lagrosen, Y., & Bergquist, B. (2020). Quality 2030: quality management for the future. *Total Quality Management and Business Excellence*, *0*(0), 1–17. https://doi.org/10.1080/14783363.2020.1863778

Glogovac, M., Ruso, J., & Maricic, M. (2020). ISO 9004 maturity model for quality in industry 4.0. *Total Quality Management and Business Excellence*, 0–19. https://doi.org/https://doi.org/10.1080/14783363.2020.1865793

Goetsch, D. L., & Davis, S. (2013). *Quality management for organizational excellence : introduction to total quality*. *Always learning TA - TT* - (Seventh Ed). Pearson Education Limited. https://doi.org/British Library Cataloguing-In Publication data

Gök, O., & Peker, S. (2017). Understanding the links among innovation performance, market performance and financial performance. *Review of Managerial Science*, *11*(3), 605–631. https://doi.org/10.1007/s11846-016-0198-8

Hair, J. F., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM)* (3rd ed.). CA: Sage.

Hair, Joe F., Matthews, L. M., Matthews, R. L., & Sarstedt, M. (2017). PLS-SEM or CB-SEM: updated guidelines on which method to use. *International Journal of Multivariate Data Analysis*, *1*(2), 107. https://doi.org/10.1504/IJMDA.2017.087624

Hair, Joe F., Ringle, C. M., & Sarstedt, M. (2011). PLS-SEM: Indeed a Silver Bullet. *Journal of Marketing Theory and Practice*, *19*(2), 139–152.

https://doi.org/10.2753/MTP1069-6679190202

Hart, S. L. (1995). A Natural-Resource-Based View of the Firm. *The Academy of Management Review*, *20*(4), 986. https://doi.org/10.2307/258963

Hart, S. L., Academy, T., & Oct, N. (2008). A Natural-Resource-Based View of the Firm, *20*(4), 986–1014.

Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, *43*(1), 115–135. https://doi.org/10.1007/s11747-014-0403-8

Hsu, S. H., Chen, W. H., & Hsieh, M. J. (2006). Robustness testing of PLS, LISREL, EQS and ANN-based SEM for measuring customer satisfaction. *Total Quality Management and Business Excellence*, *17*(3), 355–372. https://doi.org/10.1080/14783360500451465

Huang, Z., Shahzadi, A., & Khan, Y. D. (2022). Unfolding the Impact of Quality 4.0 Practices on Industry 4.0 and Circular Economy Practices: A Hybrid SEM-ANN Approach. *Sustainability (Switzerland)*, *14*(23), 1–20. https://doi.org/10.3390/su142315495

Isaksson, R. (2019). Excellence for sustainability – maintaining the license to operate. *Total Quality Management & Business Excellence*, *32*(5–6), 489–500. https://doi.org/10.1080/14783363.2019.1593044

ISO. (2021). ISO 9000 FAMILY QUALITY MANAGEMENT. Retrieved from https://www.iso.org/iso-9001-quality-management.html

Jaca, C., & Psomas, E. (2015). Total quality management practices and performance outcomes in Spanish service companies. *Total Quality Management and Business Excellence*, *26*(9–10), 958–970. https://doi.org/10.1080/14783363.2015.1068588

Judge, W. Q., & Douglas, T. J. (1998). Performance Implications of Incorporating Natural Environmental Issues into the Strategic Planning Process: An Empirical Assessment. *Journal of Management Studies*, *35*(2), 241–262. https://doi.org/10.1111/1467-6486.00092

Kafetzopoulos, D. P., Psomas, E. L., & Gotzamani, K. D. (2015). The impact of quality management systems on the performance of manufacturing firms. *International Journal of Quality & Reliability Management*, *32*(4), 381–399. https://doi.org/10.1108/IJQRM-11-2013-0186

Kalinić, Z., Marinković, V., Kalinić, L., & Liébana-Cabanillas, F. (2021). Neural network modeling of consumer satisfaction in mobile commerce: An empirical analysis. *Expert Systems with Applications*, *175*, 114803. https://doi.org/10.1016/j.eswa.2021.114803

Kock, N., & Hadaya, P. (2018). Minimum sample size estimation in PLS-SEM:

The inverse square root and gamma-exponential methods. *Information Systems Journal*, *28*(1), 227–261. https://doi.org/10.1111/isj.12131

Kupper, D., Knizek, C., Ryeson, D., & Jan, N. (2019). *Quality 4 . 0 Takes More Than Technology*. *Boston Consulting Group (BCG)*. Retrieved from https://www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology

Lawshe, C. H. (1975). a Quantitative Approach To Content Validity. *Personnel Psychology*, *28*(4), 563–575. https://doi.org/10.1111/j.1744-6570.1975.tb01393.x

Li, L. (2022). Digital transformation and sustainable performance: The moderating role of market turbulence. *Industrial Marketing Management*, *104*(September 2021), 28–37. https://doi.org/10.1016/j.indmarman.2022.04.007

Maganga, D. P., & Taifa, I. W. R. (2022). Quality 4.0 transition framework for Tanzanian manufacturing industries. *The TQM Journal*. https://doi.org/10.1108/TQM-01-2022-0036

Manz, C. C., & Stewart, G. L. (1997). Attaining Flexible Stability by Integrating Total Quality Management and Socio-Technical Systems Theory. *Organization Science*, *8*(1), 59–70. https://doi.org/10.1287/orsc.8.1.59

Markley, M. J., & Davis, L. (2007). Exploring future competitive advantage through sustainable supply chains. *International Journal of Physical Distribution & Logistics Management*, *37*(9), 763–774. https://doi.org/10.1108/09600030710840859

Miller, W. J. (1996). A working definition for total quality management (TQM) researchers. *Journal of Quality Management*, *1*(2), 149–159. https://doi.org/10.1016/s1084-8568(96)90011-5

Min, J. C. H. (2015). Guiding the guides: developing indicators of tour guides' service quality. *Total Quality Management and Business Excellence*, *27*(9–10), 1043–1062. https://doi.org/10.1080/14783363.2015.1060123

Murry, J. W., & Hammons, J. O. (1995). Delphi: A Versatile Methodology for Conducting Qualitative Research. *The Review of Higher Education*, *18*(4), 423–436. https://doi.org/10.1353/rhe.1995.0008

Nasiri, M., Ukko, J., Saunila, M., & Rantala, T. (2020). Managing the digital supply chain: The role of smart technologies. *Technovation*, *96–97*, 102121. https://doi.org/10.1016/j.technovation.2020.102121

Neumann, W. P., Winkelhaus, S., Grosse, E. H., & Glock, C. H. (2021). Industry 4.0 and the human factor – A systems framework and analysis methodology for successful development. *International Journal of Production Economics*, *233*(September 2020), 107992. https://doi.org/10.1016/j.ijpe.2020.107992

Nguyen, T. A. Van, Tucek, D., & Pham, N. T. (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. https://doi.org/10.1080/14783363.2022.2039062

Nikolaou, I. E., Evangelinos, K. I., & Allan, S. (2013). A reverse logistics social responsibility evaluation framework based on the triple bottom line approach. *Journal of Cleaner Production*, *56*, 173–184. https://doi.org/10.1016/j.jclepro.2011.12.009

Pan, C., Guo, H., Jiang, Y., Wang, H., & Qi, W. (2020). The double effects of female executives' participation on corporate sustainable competitive advantage through unethical environmental behavior and proactive environmental strategy. *Business Strategy and the Environment*, *29*(6), 2324–2337. https://doi.org/10.1002/bse.2505

Pansare, R., & Yadav, G. (2022). Repurposing production operations during COVID-19 pandemic by integrating Industry 4.0 and reconfigurable manufacturing practices: an emerging economy perspective. *Operations Management Research*, *15*(3–4), 1270–1289. https://doi.org/10.1007/s12063-022-00310-7

Park, S. ., Shin, W. ., Park, Y. ., & Lee, Y. (2017). Building a new culture for quality management in the era of the Fourth Industrial Revolution. *Total Quality Management and Business Excellence*, *28*(9–10), 934–945. https://doi.org/10.1080/14783363.2017.1310703

Pieroni, M. P. P., McAloone, T. C., & Pigosso, D. C. A. (2019). Business model innovation for circular economy and sustainability: A review of approaches. *Journal of Cleaner Production*, *215*(November 2019), 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036

Piyathanavong, V., Huynh, V. N., Karnjana, J., & Olapiriyakul, S. (2022). Role of project management on Sustainable Supply Chain development through Industry 4.0 technologies and Circular Economy during the COVID-19 pandemic: A multiple case study of Thai metals industry. *Operations Management Research*. https://doi.org/10.1007/s12063-022-00283-7

Prajogo, D. I. (2006). The relationship between innovation and business performance—a comparative study between manufacturing and service firms. *Knowledge and Process Management*, *13*(3), 218–225. https://doi.org/10.1002/kpm.259

Rajput, S., & Singh, S. P. (2020). Industry 4.0 Model for circular economy and cleaner production. *Journal of Cleaner Production*, *277*, 123853. https://doi.org/10.1016/j.jclepro.2020.123853

Ramanathan, N. (2019). Quality-based management for future-ready corporations serving society and planet. *Total Quality Management & Business*

Excellence, *32*(5–6), 541–557. https://doi.org/10.1080/14783363.2019.1599715

Raut, R. D., Priyadarshinee, P., Gardas, B. B., & Jha, M. K. (2018). Analyzing the factors influencing cloud computing adoption using three stage hybrid SEM-ANN-ISM (SEANIS) approach. *Technological Forecasting and Social Change*, *134*(July 2017), 98–123. https://doi.org/10.1016/j.techfore.2018.05.020

Saaty, R. W. (1987). The analytic hierarchy process—what it is and how it is used. *Mathematical Modelling*, *9*(3–5), 161–176. https://doi.org/10.1016/0270-0255(87)90473-8

Saaty, T. L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research*, *48*(1), 9–26. https://doi.org/10.1016/0377-2217(90)90057-I

Sader, S., Husti, I., & Daroczi, M. (2021). A review of quality 4.0: definitions, features, technologies, applications, and challenges. *Total Quality Management and Business Excellence*, *0*(0), 1–19. https://doi.org/10.1080/14783363.2021.1944082

Sader, S., Husti, I., & Daróczi, M. (2019). Industry 4.0 as a Key Enabler toward Successful Implementation of Total Quality Management Practices. *Periodica Polytechnica Social and Management Sciences*, *27*(2), 131–140. https://doi.org/10.3311/PPso.12675

Saunders, M. N. K., Philip, L., & Adrian, T. (2019). *Research Methods for Business Students* (Eighth). Pearson Education Limited.

Sharma, A., Dwivedi, Y. K., Arya, V., & Siddiqui, M. Q. (2021). Does SMS advertising still have relevance to increase consumer purchase intention? A hybrid PLS-SEM-neural network modelling approach. *Computers in Human Behavior*, *124*, 106919. https://doi.org/10.1016/j.chb.2021.106919

Sirmon, D. G., Hitt, M. A., Ireland, R. D., & Gilbert, B. A. (2011). Resource Orchestration to Create Competitive Advantage. *Journal of Management*, *37*(5), 1390–1412. https://doi.org/10.1177/0149206310385695

Sony, M., Antony, J., & Douglas, J. A. (2020). Essential ingredients for the implementation of Quality 4.0: A narrative review of literature and future directions for research. *TQM Journal*, *32*(4), 779–793. https://doi.org/10.1108/TQM-12-2019-0275

Sony, M., & Naik, S. (2020). Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model. *Technology in Society*, *61*(August 2019), 101248. https://doi.org/10.1016/j.techsoc.2020.101248

Speringer, M. (2019). *Differentiation of Industry 4 . 0 Models*.

https://doi.org/10.13140/RG.2.2.35510.55363

Srinivasan, K., Sarulkar, P., & Yadav, V. K. (2023). Operational excellence of the steel industry using the Lean Six Sigma approach: a case study. *International Journal of Quality & Reliability Management*. https://doi.org/10.1108/IJQRM-08-2022-0250

Talwar, B. (2011). Business excellence models and the path ahead …. *The TQM Journal*, *23*(1), 21–35. https://doi.org/10.1108/17542731111097461

Trist, E. L. (1981). *The evolution of socio-technical systems*. Toronto: Ontario Quality of Working Life Centre.

Van Dun, D. H., & Kumar, M. (2023). Social enablers of Industry 4.0 technology adoption: transformational leadership and emotional intelligence. *International Journal of Operations and Production Management*, *43*(13), 152–182. https://doi.org/10.1108/IJOPM-06-2022-0370

Van Riel, A. C. R., Henseler, J., Kemény, I., & Sasovova, Z. (2017). Estimating hierarchical constructs using consistent partial least squares: The case of second-order composites of common factors. *Industrial Management and Data Systems*, *117*(3), 459–477. https://doi.org/10.1108/IMDS-07-2016-0286

Vasudevan, H. (2021). RESOURCE-BASED VIEW THEORY APPLICATION ON THE EDUCATIONAL SERVICE QUALITY. *International Journal of Engineering Applied Sciences and Technology*, *6*(6), 174–186. https://doi.org/10.33564/IJEAST.2021.v06i06.026

Wade, J. (2000). Business excellence - Excellence! the journey starts here. *Qualityworld*, *26*(5), 20–23.

Westland, J. . (2010). Lower bounds on sample size in structural equation modeling. *Electronic Commerce Research and Applications*, *9*(6), 476–487. https://doi.org/10.1016/j.elerap.2010.07.003

Wong, A. K. F., Kim, S., Lee, S., & Elliot, S. (2020). An application of Delphi method and analytic hierarchy process in understanding hotel corporate social responsibility performance scale. *Journal of Sustainable Tourism*, *29*(7), 1153–1179. https://doi.org/10.1080/09669582.2020.1773835

Xu, L., Peng, X., Pavur, R., & Prybutok, V. (2020). Quality management theory development via meta-analysis. *International Journal of Production Economics*, *229*(April). https://doi.org/10.1016/j.ijpe.2020.107759

Zhang, C., Moreira, M. R. A., & Sousa, P. S. A. (2020). A bibliometric view on the use of total quality management in services. *Total Quality Management and Business Excellence, 0*(0), 1–28. https://doi.org/10.1080/14783363.2020.1732811

Zhou, X., Song, M., & Cui, L. (2020). Driving force for China’s economic development under Industry 4.0 and circular economy: Technological innovation or structural change? *Journal of Cleaner Production*, *271*, 122680. https://doi.org/10.1016/j.jclepro.2020.122680

Zhu, Q., & Sarkis, J. (2004). Relationships between operational practices and performance among early adopters of green supply chain management practices in Chinese manufacturing enterprises. *Journal of Operations Management*, *22*(3), 265–289. https://doi.org/10.1016/j.jom.2004.01.005

APPENDICES

Appendix 1: Questionnaire of the Delphi round 1.

QUESTIONNAIRE Email: vohoathong@gmail.com

Bảng câu hỏi

My name is Nguyen Thi Anh Van, a lecturer at HCMC University of Technology and Education. I am also a PhD student at Tomas Bata University in Zlin, Czech Public. I am investigating on Total Quality Management model in the industry 4.0 context (TQM 4.0) in manufacturing sector? ". I am looking forward to receiving your comments on the model. I promise that the information you provide will be kept confidential and only used for the research process. I thank you very much for your answer.

Tôi là Nguyễn Thị Anh Vân, hiện là giảng viên trường ĐH Sư phạm Kỹ thuật TP HCM. Hiện tôi đang nghiên cứu về mô hình quản trị chất lượng toàn diện trong Công nghiệp 4.0 (gọi tắt là TQM 4.0) tại các doanh nghiệp sản xuất. Rất mong sẽ nhận được sự góp ý của quý anh/ chị cho mô hình mà tôi đang nghiên cứu. Tôi cam kết những thông tin quý anh/ chị cung cấp được bảo mật, chỉ phục vụ cho quá trình nghiên cứu. Tôi rất cảm ơn sự cộng tác của anh/ chị.

I - Total Quality Management 4.0 model (TQM 4.0)

Nội dung về mô hình quản trị chất lượng toàn diện 4.0 (TQM 4.0)

TQM 4.0 model is the integration of Industry 4.0 tools into Total Quality Management system. I developed the TQM 4.0 model based on TQM principles and the huge application of new technologies of Industry 4.0 to the management system. The TQM 4.0 model consists of 11 factors (44 observed variables) with two main aspects: social and technical aspects. Applications of Industry 4.0 tools include Automated document control, Automated data collection using Cyber-Physical Systems, intelligence sensors, and IoT; Smart Quality Control by using RFID technology and smart sensors on products and packaging to identify and trace products; Smart Quality Assurance by collecting and analysing big data to make accurate predictions to understand customer needs better and identify and eliminate the root causes of production defects and will take immediate action to avoid defects and production failure, etc.

Mô hình TQM 4.0 là sự tích hợp các công cụ của Công nghiệp 4.0 vào hệ thống quản trị chất lượng toàn diện. Mô hình TQM 4.0 được xây dựng dựa trên các nguyên tắc của TQM và sự áp dụng mạnh mẽ các công nghệ mới của Công nghiệp 4.0 vào hệ thống quản lý. Mô hình được trình bày gồm 11 yếu tố (44 biến quan sát) với hai khía cạnh chính: khía cạnh về xã hội và khía cạnh về công nghệ. Các áp dụng của các công cụ Công nghiệp 4.0 bao gồm: Kiểm soát tài liệu tự động, Thu thập dữ liệu tự động bằng hệ thống không gian mạng thực-ảo, các cảm biến thông minh và Internet vạn vật; Kiểm soát chất lượng thông minh bằng công nghệ RFID và cảm biến thông minh *trên sản phẩm và bao bì để nhận diện và truy xuất nguồn gốc các sản phẩm; Đảm bảo chất lượng thông minh bằng việc thu thập và phân tích dữ liệu lớn để đưa ra dự đoán chính xác để hiểu rõ hơn nhu cầu của khách hàng, cũng như xác định và loại bỏ các nguyên nhân gốc rễ của các lỗi sản xuất và sẽ thực hiện hành động sớm ngay lập tức để tránh các khuyết tật và lỗi sản xuất ,..*

1. Please give some information about your understanding of TQM 4.0? Please tick (X) the box that is correct.

Anh/chị hãy cho biết một vài thông tin về sự hiểu biết về TQM 4.0 của anh/chị? Xin hãy tích (X) vào ô mà anh/chị thấy đúng.

☐ Your company has applied new technologies in production and quality such as: RFID technology and smart sensors, automatic data collection, real-time data collection,.... (*Trong công ty anh/chị có áp dụng các công nghệ mới trong sản xuất, chất lượng như: Công nghệ RFID và cảm biến thông minh, thu thập dữ liệu tự động, thu thập dữ liệu trong thời gian thực,....*)

☒ You have knowledgeable of Total Quality Management (*Các anh/chị có hiểu biết về quản trị chất lượng toàn diện*)

☐ You have knowledgeable of the tools in Industry 4.0 (*Các anh/chị có hiểu biết về các công cụ trong cuộc cách mạng công nghiệp 4.0*)

☒ You have been trained in TQM for the last 3 years (*Các anh/chị được đào tạo về kiến thức về quản trị chất lượng trong thời gian 3 năm gần đây*)

☐ You have been trained in new technology in Industry 4.0 tools such as for the last 3 years (*Các anh/chị được đào tạo về các công nghệ mới trong Công nghiệp 4.0 trong thời gian 3 năm gần đây*)

☒ You have studied and researched on the application of new technologies in production/quality management (*Anh chị từng tìm hiểu, nghiên cứu về việc áp dụng các công nghệ mới trong quản trị sản xuất/ chất lượng*)

If you do not have any understanding of the tools of industry 4.0 in production/quality management, the survey ends here. If you choose any of the options above, please continue the survey. Thank you very much.

Nếu anh/chị không có bất kỳ sự hiểu biết gì về các công cụ của công nghiệp 4.0 trong quản trị sản xuất/ chất lượng thì cuộc khảo sát đến đây kết thúc. Nếu anh/chị chọn bất kỳ tùy chọn nào ở trên thì xin mời tiếp tục cuộc khảo sát. Cảm ơn anh/chị rất nhiều.

2. The factors of TQM 4.0 model.

Please rate the importance of the factors in the TQM 4.0 model that I have given by ticking (X) in the appropriate boxes with the following convention:

(1: not important; 2: slightly important; 3:moderately important; 4: very important; and 5: extremely important)

You rate the factors based on your knowledge and experiences to answer the question " What factors are important for the TQM 4.0 model?". This question is NOT evaluate the TQM 4.0 implementation in your company.

Anh/ chị hãy cho đánh giá sự quan trọng của các yếu tố trong mô hình TQM 4.0 mà tôi đã đưa ra bằng cách đánh dấu (X) vào các ô thích hợp với qui ước sau:

(1: Rất ít quan trọng; 2: Ít quan trọng; 3:Quan trọng; 4:Rất quan trọng; 5:Hoàn toàn quan trọng)

Anh/ chị hãy đánh giá các yếu tố dựa trên kiến thức và kinh nghiệm của mình để trả lời câu hỏi "Yếu tố nào là quan trọng của mô hình TQM 4.0?". Câu hỏi này KHÔNG phải là đánh giá việc triển khai TQM 4.0 trong công ty của anh/chị.

	Factors (Các yếu tố)	1	2	3	4	5
	Top management (Sự lãnh đạo)					
1	In TQM 4.0 model, top managements need to commit for TQM 4.0 development. *Trong mô hình TQM 4.0, các quản lý cao nhất cần phải cam kết phát triển TQM 4.0*	1	2	3	4	X
2	In TQM 4.0 model, top managements need to involve for TQM 4.0 development. *Trong mô hình TQM 4.0, các quản lý cao nhất cần tham gia phát triển TQM 4.0*	1	2	3	4	X
3	In TQM 4.0 model, top managements need to provide resources for TQM 4.0 development. *Trong mô hình TQM 4.0, các quản lý cao nhất cần cung cấp các nguồn lực để phát triển TQM 4.0*	1	2	3	4	X
4	In TQM 4.0 model, top managements need to establish policy, strategic, objectives and indicators for TQM 4.0 *Trong mô hình TQM 4.0, các quản lý cao nhất cần thiết lập chính sách, chiến lược, mục tiêu và các chỉ tiêu cho TQM 4.0*	1	2	3	4	X
	Quality Culture 4.0 (Văn hóa chất lượng 4.0)					
1	TQM 4.0 should encourage employees self-leaders and to actively solving problems instead of waiting for regular processes. *TQM 4.0 nên khuyến khích nhân viên tự quản lý và chủ động giải quyết vấn đề thay vì chờ đợi quy trình thông thường.*	1	2	3	X	5
2	TQM 4.0 model should encourage employees empowerment in the organisation. *Mô hình TQM 4.0 nên khuyến khích trao quyền cho nhân viên trong tổ chức.*	1	2	3	X	5
3	TQM 4.0 should encourage individuals across the organization understand their roles in achieving quality goals *TQM 4.0 nên khuyến khích các cá nhân trong tổ chức hiểu rõ vai trò của họ trong việc đạt được các mục tiêu chất lượng*	1	2	3	X	5
4	In TQM 4.0 model, organisations will use digital media to articulate quality goals and objectives to all layers of the organisation. *Trong mô hình TQM 4.0, tổ chức sử dụng phương tiện kỹ thuật số để truyền đạt các mục tiêu chất lượng tại tất cả các cấp và bộ phận chức năng của tổ chức.*	1	2	3	X	5

	Skill 4.0					
1	In TQM 4.0 model, quality control staff should acquire more knowledge of skills related to data analytics *Trong mô hình TQM 4.0, nhân viên kiểm soát chất lượng (QC) cần có thêm các kỹ năng liên quan đến phân tích dữ liệu.*	1	2	X	4	5
2	In TQM 4.0 model, quality staff will spend less time in operative tasks such as inspections and more time problem-solving and preventive activities. *Trong mô hình TQM 4.0, nhân viên chất lượng sẽ dành ít thời gian hơn cho việc kiểm tra chất lượng sản phẩm mà dành nhiều thời gian hơn trong việc giải quyết vấn đề và đưa ra các hoạt động phòng ngừa.*	1	2	3	4	X
3	TQM 4.0 model requires employees apply digital tools and can tell data-driven stories *Mô hình TQM 4.0 yêu cầu nhân viên áp dụng các công cụ kỹ thuật số và có thể kể câu chuyện dựa trên dữ liệu.*	1	2	3	4	X
4	In TQM 4.0 model, data scientists as quality experts. *Trong mô hình TQM 4.0, các nhà khoa học dữ liệu (data scientists) được coi là các chuyên gia chất lượng (quality experts).*	1	2	X	4	5
5	In TQM 4.0 model, creative thinking emphasises team activities in the design stage and QM activities. *Trong mô hình TQM 4.0, tư duy sáng tạo được chú trọng trong các hoạt động nhóm ở giai đoạn thiết kế và các hoạt động quản trị chất lượng.*	1	2	3	X	5
	Intellectual capital management (Quản trị vốn trí tuệ)					
1	Besides managing human resources, TQM 4.0 model should also focus on current developing and leveraging human capital such as experience and skills of employees *Bên cạnh việc quản lý nguồn nhân lực, mô hình TQM 4.0 nên tập trung vào việc phát triển và tận dụng vốn nhân lực (human capital) hiện tại như kinh nghiệm và kỹ năng của nhân viên.*	1	2	3	X	5
2	TQM 4.0 model should focus on developing social capital, such as the working relationships of people both within and outside an organization. *Mô hình TQM 4.0 nên tập trung phát triển vốn xã hội(social capital), cụ thể là các mối quan hệ làm việc của mọi người cả trong và ngoài tổ chức.*	1	2	X	4	5
3	TQM 4.0 should focus on intellectual capital management such as reputation, employee loyalty, customer relationships, company values, brand image. *Mô hình TQM 4.0 nên tập trung vào quản trị vốn trí tuệ (ví dụ như danh tiếng, lòng trung thành của nhân viên, mối quan hệ với khách hàng, giá trị công ty, hình ảnh thương hiệu)*	1	2	3	X	5

	Smart organisation (Tổ chức thông minh)					
1	In TQM 4.0 model, top managements will support initiatives, spread organisational knowledge, and scale up successful innovations. *Trong mô hình TQM 4.0, các nhà quản lý cao nhất sẽ hỗ trợ các sáng kiến, truyền bá tri thức của tổ chức và mở rộng quy mô các đổi mới thành công.*	**1**	**2**	**3**	X	**5**
2	TQM 4.0 will rise to lean structures organisation which bring operational efficiencies and make decision making quicker by AI-based systems. *TQM 4.0 sẽ tạo ra cấu trúc tổ chức tinh gọn (lean structures organisation) mang lại hiệu quả hoạt động và giúp việc ra quyết định nhanh hơn nhờ các hệ thống dựa trên trí tuệ nhân tạo.*	**1**	**2**	**3**	X	**5**
3	TQM 4.0 tools will help improve communication from connectivity features and social networking, facilitating innovation and sharing ideas between production parties and stakeholders (such as: suppliers, patterners, customers, investors) *Các công cụ TQM 4.0 sẽ giúp cải thiện giao tiếp từ các tính năng kết nối và mạng xã hội, tạo điều kiện đổi mới và chia sẻ ý tưởng giữa sản xuất và các bên liên quan (chẳng hạn như nhà cung cấp, nhà thiết kế, khách hàng, nhà đầu tư)*	**1**	**2**	**3**	X	**5**
4	In TQM 4.0 model, company will provide a virtual platform used by buyers and sellers; and credit card companies and logistics providers also use the same platform to provide services seamlessly. *Trong TQM 4.0, công ty sẽ cung cấp một nền tảng ảo được người mua;người bán sử dụng; và các công ty thẻ tín dụng và nhà cung cấp dịch vụ hậu cần cùng sử dụng cùng một nền tảng để cung cấp dịch vụ một cách liền mạch.*	**1**	**2**	**3**	X	**5**
5	TQM 4.0 model will adapt fast-changing environment with exploration (external innovation such as innovation of products) and exploitation (innovation with an internal focus, for instance, on processes) *Mô hình TQM 4.0 sẽ thích ứng với môi trường thay đổi nhanh thông qua sự đổi mới cho bên ngoài (ví dụ đổi mới sản phẩm) và sự đổi mới cho bên trong (ví dụ đổi mới quy trình)*	**1**	**2**	**3**	X	**5**
	Integrating sustainable development (Tích hợp phát triển bền vững)					
1	TQM 4.0 model needs to link quality and sustainability. *Mô hình TQM 4.0 cần gắn kết giữa chất lượng và tính bền vững*	**1**	**2**	**3**	X	**5**
2	TQM 4.0 model will focus on quality-based management for ready serving society *Mô hình TQM 4.0 sẽ tập trung vào quản lý dựa trên chất lượng để sẵn sàng phục vụ xã hội*	**1**	**2**	**3**	X	**5**
3	TQM 4.0 model need to develop operations in a more sustainable way *Mô hình TQM 4.0 cần phát triển hoạt động theo hướng bền vững hơn*	**1**	**2**	**3**	X	**5**
4	TQM 4.0 model need to integrate of environmental management systems. *Mô hình TQM 4.0 cần tích hợp các hệ thống quản lý môi trường.*	**1**	**2**	**3**	X	**5**

Technical factors						
	Automated document control (Kiểm soát tài liệu tự động)					
1	TQM 4.0 model need to integrate quality management documentation into ERP modules and automatic revision when products/processes change *Mô hình TQM 4.0 cần tích hợp tài liệu quản lý chất lượng vào các mô-đun ERP và tự động sửa đổi khi sản phẩm / quy trình thay đổi*	**1**	**2**	**3**	**4**	**5**
2	In TQM 4.0 model, using electronic documentation for Quality Management System is necessary. *Trong mô hình TQM 4.0, sử dụng tài liệu điện tử cho Hệ thống quản lý chất lượng là cần thiết.*	**1**	**2**	**3**	**4**	**5**
3	In TQM 4.0 model, work instructions are automated and controlled in real-time. *Trong mô hình TQM 4.0, hướng dẫn công việc được tự động hóa và kiểm soát trong thời gian thực.*	**1**	**2**	**3**	**4**	**5**
4	TQM 4.0 will provide digital standard operating procedures (SOPs) to ensure that workers have the most up-to-date instructions *TQM 4.0 sẽ cung cấp các quy trình vận hành tiêu chuẩn kỹ thuật số (digital SOP)để đảm bảo người lao động có các hướng dẫn cập nhật nhất.*	**1**	**2**	**3**	**4**	**5**
	Automatic data collection (Thu thập dữ liệu tự động)					
1	In TQM 4.0 model, data will be collected automatically throughout the product lifecycle using Cyber-Physical Systems, sensors, and IoT. *Trong mô hình TQM 4.0, dữ liệu sẽ được thu thập tự động trong suốt vòng đời sản phẩm bằng hệ thống không gian mạng thực-ảo(CPS) và các cảm biến được kết nối với Internet vạn vật (IoT).*	**1**	**2**	**3**	**4**	**5**
2	In TQM 4.0 model, many types of product-related data to be automatically collected (for example: quantity of nonconforming or scrap products, the number of labour and machine hours spent on reworks and the number of complaints and returned products, and etc.) *Trong mô hình TQM 4.0, nhiều loại dữ liệu liên quan đến sản phẩm được thu thập tự động (ví dụ như số lượng sản phẩm không phù hợp hoặc phế phẩm, số lượng lao động và giờ máy dành cho việc làm lại và số lượng khiếu nại và trả lại sản phẩm,..)*	**1**	**2**	**3**	**4**	**5**
3	In TQM 4.0 model, customer-related data such as product requirements, complaints and satisfaction levels to be collected automatically *Trong mô hình TQM 4.0, dữ liệu liên quan đến khách hàng được thu thập tự động (ví dụ: sản phẩm yêu cầu, khiếu nại và mức độ hài lòng,..)*	**1**	**2**	**3**	**4**	**5**

	Smart Quality Control (Kiểm soát chất lượng thông minh)					
1	TQM 4.0 model will allow real-time quality inspection. *TQM 4.0 sẽ cho phép kiểm tra chất lượng theo thời gian thực.*	1	2	3	4	5
2	TQM 4.0 model will allow total inspection instead of sample inspection. *TQM 4.0 sẽ cho phép kiểm tra chất lượng sản phẩm tổng thể thay vì kiểm tra rút mẫu*	1	2	3	4	5
3	In TQM 4.0 model, a new kind of SPC [statistical process control] based on machine learning predicts all kinds of defects during machining and gives feedback to the machine itself, automatically correcting its parameters without human interaction. *Trong mô hình TQM 4.0, SPC (kiểm soát quá trình bằng thống kê)sẽ dựa trên học máy (machine learning) để dự đoán tất cả các loại lỗi trong quá trình gia công và đưa ra phản hồi cho chính máy đó, tự động sửa các thông số của nó mà không cần sự tương tác của con người.*	1	2	3	4	5
4	In TQM 4.0 model, quality data are collected automatically from different processes and integrated with ERP modules such as the manufacturing execution system (MES) and the product life cycle management (PLM),… *Trong mô hình TQM 4.0,dữ liệu chất lượng được thu thập tự động từ các quy trình khác nhau và được tích hợp trong các mô-đun ERP như hệ thống thực thi sản xuất (MES) và quản lý vòng đời sản phẩm (PLM),..*	1	2	3	4	5
	Smart Quality Assurance (Đảm bảo chất lượng thông minh)					
1	TQM 4.0 model will use AI software for predictive maintenance in advance and preventive intervention to avoid downtime or system failure. *Mô hình TQM 4.0 sẽ sử dụng phần mềm trí tuệ nhân tạo (AI) để dự đoán trước và can thiệp phòng ngừa nhằm tránh thời gian chết hoặc lỗi hệ thống*	1	2	3	4	5
2	TQM 4.0 model will aid processes' optimisation, improve efficiency and resources allocation by using sensors at each production stage, and provide means to support quality activities that will minimise rework and scrape. *Mô hình TQM 4.0 sẽ hỗ trợ tối ưu hóa quy trình, cải thiện hiệu quả và phân bổ nguồn lực bằng cách sử dụng các cảm biến ở mỗi giai đoạn SX và cung cấp các phương tiện để hỗ trợ các hoạt động chất lượng giúp giảm thiểu việc làm lại và phế phẩm.*	1	2	3	4	5
3	In the TQM 4.0 model, big-data analysis will collect real-time data generated during production and transform it into friendly useful information. *Trong mô hình TQM 4.0, việc phân tích dữ liệu lớn (big-data analysis) sẽ thu thập dữ liệu thời gian thực được tạo ra trong quá trình sản xuất, chuyển nó thành thông tin hữu ích.*	1	2	3	4	5
4	TQM 4.0 will be capable of making intelligent adjustments based on real-time data and maintain digital records. *TQM 4.0 sẽ cung cấp khả năng thực hiện các điều chỉnh thông minh dựa trên dữ liệu thời gian thực và duy trì hồ sơ số (digital records).*	1	2	3	4	5

	Smart product (Sản phẩm thông minh)					
1	TQM 4.0 model will support making accurate early predict market demand and consumption trends and changes. *Mô hình TQM 4.0 sẽ hỗ trợ đưa ra dự đoán sớm chính xác về nhu cầu thị trường cũng như những xu hướng và thay đổi tiêu dùng.*	1	2	3	4	5
2	In TQM 4.0 model, smart technologies can significantly assist companies in the identification and tracking of products. *Trong mô hình TQM 4.0,các công nghệ thông minh có thể hỗ trợ đáng kể các công ty trong việc xác định và theo dõi sản phẩm.*	1	2	3	4	5
3	In TQM 4.0 model, RFID technologies and smart sensors on products and packaging be used to identify and trace products. *Trong mô hình TQM 4.0, công nghệ RFID và cảm biến thông minh trên sản phẩm và bao bì được sử dụng để nhận diện và truy xuất nguồn gốc các sản phẩm.*	1	2	3	4	5
4	In TQM 4.0 model, industry 4.0 connectivity features will allow customers involvement in the production process rather than only being the recipient of it. *Trong mô hình TQM 4.0, các tính năng kết nối của nền công nghiệp 4.0 sẽ cho phép khách hàng tham gia vào quá trình sản xuất thay vì chỉ là người tiếp nhận.*	1	2	3	4	5

II. Phần câu hỏi mở

1. Do you have any comments for the model TQM 4.0 above?

Các anh/ chị có đóng góp ý kiến gì cho mô hình TQM 4.0 ở trên?

Không

2. In addition to the above factors, what factors belong to the TQM 4.0 model in manufacturing enterprises that I have not mentioned (For example: your own way for application of TQM 4.0 in your company).

Ngoài các yếu tố trên, theo anh/ chị các yếu tố nào thuộc mô hình TQM 4.0 trong các doanh nghiệp sản xuất mà tôi chưa nhắc đến (Ví dụ như việc áp dụng cụ thể về TQM 4.0 trong doanh nghiệp của anh/ chị),

Cần đưa thêm câu hỏi về họp trực tuyến, sử dụng các công cụ trực tuyến trong làm việc. Hoặc nhân viên có thể sử dụng các phần mềm hỗ trợ để quản lý quy trình, quản lý chất lượng sản phẩm từ điện thoại của mình, có thể quản lý từ xa.

III. General information section *(Phần thông tin tổng quan)*

1. Please tell about the field of the company that you are working for:

Xin vui lòng cho biết về lĩnh vực hoạt động của công ty mà anh/ chị đang làm việc:

- ☐ Computer, electronic and optical products, electrical equipment (*Sản phẩm máy tính, điện tử và quang học, các thiết bị điện*)
- ☐ Paper and paper products (*Giấy và các sản phẩm từ giấy*)
- ☐ Textile and leather products (*Sản phẩm dệt da may mặc*)
- ☐ Chemicals and chemical products (*Hóa chất và sản phẩm hóa chất*)
- ☒ Wood products (*Sản phẩm gỗ*)
- ☐ Metal products, basic metals and fabricated metal products (*Sản phẩm kim loại, Kim loại cơ bản và các sản phẩm kim loại chế tạ*
- ☐ Food and foodstuff (*Lương thực và thực phẩm*)
- ☐ Beverages and tobacco (*Đồ uống và thuốc lá*)
- ☐ Motor vehicles, trailers and semi-trailers, other transport equipment (*Xe cơ giới, rơ moóc và sơ mi rơ moóc, các thiệt bị vận tải khác*)
- ☐ Rubber and plastic products (*Sản phẩm cao su và nhựa*)
- ☐ Medicinal and pharmaceutical products (*Các sản phẩm thuốc và dược phẩm*)
- ☐ Coke and refined petroleum (*Than cốc và dầu mỏ tinh chế*)
- ☐ Others (*Khác*)

2. Please tell about your position:

Xin vui lòng cho biết về vị trí anh/ chị đang làm việc:

- ☒ Company/factory manager (*Giám đốc công ty/ nhà máy*)
- ☐ Quatity manager (*Trưởng/ phó phòng chất lượng*)
- ☐ QA or QC manager (*Trưởng/ phó phòng QA/ QC*)
- ☐ QA or QC supervisor (*Giám sát QA/ QC*)
- ☐ Quality staff/engineer (*Nhân viên chất lượng*)
- ☐ Department manager (*Trưởng/ phó phòng*)
- ☐ Production manager (*Trưởng/ phó phòng sản xuất*)
- ☐ Production suppervior (*Giám sát sản xuất*)
- ☐ Production staff/engineer (*Nhân viên sản xuất*)

3. How many years do you work in the field of production/quality management?

Xin vui lòng cho biết số năm kinh nghiệm của anh/ chị trong lĩnh vực quản trị sản xuất/chất lượng?

☐ Under 5 years (*Dưới 5 năm*) ☐ 5-10 years (*5-10 năm*)

☒ 11-15 years (*11-15 năm*) ☐ 16-20 years (*16-20 năm*)

☐ Above 20 years (*Trên 20 năm*)

Thank you very much for your cooperation!

Xin chân thành cảm ơn sự cộng tác của anh/chị!

Appendix 2: Questionnaire of the Delphi round 2.

QUESTIONNAIRE

Bảng câu hỏi

My name is Nguyen Thi Anh Van, a lecturer at HCMC University of Technology and Education. I am also a PhD student at Tomas Bata University in Zlin, Czech Public. I invite you to join the survey because you answered the first round. Based on the first-round results, I adjust TQM 4.0 model and I hope the factors in adjusted TQM 4.0 will be confirmed in this survey. I am looking forward to receiving your comments on the model. I promise that the information you provide will be kept confidential and only used for the research process. I thank you very much for your answer.

Please rate the importance of the factors in the TQM 4.0 model that I have given by ticking (X) in the appropriate boxes with the following convention:

(1: least important; 2: less important; 3:moderately important; 4:more important; and 5:most important)

You rate the factors based on your knowledge and experiences to answer the question " What factors are important for the TQM 4.0 model?". This question is NOT evaluate the TQM 4.0 implementation in your company.

Tôi là Nguyễn Thị Anh Vân, hiện là giảng viên trường ĐH Sư phạm Kỹ thuật TP HCM. Anh/chị được mời tham gia cuộc khảo sát này vì anh/chị đã tham gia cuộc khảo sát lần 1 của tôi về mô hình TQM 4.0. Dựa vào kết quả cuộc khảo sát 1, mô hình của tôi đã có một vài sự thay đổi các yếu tố. Cuộc khảo sát này nhằm khẳng định lại các yếu tố trong mô hình TQM 4.0. Rất mong sẽ nhận được sự góp ý của quý anh/ chị cho mô hình mà tôi đang nghiên cứu. Tôi cam kết những thông tin quý anh/ chị cung cấp được bảo mật, chỉ phục vụ cho quá trình nghiên cứu. Tôi rất cảm ơn sự cộng tác của anh/ chị.

Mong anh/chị hãy đánh giá sự quan trọng của các yếu tố trong mô hình TQM 4.0 mà tôi đã đưa ra bằng cách đánh dấu (X) vào các ô thích hợp với qui ước sau:

(1: Rất ít quan trọng; 2: Ít quan trọng; 3:Quan trọng; 4:Rất quan trọng; 5:Hoàn toàn quan trọng)

Anh/ chị hãy đánh giá các yếu tố dựa trên kiến thức và kinh nghiệm của mình để trả lời câu hỏi "Yếu tố nào là quan trọng của mô hình TQM 4.0?". Câu hỏi này KHÔNG phải là đánh giá việc triển khai TQM 4.0 trong công ty của anh/chị.

	Factors (Các yếu tố)	**1**	**2**	**3**	**4**	**5**
	Top management (Sự lãnh đạo)					

1	In TQM 4.0 model, top managements need to commit for TQM 4.0 development. *Trong mô hình TQM 4.0, các quản lý cao nhất cần phải cam kết phát triển TQM 4.0*	**1**	**2**	**3**	**4**	**5**
2	In TQM 4.0 model, top managements need to involve for TQM 4.0 development. *Trong mô hình TQM 4.0, các quản lý cao nhất cần tham gia phát triển TQM 4.0*	**1**	**2**	**3**	**4**	**5**
3	In TQM 4.0 model, top managements need to provide resources for TQM 4.0 development. *Trong mô hình TQM 4.0, các quản lý cao nhất cần cung cấp các nguồn lực để phát triển TQM 4.0*	**1**	**2**	**3**	**4**	**5**
4	In TQM 4.0 model, top managements need to establish policy, strategic, objectives and indicators for TQM 4.0 *Trong mô hình TQM 4.0, các quản lý cao nhất cần thiết lập chính sách, chiến lược, mục tiêu và các chỉ tiêu cho TQM 4.0*	**1**	**2**	**3**	**4**	**5**
	Quality Culture 4.0 (Văn hóa chất lượng 4.0)					
1	TQM 4.0 should encourage employees self-leaders and to actively solving problems instead of waiting for regular processes. *TQM 4.0 nên khuyến khích nhân viên tự quản lý và chủ động giải quyết vấn đề thay vì chờ đợi quy trình thông thường.*	**1**	**2**	**3**	**4**	**5**
2	TQM 4.0 model should encourage employees empowerment in the organisation. *Mô hình TQM 4.0 nên khuyến khích trao quyền cho nhân viên trong tổ chức.*	**1**	**2**	**3**	**4**	**5**
3	TQM 4.0 should encourage individuals across the organization understand their roles in achieving quality goals *TQM 4.0 nên khuyến khích các cá nhân trong tổ chức hiểu rõ vai trò của họ trong việc đạt được các mục tiêu chất lượng*	**1**	**2**	**3**	**4**	**5**
4	In TQM 4.0 model, organisations will use digital media to articulate quality goals and objectives to all layers of the organisation. *Trong mô hình TQM 4.0, tổ chức sử dụng phương tiện kỹ thuật số để truyền đạt các mục tiêu chất lượng tại tất cả các cấp và bộ phận chức năng của tổ chức.*	**1**	**2**	**3**	**4**	**5**
	Skill 4.0					
1	In TQM 4.0 model, quality control staff should acquire more knowledge of skills related to data analytics *Trong mô hình TQM 4.0, nhân viên kiểm soát chất lượng (QC) cần có thêm các kỹ năng liên quan đến phân tích dữ liệu.*	**1**	**2**	**3**	**4**	**5**
2	In TQM 4.0 model, quality staff will spend less time in operative tasks such as inspections and more time problem-solving and preventive activities. *Trong mô hình TQM 4.0, nhân viên chất lượng sẽ dành ít thời gian hơn cho việc kiểm tra chất lượng sản phẩm mà dành nhiều thời gian hơn trong việc giải quyết vấn đề và đưa ra các hoạt động phòng ngừa.*	**1**	**2**	**3**	**4**	**5**
3	TQM 4.0 model requires employees apply digital tools and can tell data-driven stories *Mô hình TQM 4.0 yêu cầu nhân viên áp dụng các công cụ kỹ thuật số và có thể kể câu chuyện dựa trên dữ liệu.*	**1**	**2**	**3**	**4**	**5**
4	In TQM 4.0 model, creative thinking emphasises team activities in the design stage and QM activities.	**1**	**2**	**3**	**4**	**5**

	Trong mô hình TQM 4.0, tư duy sáng tạo được chú trọng trong các hoạt động nhóm ở giai đoạn thiết kế và các hoạt động quản trị chất lượng.					
	Smart organisation (Tổ chức thông minh)					
1	In TQM 4.0 model, top managements will support initiatives, spread organisational knowledge, and scale up successful innovations. *Trong mô hình TQM 4.0, các nhà quản lý cao nhất sẽ hỗ trợ các sáng kiến, truyền bá tri thức của tổ chức và mở rộng quy mô các đổi mới thành công.*	**1**	**2**	**3**	**~~4~~**	**~~5~~**
2	TQM 4.0 will rise to lean structures organisation which bring operational efficiencies and make decision making quicker by AI-based systems. *TQM 4.0 sẽ tạo ra cấu trúc tổ chức tinh gọn (lean structures organisation) mang lại hiệu quả hoạt động và giúp việc ra quyết định nhanh hơn nhờ các hệ thống dựa trên trí tuệ nhân tạo.*	**1**	**2**	**3**	**~~4~~**	**5**
3	TQM 4.0 tools will help improve communication from connectivity features and social networking, facilitating innovation and sharing ideas between production parties and stakeholders (such as: suppliers, patterners, customers, investors) *Các công cụ TQM 4.0 sẽ giúp cải thiện giao tiếp từ các tính năng kết nối và mạng xã hội, tạo điều kiện đổi mới và chia sẻ ý tưởng giữa sản xuất và các bên liên quan (chẳng hạn như nhà cung cấp, nhà thiết kế, khách hàng, nhà đầu tư)*	**1**	**2**	**3**	**4**	**~~5~~**
4	TQM 4.0 model will adapt fast-changing environment with exploration (external innovation such as innovation of products) and exploitation (innovation with an internal focus, for instance, on processes) *Mô hình TQM 4.0 sẽ thích ứng với môi trường thay đổi nhanh thông qua sự đổi mới cho bên ngoài (ví dụ đổi mới sản phẩm) và sự đổi mới cho bên trong (ví dụ đổi mới quy trình)*	**1**	**2**	**3**	**~~4~~**	**5**
5	TQM 4.0 model should promote the use of online tools in training, meetings, and work management. *Mô hình TQM 4.0 nên thúc đẩy sử dụng các công cụ trực tuyến trong đào tạo, họp hành, điều hành công việc.*	**1**	**2**	**3**	**~~4~~**	**5**
	Integrating sustainable development (Tích hợp phát triển bền vững)					
1	TQM 4.0 model needs to link quality and sustainability. *Mô hình TQM 4.0 cần gắn kết giữa chất lượng và tính bền vững*	**1**	**2**	**3**	**4**	**~~5~~**
2	TQM 4.0 model will focus on quality-based management for ready serving society *Mô hình TQM 4.0 sẽ tập trung vào quản lý dựa trên chất lượng để sẵn sàng phục vụ xã hội*	**1**	**2**	**3**	**~~4~~**	**5**
3	TQM 4.0 model need to develop operations in a more sustainable way *Mô hình TQM 4.0 cần phát triển hoạt động theo hướng bền vững hơn*	**1**	**2**	**3**	**4**	**~~5~~**
4	TQM 4.0 model need to integrate of environmental management systems. *Mô hình TQM 4.0 cần tích hợp các hệ thống quản lý môi trường.*	**1**	**2**	**3**	**~~4~~**	**5**

Technical factors						
	Automated document control (Kiểm soát tài liệu tự động)					
1	TQM 4.0 model need to integrate quality management documentation into ERP modules and automatic revision when products/processes change *Mô hình TQM 4.0 cần tích hợp tài liệu quản lý chất lượng vào các mô-đun ERP và tự động sửa đổi khi sản phẩm / quy trình thay đổi*	**1**	**2**	**3**	**4**	**5**
2	In TQM 4.0 model, using electronic documentation for Quality Management System is necessary. *Trong mô hình TQM 4.0, sử dụng tài liệu điện tử cho Hệ thống quản lý chất lượng là cần thiết.*	**1**	**2**	**3**	**4**	**5**
3	In TQM 4.0 model, work instructions are automated and controlled in real-time. *Trong mô hình TQM 4.0, hướng dẫn công việc được tự động hóa và kiểm soát trong thời gian thực.*	**1**	**2**	**3**	**4**	**5**
4	TQM 4.0 will provide digital standard operating procedures (SOPs) to ensure that workers have the most up-to-date instructions *TQM 4.0 sẽ cung cấp các quy trình vận hành tiêu chuẩn kỹ thuật số (digital SOP)để đảm bảo người lao động có các hướng dẫn cập nhật nhất.*	**1**	**2**	**3**	**4**	**5**
	Automatic data collection (Thu thập dữ liệu tự động)					
1	In TQM 4.0 model, data will be collected automatically throughout the product lifecycle using Cyber-Physical Systems, sensors, and IoT. *Trong mô hình TQM 4.0, dữ liệu sẽ được thu thập tự động trong suốt vòng đời sản phẩm bằng hệ thống không gian mạng thực-ảo(CPS) và các cảm biến được kết nối với Internet vạn vật (IoT).*	**1**	**2**	**3**	**4**	**5**
2	In TQM 4.0 model, many types of product-related data to be automatically collected (for example: quantity of nonconforming or scrap products, the number of labour and machine hours spent on reworks and the number of complaints and returned products, and etc.) *Trong mô hình TQM 4.0, nhiều loại dữ liệu liên quan đến sản phẩm được thu thập tự động (ví dụ như số lượng sản phẩm không phù hợp hoặc phế phẩm, số lượng lao động và giờ máy dành cho việc làm lại và số lượng khiếu nại và trả lại sản phẩm,..)*	**1**	**2**	**3**	**4**	**5**
3	In TQM 4.0 model, customer-related data such as product requirements, complaints and satisfaction levels to be collected automatically *Trong mô hình TQM 4.0, dữ liệu liên quan đến khách hàng được thu thập tự động (ví dụ: sản phẩm yêu cầu, khiếu nại và mức độ hài lòng,..)*	**1**	**2**	**3**	**4**	**5**

	Smart Quality Control (Kiểm soát chất lượng thông minh)					
1	TQM 4.0 model will allow real-time quality inspection. *TQM 4.0 sẽ cho phép kiểm tra chất lượng theo thời gian thực.*	1	2	3	4	5
2	TQM 4.0 model will allow total inspection instead of sample inspection. *TQM 4.0 sẽ cho phép kiểm tra chất lượng sản phẩm tổng thể thay vì kiểm tra rút mẫu*	1	2	3	4	5
3	In TQM 4.0 model, a new kind of SPC [statistical process control] based on machine learning predicts all kinds of defects during machining and gives feedback to the machine itself, automatically correcting its parameters without human interaction. *Trong mô hình TQM 4.0, SPC (kiểm soát quá trình bằng thống kê)sẽ dựa trên học máy (machine learning) để dự đoán tất cả các loại lỗi trong quá trình gia công và đưa ra phản hồi cho chính máy đó, tự động sửa các thông số của nó mà không cần sự tương tác của con người.*	1	2	3	4	5
4	In TQM 4.0 model, quality data are collected automatically from different processes and integrated with ERP modules such as the manufacturing execution system (MES) and the product life cycle management (PLM),… *Trong mô hình TQM 4.0,dữ liệu chất lượng được thu thập tự động từ các quy trình khác nhau và được tích hợp trong các mô-đun ERP như hệ thống thực thi sản xuất (MES) và quản lý vòng đời sản phẩm (PLM),..*	1	2	3	4	5
	Smart Quality Assurance (Đảm bảo chất lượng thông minh)					
1	TQM 4.0 model will use AI software for predictive maintenance in advance and preventive intervention to avoid downtime or system failure. *Mô hình TQM 4.0 sẽ sử dụng phần mềm trí tuệ nhân tạo (AI) để dự đoán trước và can thiệp phòng ngừa nhằm tránh thời gian chết hoặc lỗi hệ thống*	1	2	3	4	5
2	TQM 4.0 model will aid processes' optimisation, improve efficiency and resources allocation by using sensors at each production stage, and provide means to support quality activities that will minimise rework and scrape. *Mô hình TQM 4.0 sẽ hỗ trợ tối ưu hóa quy trình, cải thiện hiệu quả và phân bổ nguồn lực bằng cách sử dụng các cảm biến ở mỗi giai đoạn sản xuất và cung cấp các phương tiện để hỗ trợ các hoạt động chất lượng giúp giảm thiểu việc làm lại và phế phẩm.*	1	2	3	4	5
3	In the TQM 4.0 model, big-data analysis will collect real-time data generated during production and transform it into friendly useful information. *Trong mô hình TQM 4.0, việc phân tích dữ liệu lớn (big-data analysis) sẽ thu thập dữ liệu thời gian thực được tạo ra trong quá trình sản xuất, chuyển nó thành thông tin hữu ích.*	1	2	3	4	5
4	TQM 4.0 will be capable of making intelligent adjustments based on real-time data and maintain digital records.	1	2	3	4	5

	TQM 4.0 sẽ cung cấp khả năng thực hiện các điều chỉnh thông minh dựa trên dữ liệu thời gian thực và duy trì hồ sơ số (digital records).					
5	TQM 4.0 model will enhance machine learning (Machine Learning), machines will improve their performance using collected and stored data. *Mô hình TQM 4.0 sẽ tăng cường học máy (Machine Learning), máy móc sẽ cải thiện hiệu suất của chúng bằng cách sử dụng dữ liệu được thu thập và lưu trữ..*	1	2	3	4	5
	Smart product (Sản phẩm thông minh)					
1	TQM 4.0 model will support making accurate early predict market demand and consumption trends and changes. *Mô hình TQM 4.0 sẽ hỗ trợ đưa ra dự đoán sớm chính xác về nhu cầu thị trường cũng như những xu hướng và thay đổi tiêu dùng.*	1	2	3	4	5
2	In TQM 4.0 model, smart technologies can significantly assist companies in the identification and tracking of products. *Trong mô hình TQM 4.0,các công nghệ thông minh có thể hỗ trợ đáng kể các công ty trong việc xác định và theo dõi sản phẩm.*	1	2	3	4	5
3	In TQM 4.0 model, RFID technologies and smart sensors on products and packaging be used to identify and trace products. *Trong mô hình TQM 4.0, công nghệ RFID và cảm biến thông minh trên sản phẩm và bao bì được sử dụng để nhận diện và truy xuất nguồn gốc các sản phẩm.*	1	2	3	4	5
4	In TQM 4.0 model, industry 4.0 connectivity features will allow customers involvement in the production process rather than only being the recipient of it. *Trong mô hình TQM 4.0, các tính năng kết nối của nền công nghiệp 4.0 sẽ cho phép khách hàng tham gia vào quá trình sản xuất thay vì chỉ là người tiếp nhận.*	1	2	3	4	5

II. General information section *(Phần thông tin tổng quan)*

1. Please tell about your position:

Xin vui lòng cho biết về vị trí anh/ chị đang làm việc:

☐ Company/factory manager (*Giám đốc công ty/ nhà máy*)
☐ Quatity manager (*Trưởng/ phó phòng chất lượng*)
☐ QA or QC manager (*Trưởng/ phó phòng QA/ QC*)
☒ QA or QC supervisor (*Giám sát QA/ QC*)
☐ Quality staff/engineer (*Nhân viên chất lượng*)

☐ Department manager (*Trưởng/ phó phòng*)
☐ Production manager (*Trưởng/ phó phòng sản xuất*)
☐ Production suppervior (*Giám sát sản xuất*)
☐ Production staff/engineer (*Nhân viên sản xuất*)
☐ Academic specialists, researchers *(Giảng viên, nghiên cứu viên*)
☐ Consultants (*Tư vấn chất lượng*)
☐ Assessors (*Kiểm định chất lượng*)

2. How many years do you work in the field of production/quality management?

Xin vui lòng cho biết số năm kinh nghiệm của anh/ chị trong lĩnh vực quản trị sản xuất/chất lượng?

☐ Under 5 years (*Dưới 5 năm*) ☐ 5-10 years (*5-10 năm*)
☒ 11-15 years (*11-15 năm*) ☐ 16-20 years (*16-20 năm*)
☐ Above 20 years (*Trên 20 năm*)

Thank you very much for your answer!
Xin chân thành cảm ơn sự cộng tác của anh/chị!

Appendix 3: Questionnaire of the AHP method (part 1).

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
Top management							√				~~√~~							Quality Culture 4.0
Top management				√														Skill 4.0
Top management			√															Smart organisation
Top management				√														Integrating sustainable development
Top management	√																	Automated document control
Top management	√																	Automatic data collection
Top management	√																	Smart Quality Control
Top management	√																	Smart Quality Assurance
Top management		√																Smart product
Quality Culture 4.0				√														Skill 4.0
Quality Culture 4.0			~~√~~		√													Smart organisation
Quality Culture 4.0			√															Integrating sustainable development
Quality Culture 4.0		√																Automated document control
Quality Culture 4.0			√															Automatic data collection

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
Quality Culture 4.0			√															Smart Quality Control
Quality Culture 4.0				√														Smart Quality Assurance
Quality Culture 4.0	√																	Smart product
Skill 4.0									√									Smart organisation
Skill 4.0										√								Integrating sustainable development
Skill 4.0					√													Automated document control
Skill 4.0					√													Automatic data collection
Skill 4.0						√												Smart Quality Control
Skill 4.0						√												Smart Quality Assurance
Skill 4.0						√												Smart product
Smart organisation										√								Integrating sustainable development
Smart organisation						√												Automated document control
Smart organisation						√												Automatic data collection
Smart organisation								√										Smart Quality Control
Smart organisation								√										Smart Quality Assurance
Smart organisation							√											Smart product

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
Integrating sustainable development					√													Automated document control
Integrating sustainable development				√														Automatic data collection
Integrating sustainable development						√												Smart Quality Control
Integrating sustainable development							√											Smart Quality Assurance
Integrating sustainable development					√													Smart product
Automated document control									√									Automatic data collection
Automated document control											√							Smart Quality Control
Automated document control												√						Smart Quality Assurance
Automated document control														√				Smart product
Automatic data collection												√						Smart Quality Control
Automatic data collection														√				Smart Quality Assurance
Automatic data collection										√								Smart product
Smart Quality Control													√					Smart Quality Assurance
Smart Quality Control									√									Smart product
Smart Quality Assurance								√										Smart product

Appendix 4: Questionnaire of the AHP method (part 2).

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
In "Top management"																		
Top managements commitment			✓								~~✓~~							Top managements involvement
Top managements commitment					✓										~~✓~~			Top managements provide resources
Top managements commitment							✓				~~✓~~							Top managements establish policy, objectives and indicators
Top managements involvement										✓								Top managements provide resources
Top managements involvement											✓							Top managements establish policy, objectives and indicators
Top managements provide resources											✓							Top managements establish policy, objectives and indicators
In "Quality culture 4.0"																		
Quality-driven mindfulness								✓										Employees empowerment
Quality-driven mindfulness										✓								Individuals understanding of their role in achieving quality goals
Quality-driven mindfulness													✓					Quality articulation

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
Employees empowerment											✓							Individuals understanding of their role in achieving quality goals
Employees empowerment															✓			Quality articulation
Individuals understanding of their role in achieving quality goals											✓							Quality articulation
In "Skill 4.0"																		
Skills related to analytics, AI, CPS							✓											Digital skills for quality staff
Skills related to analytics, AI, CPS								✓										Digital communication skill
Skills related to analytics, AI, CPS			✓															Team creativity
Digital skills for quality staff								✓										Digital communication skill
Digital skills for quality staff					✓													Team creativity
Digital communication skill						✓												Team creativity

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
									In "Smart organisation "									
Top managements support initiatives												√						Lean structure organisation
Top managements support initiatives											√							Collaboration all stakeholders
Top managements support initiatives													√					Adapitility in fast-changing environment
Top managements support initiatives																	√	Application online tools in training, meetings, and work management
Lean structure organisation								√										Collaboration all stakeholders
Lean structure organisation											√							Adapitility in fast-changing environment
Lean structure organisation													√					Application online tools in training, meetings, and work management
Collaboration all stakeholders										√								Adapitility in fast-changing environment
Collaboration all stakeholders												√						Application online tools in training, meetings, and work management
Adapitility in fast-changing environment									√									Application online tools in training, meetings, and work management

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
In "Integrating sustainable development "																		
Link quality and sustainability										✓								Corporations serving society
Link quality and sustainability											✓							Operations in a more sustainable way
Link quality and sustainability													✓					Integration of environmental management systems
Corporations serving society									✓									Operations in a more sustainable way
Corporations serving society												✓						Integration of environmental management systems
Operations in a more sustainable way											✓							Integration of environmental management systems
In "Automated document control "																		
Integration of documentation into ERP modules							✓											Electronic documentation
Integration of documentation into ERP modules											✓							Real-time document control
Integration of documentation into ERP modules					✓													Digital standard operating procedures (SOPs)
Electronic documentation													✓					Real-time document control

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
Electronic documentation							✓											Digital standard operating procedures (SOPs)
Real-time document control			✓															Digital standard operating procedures (SOPs)
In "Automatic data collection "																		
Automatic collection of data throughout the product lifecycle													✓					Automatic collect many types of product-related data
Automatic collection of data throughout the product lifecycle											✓							Automatic collect many types of customer-related data
Automatic collect many types of product-related data								✓										Automatic collect many types of customer-related data
In "Smart Quality Control "																		
Real-time quality inspection					✓													Total inspection
Real-time quality inspection							✓											A new kind of SPC based on machine learning
Real-time quality inspection			✓															Data integration with enterprise resource planning
Total inspection											✓							A new kind of SPC based on machine learning

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
Total inspection								✓										Data integration with enterprise resource planning
A new kind of SPC based on machine learning						✓												Data integration with enterprise resource planning
In "Smart Quality Assurance "																		
Using AI software for prediction and prevention					✓													Using sensors at each production stage
Using AI software for prediction and prevention								✓										Big-data analysis
Using AI software for prediction and prevention			✓															Making intelligent adjustments
Using AI software for prediction and prevention							✓											Machine Learning enhancement
Using sensors at each production stage											✓							Big-data analysis
Using sensors at each production stage								✓										Making intelligent adjustments
Using sensors at each production stage										✓								Machine Learning enhancement
Big-data analysis					✓													Making intelligent adjustments
Big-data analysis							✓											Machine Learning enhancement

A Options	9. Extremly	8	7. Very	6	5. Strongly	4	3. Moderately	2	1. Equally	2	3. Moderately	4	5. Strongly	6	7. Very	8	9. Extremly	B Options
Making intelligent adjustments											✓							Machine Learning enhancement
In" Smart product "																		
Predict market demand and consumption trends															✓			Smart technologies for identification and traceability
Predict market demand and consumption trends													✓					RFID technologies and smart sensors
Predict market demand and consumption trends											✓							Customers involvement in the production process
Smart technologies for identification and traceability							✓											RFID technologies and smart sensors
Smart technologies for identification and traceability					✓													Customers involvement in the production process
RFID technologies and smart sensors							✓											Customers involvement in the production process

Appendix 5: Questionnaire of the TQM 4.0 practices and Sustainable Excellence.

QUESTIONNAIRE

My name is Nguyen Thi Anh Van, a lecturer at HCMC University of Technology and Education. I am also a PhD student at Tomas Bata University in Zlin, Czech Public. I am investigating on Total Quality Management model in the industry 4.0 context (TQM 4.0) and Sustainable Excellence in manufacturing sector. I am looking forward to receiving your answer about TQM 4.0 practice in your organisation. I promise that the information you provide will be kept confidential and only used for the research process. Thank you very much for your answer.

Tôi là Nguyễn Thị Anh Vân, hiện là giảng viên trường ĐH Sư phạm Kỹ thuật TP HCM. Hiện tôi đang nghiên cứu về mô hình quản trị chất lượng toàn diện trong Công nghiệp 4.0 (gọi tắt là TQM 4.0) và sự xuất sắc bền vững tại các doanh nghiệp sản xuất. Rất mong sẽ nhận được sự trả lời của quý anh/ chị việc thực hiện TQM 4.0 trong doanh nghiệp anh/chị. Tôi cam kết những thông tin quý anh/ chị cung cấp được bảo mật, chỉ phục vụ cho quá trình nghiên cứu. Tôi rất cảm ơn sự cộng tác của anh/ chị.

1. Please provide some information about TQM practice in your organisation? Please tick (X) the box that is correct.

Hãy cho biết một số thông tin về áp dụng TQM trong tổ chức của bạn? Hãy đánh dấu (X) vào ô đúng.

Your company has applied: *(Công ty của bạn đã áp dụng:)*

☒ ISO 9001 standard *(Tiêu chuẩn ISO 9001)*

☐ ISO 14001 standard *(Tiêu chuẩn ISO 14001)*

☐ Other quality management standards such as: ISO 22001, HACCP, GMP,…
(Các tiêu chuẩn quản lý chất lượng khác như: ISO 22001, HACCP, GMP,...)

☒ Quality methods such as: Kaizen, or 6 sigma, or Benchmarking, or Lean,…
(Các phương pháp chất lượng như: Kaizen, hoặc 6 sigma, hoặc Benchmarking, hoặc Lean,...)

☒ Quality tools as: statistical process control (SPC), failure mode and effects analysis (FMEA),…
(Các công cụ chất lượng như: kiểm soát quá trình thống kê (SPC), FMEA,...)

☒ Quality control and assurance for productions
(Kiểm soát và đảm bảo chất lượng trong quá trình sản xuất)

If your organisation does not apply any activities of total quality management, the survey ends here. If you choose any of the options above, please continue the survey. Thank you very much.

Nếu công ty anh/chị không áp dụng bất kỳ hoạt động nào của quản lý chất lượng toàn diện, cuộc khảo sát sẽ kết thúc tại đây. Nếu anh/chị chọn bất kỳ tùy chọn nào ở trên, vui lòng tiếp tục khảo sát. Cảm ơn anh/chị rất nhiều.

2. Please provide some information about application of Industry 4.0 tools into TQM practice in your organisation? Please tick (X) the box that is correct.

Anh/chị hãy cho biết một vài thông tin về sự áp dụng các công cụ của công nghiệp 4.0 vào hoạt động TQM trong công ty anh/chị? Xin hãy tích (X) vào ô mà anh/chị thấy đúng.

Your company has applied new technologies in production and quality management such as:

(*Trong công ty anh/chị có áp dụng các công nghệ mới trong quản trị sản xuất, chất lượng như:)*

☐ Cyber-Physical Systems (CPS), and Internet of Things (IoT)
☒ Automatic data collection *(Thu thập dữ liệu tự động)*
☒ Online tools in training, meetings, and work management (*Các công cụ online trong đào tạo, họp, quản lý công việc*)
☐ Artificial Intelligence (AI) or Machine Learning (*Trí tuệ nhân tạo hoặc học máy*)
☐ Big-data analysis (*Phân tích dữ liệu lớn*)
☒ RFID technology and smart sensors (*Công nghệ RFID và cảm biến thông minh*)

If your organisation does not apply any tools of industry 4.0 in production/quality management, the survey ends here. If you choose any of the options above, please continue the survey. Thank you very much.

Nếu công ty anh/ chị không áp dụng bất kỳ công cụ nào của công nghiệp 4.0 trong quản trị sản xuất/ chất lượng thì cuộc khảo sát đến đây kết thúc. Nếu anh/chị chọn bất kỳ tùy chọn nào ở trên thì xin mời tiếp tục cuộc khảo sát. Cảm ơn anh/chị rất nhiều.

I- TQM 4.0 practices

The following statements relate to TQM 4.0 implementation of your company, please indicate your level of agreement (1= strongly disagree, 5= strongly agree).

Các phát biểu sau đây liên quan đến việc áp dụng TQM 4.0 của công ty bạn, vui lòng cho biết mức độ đồng ý của bạn (1 = rất không đồng ý, 5 = rất đồng ý).

	Top management In my organisation … (*Trong công ty tôi)*					
1	Top managements commit for TQM 4.0 development. *Các quản lý cấp cao cam kết phát triển TQM 4.0*	1	2	3	4	5
2	Top managements involve in TQM 4.0 development. *Các quản lý cấp cao tham gia phát triển TQM 4.0*	1	2	3	4	5
3	Top managements provide resources for TQM 4.0 development. *Các quản lý cấp cao cung cấp các nguồn lực để phát triển TQM 4.0*	1	2	3	4	5
4	Top managements establish policy, strategic, objectives and indicators for TQM 4.0. *Các quản lý cấp cao thiết lập chính sách, chiến lược, mục tiêu và các chỉ tiêu cho TQM 4.0*	1	2	3	4	5
	Quality culture 4.0 In my organisation … *(trong công ty tôi...)*					
1	Employees are encouraged to be self-leaders and to actively solve problems instead of waiting for regular processes. *Nhân viên được khuyến khích tự quản lý và chủ động giải quyết vấn đề thay vì chờ đợi quy trình thông thường.*	1	2	3	4	5
2	Employees are empowered *Nhân viên được trao quyền*	1	2	3	4	5
3	Employees understand their roles in achieving quality goals *Nhân viên hiểu rõ vai trò của họ trong việc đạt được các mục tiêu chất lượng*	1	2	3	4	5
4	Quality goals and objectives are delivered by using digital media *Các mục tiêu chất lượng được truyền đạt bằng các phương tiện kỹ thuật số*	1	2	3	4	5
	Skill 4.0 In my organisation …*(Trong công ty tôi...)*					
1	Quality staffs gain more knowledge and skills related to data analytics *Nhân viên chất lượng có thêm các kiến thức và kỹ năng liên quan đến phân tích dữ liệu.*	1	2	3	4	5
2	Quality staffs apply digital tools for telling data-driven stories.	1	2	3	4	5

	Nhân viên chất lượng áp dụng các công cụ kỹ thuật số để kể những câu chuyện dựa vào dữ liệu.					
3	Employees apply digital communication tools such as email, video calls, and social networks. *Nhân viên áp dụng các công cụ giao tiếp kỹ thuật số như email, cuộc gọi video và mạng xã hội.*	1	2	3	4	5
4	Team creativity skill is emphasised in the design stage and QM activities. *Kỹ năng sáng tạo nhóm được nhấn mạnh trong giai đoạn thiết kế và các hoạt động quản trị chất lượng*	1	2	3	4	5
	Smart organisation In my organisation ...*(Trong công ty tôi...)*					
1	Top managements support initiatives and innovations. *Các nhà quản lý cấp cao hỗ trợ các sáng kiến các đổi mới.*	1	2	3	4	5
2	AI-based systems are used to lean structures to bring operational efficiencies and make decision making quicker. *Các hệ thống dựa trên AI được sử dụng để tinh gọn cấu trúc nhằm mang lại hiệu quả hoạt động và đưa ra quyết định nhanh hơn.*	1	2	3	4	5
3	TQM 4.0 tools improve the collaboration of all stakeholders *Các công cụ TQM 4.0 cải thiện sự hợp tác của tất cả các bên liên quan*	1	2	3	4	5
4	The ability for adapting into fast-changed environment is improved *Khả năng thích ứng với môi trường thay đổi nhanh được cải thiện.*	1	2	3	4	5
5	Online tools are promoted in training, meetings, and work management. *Các công cụ trực tuyến được phát huy trong đào tạo, họp và quản lý công việc.*	1	2	3	4	5
	Integrating sustainable development In my organisation ...*(Trong công ty tôi...)*					
1	TQM 4.0 and sustainability are linked. *TQM 4.0 và tính bền vững được gắn kết với nhau.*	1	2	3	4	5
2	TQM 4.0 includes policies to serve society *TQM 4.0 bao gồm các hoạt động nhằm phục vụ xã hội*	1	2	3	4	5
3	TQM 4.0 develops operations in a more sustainable way *TQM 4.0 phát triển các hoạt động theo hướng bền vững hơn*	1	2	3	4	5
4	TQM 4.0 integrates environmental management systems. *TQM 4.0 tích hợp các hệ thống quản lý môi trường.*	1	2	3	4	5

Technical factors						
	Automated document control In my organisation …*(Trong công ty tôi...)*					
1	Quality management documentations are integrated into ERP modules and automatic revision when products/processes change *Các tài liệu quản lý chất lượng được tích hợp vào các mô-đun ERP và tự động sửa đổi khi sản phẩm / quy trình thay đổi*	1	2	3	4	5
2	Quality Management System uses electronic documentation *Hệ thống quản lý chất lượng sử dụng tài liệu điện tử*	1	2	3	4	5
3	Work instructions are automated and controlled in real-time. *Các hướng dẫn công việc được tự động hóa và kiểm soát theo thời gian thực.*	1	2	3	4	5
4	Digital standard operating procedures (SOPs) are provided *Các quy trình vận hành tiêu chuẩn kỹ thuật số (sops số) được cung cấp*	1	2	3	4	5
	Automatic data collection In my organisation …*(Trong công ty tôi...)*					
1	We collect data automatically throughout the product lifecycle using Cyber-Physical Systems, sensors, and IoT. *Chúng tôi thu thập dữ liệu tự động trong suốt vòng đời sản phẩm bằng Hệ thống thực tế ảo, cảm biến và IoT.*	1	2	3	4	5
2	We collect automatically many types of product-related data *Chúng tôi tự động thu thập nhiều loại dữ liệu liên quan đến sản phẩm*	1	2	3	4	5
3	We collect automatically customer-related data such as product requirements, complaints and satisfaction levels *Chúng tôi tự động thu thập dữ liệu liên quan đến khách hàng như yêu cầu sản phẩm, khiếu nại và mức độ hài lòng.*	1	2	3	4	5
	Smart quality control In my organisation … *(trong công ty tôi...)*					
1	TQM 4.0 allows real-time quality inspection. *TQM 4.0 cho phép kiểm tra chất lượng theo thời gian thực*	1	2	3	4	5
2	TQM 4.0 allows total inspection instead of sample inspection. *TQM 4.0 cho phép kiểm tra chất lượng sản phẩm tổng thể thay vì kiểm tra rút mẫu*	1	2	3	4	5
3	A new kind of SPC [statistical process control] based on machine learning predicts all kinds of defects during machining and gives feedback.	1	2	3	4	5

	SPC (kiểm soát quá trình bằng thống kê) dựa trên học máy (machine learning) để dự đoán tất cả các loại lỗi trong quá trình gia công và đưa ra phản hồi.					
4	Quality data is automatically collected from different processes and integrated with ERP modules *Dữ liệu chất lượng được thu thập tự động từ các quy trình khác nhau và được tích hợp trong các mô-đun ERP.*	1	2	3	4	5
	Smart quality assurance In my organisation …*(trong công ty tôi…)*					
1	TQM 4.0 model uses AI software for predictive maintenance in advance and preventive intervention to avoid downtime or system failure. *TQM 4.0 sử dụng phần mềm trí tuệ nhân tạo (AI) để dự đoán trước và can thiệp phòng ngừa nhằm tránh thời gian chết hoặc lỗi hệ thống*	1	2	3	4	5
2	We use sensors at each production stage to aid process optimisation, improve efficiency and resource allocation. *Chúng tôi sử dụng các cảm biến ở mỗi giai đoạn sản xuất để hỗ trợ tối ưu hóa quy trình, cải thiện hiệu quả và phân bổ nguồn lực.*	1	2	3	4	5
3	We use big-data analysis to collect real-time production data and transform it into useful information. *Chúng tôi sử dụng phân tích dữ liệu lớn để thu thập dữ liệu sản xuất theo thời gian thực và chuyển nó thành thông tin hữu ích.*	1	2	3	4	5
4	We can make intelligent adjustments based on real-time data and maintain digital records. *Chúng tôi có khả năng thực hiện các điều chỉnh thông minh dựa trên dữ liệu thời gian thực và duy trì hồ sơ số (digital records).*	1	2	3	4	5
5	We use Machine Learning to improve machine performance using collected and stored data. *Chúng tôi sử dụng học máy (Machine Learning) để cải thiện hiệu suất máy móc bằng cách sử dụng dữ liệu được thu thập và lưu trữ.*	1	2	3	4	5
	Smart product In my organisation …*(Trong công ty tôi…)*					
1	We make accurate predictions of market demand and consumption trends and changes. *Chúng tôi đưa ra dự đoán sớm chính xác về nhu cầu thị trường cũng như những xu hướng thay đổi tiêu dùng.*	1	2	3	4	5

2	We use smart technologies to assist in identifying and tracking products. *Chúng tôi sử dụng công nghệ thông minh để hỗ trợ trong việc xác định và theo dõi sản phẩm.*	1	2	3	4	5
3	We use RFID technologies and smart sensors on products and packaging to identify and trace products. *Chúng tôi sử dụng công nghệ RFID và cảm biến thông minh trên sản phẩm và bao bì để nhận diện và truy xuất nguồn gốc các sản phẩm.*	1	2	3	4	5
4	We allow customers to be involved in the production process rather than only recipients. *Chúng tôi cho phép khách hàng tham gia vào quá trình sản xuất thay vì chỉ người nhận.*	1	2	3	4	5

II. Digital Transformation (Chuyển đổi số)

The following statements relate to Digital Transformation of your company, please indicate your level of agreement. (1= strongly disagree, 5= strongly agree)

Các phát biểu sau đây liên quan đến Chuyển đổi số của công ty anh/chị, vui lòng cho biết mức độ đồng ý của anh/chị (1 = hoàn toàn không đồng ý, 5 = hoàn toàn đồng ý)

	Digital Transformation In my organisation ...*(Trong công ty tôi...)*					
1	We aim to digitise anything that can be digitalised. *Chúng tôi đặt mục tiêu số hóa bất cứ thứ gì có thể được số hóa.*	1	2	3	4	5
2	We collect big quantities of data from many sources. *Chúng tôi thu thập một lượng lớn dữ liệu từ nhiều nguồn*	1	2	3	4	5
3	We aim to establish more robust digital networking between the various business processes. *Chúng tôi đặt mục tiêu thiết lập mạng kỹ thuật số mạnh mẽ hơn giữa các quy trình kinh doanh.*	1	2	3	4	5
4	We aim to use digital technology to improve client interface efficiency. *Chúng tôi hướng tới việc sử dụng công nghệ kỹ thuật số để cải thiện hiệu quả giao diện khách hàng.*	1	2	3	4	5
5	We aim to achieve information exchange through digitalisation. *Chúng tôi mong muốn đạt được sự trao đổi thông tin thông qua số hóa.*	1	2	3	4	5

III. Digital Leadership

The following statements relate to Digital Leadership of your company, please indicate your level of agreement. (1= strongly disagree, 5= strongly agree)
Các phát biểu sau đây liên quan đến Kỹ năng lãnh đạo số của công ty anh/chị, vui lòng cho biết mức độ đồng ý của anh/chị (1 = hoàn toàn không đồng ý, 5 = hoàn toàn đồng ý)

	Digital Leadership In my organisation ...*(Trong công ty tôi...)*					
1	Our leaders motivate all members with the organisation's digital transformation plans. *Các nhà lãnh đạo của chúng tôi thúc đẩy tất cả các thành viên bằng các kế hoạch chuyển đổi kỹ thuật số của tổ chức.*	1	2	3	4 (X)	5
2	Our leaders give a clear vision of digital transformation for employees to follow. *Các nhà lãnh đạo của chúng tôi đưa ra tầm nhìn rõ ràng về chuyển đổi kỹ thuật số để nhân viên làm theo.*	1	2	3 (X)	4	5
3	Our leaders inspire team members to collaborate towards the same digital transformation objectives. *Các nhà lãnh đạo của chúng tôi truyền cảm hứng cho các thành viên trong nhóm hợp tác hướng tới cùng một mục tiêu chuyển đổi kỹ thuật số.*	1	2	3 (X)	4	5
4	Our leaders consider the digital transformation beliefs of all members when making decisions. *Các nhà lãnh đạo của chúng tôi xem xét niềm tin chuyển đổi kỹ thuật số của tất cả các thành viên khi đưa ra quyết định.*	1	2	3	4 (X)	5
5	Our leaders encourage all members to consider ideas for digital transformation. *Các nhà lãnh đạo của chúng tôi khuyến khích tất cả các thành viên xem xét các ý tưởng để chuyển đổi kỹ thuật số.*	1	2	3 (X)	4	5

IV. Sustainable Excellence

The following statements relate to Sustainable Excellence of your company, please indicate your level of agreement. (1= strongly disagree, 5= strongly agree)
Các phát biểu sau đây liên quan đến Sự xuất sắc bền vững của công ty anh/chị, vui lòng cho biết mức độ đồng ý của anh/chị (1 = hoàn toàn khôn đồng ý, 5 = hoàn toàn đồng ý)

	Environmental performance (EP) For the last four years (excluding the period of Covid 19), in my organisation…. *Trong bốn năm qua (không kể giai đoạn Covid 19), trong công ty tôi….*					
1	Air emissions has been reduced *Lượng khí thải giảm*	1	2	3	4	5
2	Wastewater has been reduced *Lượng nước thải giảm*	1	2	3	4	5
3	Solid waste has been reduced *Chất thải rắn giảm*	1	2	3	4	5
4	Consumption of hazardous/harmful materials has been reduced *Sự tiêu thụ các nguyên vật liệu nguy hiểm, có hại giảm.*	1	2	3	4	5
5	Environmental issues have been improved *Các vấn đề môi trường được cải thiện*	1	2	3	4	5
	Operational performance (OP) For the last four years (excluding the period of Covid 19), in my organisation…. *Trong bốn năm qua (không kể giai đoạn Covid 19), trong công ty tôi….*					
1	Production cost has been reduced *Chi phí sản xuất giảm*	1	2	3	4	5
2	Labour productivity has been increased	1	2	3	4	5

	Năng suất lao động tăng					
3	Product performance (sales volume /revenues) has been increased *Hiệu suất sản phẩm (khối lượng bán hàng /doanh thu) tăng.*	**1**	**2**	**3**	**4**	**5**
	Social performance (SP) For the last four years (excluding the period of Covid 19), in my organisation…. *Trong bốn năm qua (không kể giai đoạn Covid 19), trong công ty tôi….*					
1	In general, our employees are satisfied with their job *Nhìn chung, nhân viên của chúng tôi hài lòng với công việc của họ*	**1**	**2**	**3**	**4**	**5**
2	The amount of stress at work has been decreased *Mức độ căng thẳng trong công việc giảm*	**1**	**2**	**3**	**4**	**5**
3	Health and safety incidents have been decreased *Các sự cố về sức khỏe và an toàn giảm*	**1**	**2**	**3**	**4**	**5**
4	Injuries and lost days related to injuries have been decreased *Số ngày bị thương và số ngày mất việc liên quan đến chấn thương giảm*	**1**	**2**	**3**	**4**	**5**
	Innovation performance (IP) For the last four years (excluding the period of Covid 19), in my organisation…. *Trong bốn năm qua (không kể giai đoạn Covid 19), trong công ty tôi….*					
1	New products/services have been added new features *Sản phẩm / dịch vụ mới đã được bổ sung các tính năng mới*	**1**	**2**	**3**	**4**	**5**
2	Many new products/services have been introduced *Nhiều sản phẩm / dịch vụ mới đã được giới thiệu*	**1**	**2**	**3**	**4**	**5**
3	New technology has been adopted early *Công ty tôi áp dụng công nghệ mới sớm.*	**1**	**2**	**3**	**4**	**5**
4	Business model innovation has been applied for adapting into agile environment *Đổi mới mô hình kinh doanh đã được áp dụng để thích ứng với môi trường thay đổi nhanh chóng.*	**1**	**2**	**3**	**4**	**5**

V- **General information section** *(Phần thông tin tổng quan)*

4. ***Please tell about the field of the company that you are working for:***

Xin vui lòng cho biết về lĩnh vực hoạt động của công ty mà anh/ chị đang làm việc:

- [x] Computer, electronic and optical products, electrical equipment (*Sản phẩm máy tính, điện tử và quang học, các thiết bị điện*)
- [ ] Paper and paper products (*Giấy và các sản phẩm từ giấy*)
- [ ] Textile and leather products (*Sản phẩm dệt da may mặc*)
- [ ] Chemicals and chemical products (*Hóa chất và sản phẩm hóa chất*)
- [ ] Wood products (*Sản phẩm gỗ*)
- [ ] Metal products, basic metals and fabricated metal products (*Sản phẩm kim loại, Kim loại cơ bản và các sản phẩm kim loại chế tạo*)
- [ ] Food and foodstuff (*Lương thực và thực phẩm*)
- [ ] Beverages and tobacco (*Đồ uống và thuốc lá*)
- [ ] Motor vehicles, trailers and semi-trailers, other transport equipment (*Xe cơ giới, rơ moóc và sơ mi rơ moóc, các thiệt bị vận tải khác*)
- [ ] Rubber and plastic products (*Sản phẩm cao su và nhựa*)
- [ ] Medicinal and pharmaceutical products (*Các sản phẩm thuốc và dược phẩm*)
- [ ] Coke and refined petroleum (*Than cốc và dầu mỏ tinh chế*)
- [ ] Others (*Khác*)

5. **Please tell about your position:**

Xin vui lòng cho biết về vị trí anh/ chị đang làm việc:

☐ Company Director/ Vice-Director
☐ Quality/Production manager
☐ Purchasing/ procurement manager
☐ Company/factory manager
☒ Quality/Production supervior
☐ Logistics/Distribution manager

6. How many years do you work in manufacturing enterprises?

☐ Under 5 years
☒ 5-10 years
☐ 11-15 years
☐ 16-20 years
☐ Above 20 years

Thank you very much for your answer!

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)*

Jimp/ Scopus articles: ***(under review)***

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)*

Conference articles:

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.
2. Thi Thu Hong Nguyen, Khac-Hieu Nguyen, **Thi Anh Van Nguyen** (2021); *Innovation in tourism sector: a bibliometric analysis of publications*; The 4th Conference on Economics, Business, and Tourism (4th CEBT-2021) in Ho Chi Minh City, Vietnam during July 17, 2021, ISBN: 978-604-73-8449-5
3. Tam Minh Nguyen, Phuong Thi Lan Nguyen, **Van Thi Anh Nguyen** (2021); *Organic food purchase behavior: In the light of the theory of planned behavior, does pro-social attitude matter*? Proceedings of the 15th International Scientific Conference INPROFORUM,15-19
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

AUTHOR'S CURRICULUM VITAE

1. Personal information

Full name: Thi Anh Van Nguyen.

Address: 63/18/3, Street 6, Linh Tay ward, Thu Duc, Ho Chi Minh City, Vietnam

Present status: PhD Candidate, Tomas Bata University in Zlin, Czech Republic

Email: t5nguyen@utb.cz

2. Education

2020 – ongoing: Ph.D candidate at Tomas Bata University in Zlin, Czech Republic

2012-2014: Master degree at University of Economics HCMC

2006-2010: Bachelor degree at University of Economics HCMC

3. Work Experience

2010 – ongoing : Lecturer at Faculty of Economics, HCMC University of Technology and Education.

2017– ongoing : Research collaborator at Institute of Development Economics Research, University of Economics HCMC.

4. Research activities at FaME, TBU in Zlin

- Internal Grant Agency (IGA) in Tomas Bata University in Zlin, the Czech Republic, under projects No. IGA/FAME/ 2021/009:

The result is a conference paper and presentation in the conference: Thi Anh Van Nguyen; David Tuček; Khac-Hieu Nguyen; *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.

- International PhD seminar in context of project Interreg V-A SK-CZ/MPRV:

The result is a conference paper and presentation in the conference: 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.

- The project VaV-IP-RO/2020/01 "Research of parametric dependencies of selected parameters of production processes for setting up a model of digitisation, monitoring and evaluation of process data in real time as part of the implementation of the Industry 4.0 concept" in Tomas Bata University in Zlin, the Czech Republic:

The result is a paper in SSCI journal: Thi Anh Van Nguyen, David Tucek & Nhat Tan Pham (2022): *Indicators for TQM 4.0 model: Delphi Method and Analytic Hierarchy Process (AHP) analysis*, Total Quality Management & Business Excellence.

- The Internal Grant Agency of FaME, Tomas Bata University in Zlín no.IGA/FaME/2022/006 Investigation of the current economic topics in the Southeast Asia region.

The result are a conference paper and a paper in Scopus jounal:

Tam Minh Nguyen, Phuong Thi Lan Nguyen, **Van Thi Anh Nguyen** (2021); *Organic food purchase behavior: In the light of the theory of planned behavior, does pro-social attitude matter?* Proceedings of the 15th International Scientific Conference INPROFORUM,15-19 (presented).

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

Thi Anh Van Nguyen

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Doctoral Thesis

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