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Indicators for TQM 4.0 model: Delphi Method and Analytic Hierarchy Process (AHP) analysis

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Anchoring on Socio-technical system (STS) theory, this study applied Delphi and analytic hierarchy process (AHP) techniques to explore the key factors and specific indicators of the TQM 4.0 model implementation in manufacturing enterprises. An analysis of two Delphi rounds through experts who are academia, consultants, and production/quality supervisors/managers found ten factors and 41 indicators. In the third round, the study weighted the importance of each factor and indicator through an analysis of the AHP technique. The research suggested that social factors were more important than technical factors. Importantly, the findings indicated three key factors of the TQM 4.0 model, including top management, quality culture 4.0, and integrating sustainable development. Furthermore, the study revealed that top management commitment, quality-driven mindfulness, and employee empowerment were specified as the most critical indicators of the TQM 4.0 model. Results could be valuable for both researchers and practitioners in assessing TQM 4.0 implementation in the manufacturing sector in the future .

Keywords: TQM 4.0 model; Socio-technical system theory; Delphi method; Analytic Hierarchy Process (AHP)

1. Introduction

Researches have been attempting to build the TQM 4.0 model (some named as Quality 4.0) by applying the technical tools of Industry 4.0 to the TQM system (Chiarini & Kumar, 2021; Sony et al., 2020). However, most of the studies give general themes without fulfilling indicators for the TQM 4.0 model and use the literature review method instead of investigating it practically (Park et al., 2017; Sader et al., 2021). Few studies have used a quantitative method to assess Quality 4.0 based on 9004:2008 by Glogovac et al. (2020). Though the limitation of this research encompasses inflexibility in model adjustment since the original ISO scheme was used, and research carried out common to all manufacturing and service industries. Glogovac et al. (2020) proposed that further research on this topic could lead to more profound insight into the important level of individual items on other constructs, explore all the indicators within one factor and take into account different organisational contexts. Recently, Chiarini and Kumar (2021) tried to explore the main theme of Quality 4.0 by sequential mixed methods. However, this research only stopped at the main theme without providing a set of fulfilling indicators for each theme. It is necessary to have a set of indicators for researchers and practitioners to operate and evaluate the TQM 4.0 application in a specific field.

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A concern is that traditional TQM focuses on standardisation and stability while Industry 4.0 focuses on technical tools, so the role of human beings in the system seems to be muted. The framework based on socio-technical system (STS) theory will solve the issue. STS encourages flexibility, high degree of autonomy, and extent of empowerment given to employees. It is a perfect complement to rigid traditional TQM and technology tools of Industry 4.0. Manz and Stewart (1997) expressed the combination of STS and TQM to gain organisational stability and flexibility simultaneously. Chaudhuri & Jayaram (2019) also suggested that STS be considered as an appropriate theoretical foundation to research the impacts of social and technical integration on quality and sustainability management. With the Industry 4.0 development, STS is a remedy for scholars to combine with Industry 4.0 for sustainable implementation. Sony and Naik (2020) proposed the STS theory while designing the implementation of Industry 4.0. Therefore, exploring the TQM 4.0 model based on the STS theory will be suitable to create the TQM 4.0 framework, which balances both social and technical issues. This is also necessary compensation for previous Quality 4.0 models that lacked relevance to theories (Chiarini, 2020). STS encourages employees' empowerment, such as increasing individual and team self-control. This implies flexibility, adaptability, and innovation. STS focuses on internal resources by improving employees' productivity and building organisational culture that encourages creativeness and innovativeness.

TQM operations may be facing an increased degree of uncertainty and complexity in the future. The ongoing COVID-19 pandemic exemplifies the interconnectedness and volatility that current and future organisations need to control (Fundin et al., 2020). The impact of the Covid-19 pandemic is powerful on the economy in general and manufacturing companies in particular, so companies are looking forward to a management system that can respond flexibly and quickly. Therefore, TQM 4.0 has a lean structure, flexibility to adapt to uncertain environment and help businesses overcome post-covid difficulties. Currently, TQM 4.0 is being implemented mainly in the manufacturing sector. However, as we mentioned above, there is a lack of indicators to assess the TQM 4.0 implementation in organisations. For that reason, it is necessary to have a set of indicators to help evaluate the implementation of TQM 4.0 in manufacturing field. Consequently, this study focuses on developing the fulfilment of the TQM 4.0 model implementation from main factors to specific indicators. Moreover, this paper ranks the critical factors/indicators in the TQM 4.0 model application by employing the AHP technique.

This study has three research objectives: (1) identify the main factors of the TQM 4.0 model, (2) determine the relative importance of factors of the TQM 4.0 model, and (3) rank the relative importance of TQM 4.0 implementation indicators within a factor and in the whole indicators. This study employed both Delphi and AHP techniques to achieve those objectives.

Our study contributes to the existing literature on TQM. By extending the STS theory into the industry 4.0 context, the study explores indicators and main factors of the TQM 4.0 model. This model emphasises some social factors that were neglected in the previous studies. By doing so, this study is the first attempt to rank the importance of indicators and factors in the TQM 4.0 model by employing AHP technique. A completed TQM 4.0 model with indicator fulfilment and ranking will be a valuable framework for researchers who investigate the TQM 4.0 field in their studies. Anchoring on the STS theory is the notable contribution of this paper. Although the STS theory was proposed to design the implementation of Industry 4.0 by Sony & Naik (2020), this research primarily applies this theory to the TQM 4.0 model. It suggests the TQM 4.0 framework, which is flexible to adapt to an uncertain and fast-changing environment. Finally, the paper also managerially indicates that application of the TQM 4.0 model in organisations needs to attend both social and technical approaches and focus on the priority of the important factors or indicators.

2. Literature review

2.1. *TQM 4.0 model and STS theory*

Total Quality Management (TQM) is defined as a management method whereby top management and employees in the organisations gain stakeholder satisfaction (Goetsch and Davis, 2013; Zhang et al., 2021). While some researchers define TQM as quality management standards such as ISO 9001, ISO 9004, some studies use business excellence models (Baldrige, EFQM, and Deming Prize) that present TQM in their works. When industry 4.0 has been developed, the integrated models of TQM and Industry 4.0 are in the process of being discovered. Some authors have attempted to find the main factors of TQM practices in Industry 4.0, but most are in the form of large themes without specific items, and they lack relevance to theories (Chiarini, 2020). In this study, the authors develop fulfilled indicators for TQM 4.0 model implementation based on socio-technical system theory.

Socio-technical system theory (STS) describes a company in terms of the social and technical side (Davis et al., 2014; Manz & Stewart, 1997). The social side includes individuals, teams, groups, their interactions and work behaviours. The technical side includes processes, tools, techniques, methodologies and equipment. Some authors try to connect STS to TQM field. Manz and Stewart (1997) combined STS and TQM to achieve organisational stability and flexibility. Chaudhuri & Jayaram (2019) also suggested that STS be considered as a theoretical foundation to investigate the influences of social and technical combinations on quality and sustainability management. Industry 4.0 development has happened on the technical side and does not directly pertain to the social side of the organisation (Kupper et al., 2019). This, in turn, creates a scarcity of alignment between the social and technical sides and ignores the human side. Quality models do not offer any panacea to the current problem. Meanwhile, STS encourages flexibility, a high degree of autonomy, the extent of employee empowerment. So it is the proper complement to rigid traditional TQM and technology tools of Industry 4.0. Therefore, in this study, anchoring on the STS theory will be suitable for creating the TQM 4.0 framework, which concludes both social and technical factors.

2.2. *Social factors*

Top management 4.0: In traditional TQM, top management commitment, involvement, and support are the crucial factors to help TQM application succeed (Goetsch & Davis, 2013; Jaca & Psomas, 2015). Similarly, many researchers believed that for the successful implementation of a TQM 4.0 model, top management needed to be involved and committed (Sony et al., 2020). Chiarini and Kumar (2021) suggested that top management establish strategic goals, objectives, and indicators for TQM 4.0 and communicate them to staff, supporting its implementation through resources, training, and reviewing achieved results.

Quality culture 4.0: According to Goetsch & Davis (2013), implementing total quality without establishing a quality culture is a recipe for disaster. In the study of exploring QM models aligned with Industry 4.0, Asif (2020) emphasises mindfulness of Quality 4.0, which is the opposite of traditional QM routines. It requires observing instead of just seeing, ascertaining instead of mere conforming, and conscious actions instead of automaticity. In a quality culture 4.0, managers should encourage employee empowerment (Kupper et al., 2019). STS theory also highlights it to provide flexibility and sustainability TQM. The STS encourages employees' empowerment, like increasing individual and team self-control. TQM 4.0 should encourage individuals across the organisation to understand their roles in achieving quality goals, which is articulated to all layers of the organisation (Kupper et al., 2019).

Digital skills for quality staff: Industry 4.0 is not about reducing the workforce but about requiring a set of new skills (Kupper et al., 2019). As our study demonstrates, TQM 4.0 in no way diminishes the role of people in assuring quality. Indeed, equipping workers with the skills to use digital tools and tell data-driven stories will be critical to ensure quality in future factories. In TQM 4.0 model, quality control staff should acquire more skills related to analytics, AI, and CPS (Chiarini & Kumar, 2021; Kupper et al., 2019). In the TQM 4.0 model, quality staff will spend less time in operative tasks such as inspections and more time in problem-solving and preventive activities. Quality experts and data scientists will converge to form a single profession. Besides, Hyun Park et al. (2017) also mentioned that creative thinking in team activities is the most critical skill for driving success of TQM 4.0.

Intellectual capital management: Asif (2020) launched Quality 4.0, focusing on human, social, and intellectual capital. QM models mainly discuss human resources management but lack an explicit focus on developing and leveraging human capital. The TQM 4.0 model should focus on developing social capital, such as working relationships of people both within and outside the organisation (Glogovac et al., 2020). TQM 4.0 also focus on intellectual capital management such as reputation, employee loyalty, customer relationships, company values, brand image (Asif, 2020; Glogovac et al., 2020).

Smart organisation: In the TQM 4.0 model, leaders need to create and operate a smart organisation (Fundin et al., 2020). For example, top management will support initiatives, spread organisational knowledge, and scale up successful innovations in the TQM 4.0 model. In the TQM 4.0 model, the organisation will be leaner and more efficient (Asif, 2020). Additionally, Sader et al. (2019) emphasised that TQM 4.0 technologies will enhance communication and cooperation through connection and social networking, promoting innovation and exchanging ideas between production partners and stakeholders. Moreover, according to Asif (2020), TQM 4.0 will network companies in business ecosystems. Furthermore, TQM 4.0 will adapt to a rapidly changing environment through exploration and exploitation (Fundin et al., 2020).

Integrating sustainable development: According to Fundin et al. (2020), a sustainable organisation will manage to serve society and the planet, link quality and sustainability, be excellent in the service of sustainability (Isaksson, 2021). This subject might also be inspired by the integration of environmental management systems (EMS) (Fundin et al., 2020). Therefore, the TQM 4.0 model needs to involve dimensions forward integrating sustainable development.

2.3. *Technical factors*

Automated document control: Chiarini and Kumar (2021) stated that QMS should be paperless and integrate quality-related documents into the ERP. In the TQM 4.0 model, we hope for automated and real-time document control, particularly for designs and work instructions. TQM 4.0 will include digital standard operating procedures SOPs to guarantee that employees receive the most recent instructions (Kupper et al., 2019).

Automatic data collection: Industry 4.0 tools allow to handle data with ERP modules such as the manufacturing execution system (MES) or product life cycle management (PLM) (Chiarini & Kumar, 2021). Many forms of product-related data, such as the amount of nonconforming or scrap goods, the number of labour and machine hours spent on reworks, and the number of complaints and returned items, will be automatically gathered under the TQM 4.0 model. Customer-related data, such as product specifications, complaints, and satisfaction levels, should also be collected automatically (Chiarini & Kumar, 2021).

Smart Quality Control: Total inspection will increasingly replace sample inspection in Industry 4.0 by using sensors and real-time inspection technology (Park et al., 2017; Sader et al., 2019). Chiarini & Kumar (2021) demonstrated that a new type of SPC (statistical process control) based on machine learning anticipates all types of defects during machining and provides feedback to the machine, which automatically corrects its settings without human involvement. Chiarini and Kumar (2021) highlighted that quality data was gathered automatically from various processes and handled inside ERP modules.

Smart Quality Assurance: Industry 4.0 technologies like AI and machine learning would enable the industrial system for predictive and preventative actions (Chiarini & Kumar, 2021; Sader et al., 2019). Moreover, Sader et al. (2019) show that Industry 4.0 will optimise processes, increase efficiency and resource allocation, reduce the effort required for quality concerns by employing sensors at each step of production. Big-data analysis will collect real-time data created during production and convert it into pleasant, usable information (Sader et al., 2019). In TQM 4.0, firms will make intelligent adjustments based on real-time data and maintain digital records (Asif, 2020).

Smart product: Asif (2020) found that the application of AI allowed the precise forecast of client wants. Sader et al. (2019) also mentioned big-data analysis would forecast market demand and consumption. Therefore, smart products satisfy customers' demands using AI-based predictions and enable customers by identifying and trace items. Chiarini and Kumar (2021) showed that smart technology could greatly aid businesses in identifying and tracking items and tools in TQM 4.0 by using RFID technology and smart sensors on products and packaging. Additionally, in the TQM 4.0 model, industry 4.0 connectivity features will allow customers to be involved in the production process rather than only being its recipient (Fundin et al., 2020; Sader et al., 2019).

3. Research methodology

Dalkey and Helmer (1963) developed the traditional Delphi method, which is a consensus strategy that collects the opinions of a group of experts on a certain problem in a systematic manner. In addition, to save time and cost, Murry & Hammons (1995) introduced the modified Delphi method, which using a structured questionnaire helps experts focus on the issue at hand (Min, 2015). Hence, this study uses this questionnaire to determine the main factors and fulfil indicators of the TQM 4.0 model.

AHP is a method combined with the Delphi technique in exploring indicators. AHP created by Saaty (1990) is a powerful technique in solving fuzzy and complex decision problems. Later, many researchers used the AHP method in combination with the Delphi method to become mixed exploratory methods to investigate the managerial views on the critical factors (Min, 2015; Wong et al., 2021). In this study, the Delphi method is used to develop the fulfilment of the TQM 4.0 model from main factors to specific items. An employing AHP approach is used to determine the critical among factors of TQM 4.0 model implementation.

3.2. *Scale development process*

3.2.1 *Develop initial questionnaire*

An initial questionnaire was sent to experts. Included were a series of open-ended questions based on researchers' experience and the contributions from the summarised literature. The panel of experts included academics, consultants, and practitioner experts (Table 1). Academics were required to have research or teaching experience in TQM. Practitioner experts, including production/quality manager/supervisors, were required to have at least five years of work experience in production or quality management and basic Industry 4.0 tools knowledge. The pilot version of the questionnaire was reviewed and corrected by an assessment group. After a revision based on the panel of experts' feedbacks, we have an initial questionnaire that concludes the TQM 4.0 model consisting of 11 factors (44 variables).

3.2.2 *In the first Delphi round:*

The questionnaire included four parts. The first part introduces TQM 4.0 and questions aimed at selecting appropriate experts based on their understanding about TQM 4.0. The second part presents the factors according to the five-point Likert scale of 1 (not important) to 5 (extremely important). Then, in the third part, experts will answer open questions about the comments of the TQM 4.0 model that the authors have given and additional comments for the TQM 4.0 model. Finally, the fourth part collects generic information such as the company's field of operation, position, and experts' years of experience. In this round, we collected the respondents' email addresses to facilitate the next round survey. In round one, there are 46 observations used for analysis. The authors calculate Mean and Content Validity Ratio (CVR); Mean<3.5 or CRV < 0.29 is rejected. According to Lawshe (1975), with the number of panellists of 40 experts, the threshold of CVR is 0.29. Lawshe (1975) presumed three options for each item, including essential, useful but not essential, and not necessary. This study uses the five-point Likert scale, so two scales must match together. Correspondingly, extremely important and very important are examined as equal to essential, moderately important was assumed as equal to useful but not essential, and slightly important and not important were considered as equal to not necessary.

3.2.3 *In the second Delphi round*

The authors sent questionnaires to 46 experts involved in the first round (Table 1), Only 33 experts responded. In this round, the authors calculate Mean and CRV; Mean < 3.5 or CRV < 0.33 are rejected because, with 30 experts of panellists, the least accepted score of CVR is 0.33 (Lawshe, 1975).

Table 1. Profile of three groups of panelists in the three rounds.

No	Rounds	Managers/ supervisors	Consultants	Academics	Total
1	Literature review, in-depth interviews	2	2	3	5
2	Round 1	39	4	3	46
3	Round 2	28	3	2	33
4	Round 3 (AHP)	8	1	2	11

3.2.4 *In the third Delphi round (AHP analysis)*

In this survey, the authors determined the relative importance of each factor and indicator level through pairwise comparative judgments. According to Deng et al. (2002), panellists need to compare two factors or indicators in this process. The respondents express their preference between every two factors and translate these preferences into numerical ratings of 1-3-5-7-9 and 2-4-6-8 as intermediate values. The respondents are required to compare factors A and B in the TQM 4.0 model to see which factor is more important. If factor A is as important as factor B, choose number 1. If factor A is more important than factor B, choose a number from 2 to 9 points (choose towards A). Otherwise, choose B. Score 9 is the most important level.

The collected data will be checked the consistency and reliability by consistency index (CI). Accordingly, the consistency is defined as CR (consistency ratio) = CI/RI (random index) equality. RI is presented in Table 2. CI = (λmax-n)/(n-1) must be used for CR. If the CR value is less than 0.10, the evaluation is considered to be consistent (Saaty, 1990). After analysing the CR value, the relative weights of each indicator and factor were integrated thereafter to develop the final weighted score to measure TQM 4.0 model implementation in manufacturing enterprises.

As the number of surveyed experts who complete AHP questionnaires should not be too many, Lin et al. (2009) recommended 5- 15 as a suitable number. Therefore, the study gathers opinions from eleven experts who answered the first two surveys (See Table 1)

4. Results

4.1 *First Delphi survey*

In this round, five items (have CVR < 0.29) in the original questionnaire were rejected, including Data scientists as quality experts, Human capital management; Social capital management; Intellectual capital management; Managing networked firms in business ecosystems (See Table 3). In addition, two items from experts' recommendations will be added, including 'Application online tools in training, meetings, and work management'; 'Machine Learning enhancement'. The new questionnaire includes ten factors (41 indicators) that will survey in round two.

4.2. *Second Delphi survey*

The results in round 2 show that all indicators have Mean >3.5 and CVR > 0.33, so the variables have reached high concentration. The final TQM 4.0 model consists of 10 factors (41 indicators) (*See Table 3*).

4.3. *Third Delphi survey (AHP analysis)*

Using the AHP technique, the authors analyse the importance of each factor and indicator in the TQM 4.0 model implementation. Table 4 details the relative weight

Table 2. RI values for the different values of *n*.

N	1	2	3	4	5	6	7	8	9	10
Random Index	0.00	0.00	0.52	0.89	1.11	1.15	1.35	1.4	1.45	1.49

Table 3. The results of the two Delphi rounds.

Factor/Indicator	Round 1			Round 2		
	Avg.	CVR	Result	Avg.	CVR	Result
Top management (TM)						
(TM1) Top management commitment	4.70	0.96	Accepted	4.41	0.94	Accepted
(TM2) Top management involvement	4.39	0.70	Accepted	4.38	0.81	Accepted
(TM3) Top management providing resources	4.52	0.87	Accepted	4.59	0.94	Accepted
(TM4) Top management establishing policy, objectives and indicators	4.61	0.91	Accepted	4.16	0.81	Accepted
Quality Culture 4.0 (QC)						
*(QC1)*Quality-driven mindfulness	4.43	0.83	Accepted	4.25	0.88	Accepted
*(QC2)*Employee empowerment	4.24	0.61	Accepted	4.34	0.75	Accepted
*(QC3)*Individuals understanding their role in achieving quality goals	4.48	0.78	Accepted	4.09	0.69	Accepted
*(QC4)*Quality articulation	4.22	0.65	Accepted	4.09	0.63	Accepted
Skill 4.0 (SK)						
*(SK1)*Skills related to analytics, AI, CPS	4.41	0.78	Accepted	4.06	0.69	Accepted
(SK2) Digital skills for quality staff	4.30	0.74	Accepted	4.19	0.69	Accepted
*(SK3)*Digital communication skill	4.24	0.74	Accepted	4.09	0.75	Accepted
*(SK4)*Data scientists as quality experts	3.65	0.26	*Rejected*			
*(SK5)*Team creativity skill	4.35	0.87	Accepted	4.19	0.69	Accepted
Intellectual capital management (ICM)						
(ICM1) Human capital management	3.87	0.22	*Rejected*			
(ICM2) Social capital management	3.67	0.17	*Rejected*			
(ICM3) Intellectual capital management	3.83	0.26	*Rejected*			
Smart organisation (SO)						
(SO1) Top managements support initiatives, spread organisational knowledge	4.37	0.87	Accepted	4.16	0.63	Accepted
(SO2) Lean structure organisation	4.39	0.83	Accepted	4.38	0.94	Accepted
(SO3) Collaboration all stakeholders	4.33	0.74	Accepted	4.03	0.63	Accepted
(SO4) Managing networked firms in business ecosystems	3.63	0.17	*Rejected*			
(SO5) Adaptability in the fast-changing environment	4.33	0.83	Accepted	4.34	0.75	Accepted
(SO6) Application of online tools in training, meetings, and work management				4.28	0.81	Accepted
Integrating sustainable development (ISD)						
*(ISD1)*Link quality and sustainability	4.57	0.91	Accepted	4.41	0.94	Accepted
*(ISD2)*Corporations serving society	4.24	0.83	Accepted	3.88	0.56	Accepted
*(ISD3)*Operations in a more sustainable way	4.46	0.78	Accepted	4.25	0.75	Accepted
*(ISD4)*Integration of environmental management systems	4.33	0.65	Accepted	4.31	0.94	Accepted
Automated document control (ADOC)						
*(ADOC1)*Integration of documentation into ERP modules and automatic revision	3.82	0.04	Accepted	4.25	0.75	Accepted
*(ADOC2)*Electronic documentation	4.43	0.78	Accepted	4.44	0.94	Accepted
*(ADOC3)*Real-time document control	4.30	0.74	Accepted	4.31	0.88	Accepted
*(ADOC4)*Digital standard operating procedures (SOPs)	4.41	0.87	Accepted	4.47	0.88	Accepted
Automatic data collection (ADAC)						
*(ADAC1)*Automatic collection of data throughout the product lifecycle	4.50	0.83	Accepted	4.34	0.94	Accepted
*(ADAC2)*Automatic collection of many types of product-related data	4.37	0.74	Accepted	4.38	0.81	Accepted

(*Continued*)

Table 3. Continued.

Factor/Indicator	Round 1			Round 2		
	Avg.	CVR	Result	Avg.	CVR	Result
*(ADAC3)*Automatic collection of many types of customer-related data	4.35	0.83	Accepted	4.34	0.94	Accepted
Smart Quality Control (SQC)						
*(SQC1)*Real-time quality inspection	4.35	0.83	Accepted	4.16	0.75	Accepted
*(SQC2)*Total inspection	4.24	0.74	Accepted	4.13	0.63	Accepted
*(SQC3)*A new kind of SPC based on machine learning	4.17	0.61	Accepted	4.28	0.81	Accepted
*(SQC4)*Data integration with enterprise resource planning	4.43	0.78	Accepted	4.06	0.63	Accepted
Smart Quality Assurance (SQA)						
*(SQA1)*Using AI software for prediction and prevention	4.35	0.74	Accepted	4.16	0.75	Accepted
*(SQA2)*Using sensors at each production stage	4.39	0.83	Accepted	4.31	0.75	Accepted
*(SQA3)*Big-data analysis	4.35	0.74	Accepted	4.25	0.69	Accepted
*(SQA4)*Making intelligent adjustments	4.26	0.65	Accepted	4.34	0.88	Accepted
*(SQA5)*Improving machine performance by ML				4.13	0.63	Accepted
Smart product (SP)						
*(SP1)*Prediction of market demand and consumption trends	4.22	0.74	Accepted	4.22	0.69	Accepted
*(SP2)*Smart technologies for identification and traceability	4.35	0.74	Accepted	4.03	0.63	Accepted
*(SP3)*RFID technologies and smart sensors	4.37	0.70	Accepted	4.25	0.75	Accepted
*(SP4)*Customer involvement in the production process	4.11	0.61	Accepted	4.13	0.63	Accepted

among elements of the TQM 4.0 model and the specific of their ranking. The result shows that the most important factor is Top management. The second one is Quality culture 4.0; otherwise, the less important factor is Automatic data collection. CR value of 0.092 (Table 4) illustrates that the responses have an acceptable consistency level.

Table 4. Ranking of the key TQM 4.0 factors.

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

Table 5. Final weights of TQM 4.0 indicators.

Factors	Indicators	Weights	Rank within a factor	CR
Top management	TM1	0.6167	1	0.062
	TM2	0.0650	4	
	TM3	0.1592	2	
	TM4	0.1591	3	
Quality Culture 4.0	QC1	0.4212	1	0.060
	QC2	0.2388	2	
	QC3	0.1028	4	
	QC4	0.2372	3	
Skill 4.0	SK1	0.5175	1	0.077
	SK2	0.2801	2	
	SK3	0.1411	3	
	SK5	0.0614	4	
Smart organisation	SO1	0.0883	4	0.072
	SO2	0.3632	1	
	SO3	0.0715	5	
	SO5	0.3289	2	
	SO6	0.1480	3	
Integrating sustainable development	ISD1	0.0920	4	0.084
	ISD2	0.3258	2	
	ISD3	0.2005	3	
	IDS4	0.3817	1	
Automated document control	ADOC1	0.1247	4	0.041
	ADOC2	0.2373	2	
	ADOC3	0.2303	3	
	ADOC4	0.4077	1	
Automatic data collection	ADAC1	0.1241	3	0.020
	ADAC2	0.5612	1	
	ADAC3	0.3147	2	
Smart Quality Control	SQC1	0.6181	1	.077
	SQC2	0.1145	3	
	SQC3	0.2115	2	
	SQC4	0.0559	4	
Smart Quality Assurance	SQA1	0.5156	1	0.056
	SQA2	0.0969	4	
	SQA3	0.2352	2	
	SQA4	0.0530	5	
	SQA5	0.0993	3	
Smart product	SP1	0.0847	3	0.072
	SP2	0.5606	1	
	SP3	0.2700	2	
	SP4	0.0847	4	

Table 5 provides the results of the relative importance of the indicators within each factor and their respective rankings. The responses were consistent with CR values in each element ranging from 0.02–0.84.

The global priorities of the proposed criteria were obtained by multiplying the weight of the first-order measures (factors) and those of the second-order criteria (indicators). The global weight and the priority ranking of the 41 indicators are presented in Table 6. The five most important indicators of TQM 4.0 implementations are Top management commitment, Quality-driven mindfulness, Employee empowerment, Quality articulation, Lean structure organisation.

Table 6. The rank of the indicators for TQM 4.0.

Rank	Indicators	Global weights
1	TM1	0.1570
2	QC1	0.0864
3	QC2	0.0490
4	QC4	0.0487
5	SO2	0.0481
6	SO5	0.0435
7	TM3	0.0405
8	TM4	0.0405
9	SK1	0.0372
10	IDS4	0.0338
11	SQA1	0.0325
12	SP2	0.0318
13	ISD2	0.0289
14	ADAC2	0.0238
15	SQC1	0.0233
16	QC3	0.0211
17	SK2	0.0201
18	SO6	0.0196
19	ADOC4	0.0194
20	ISD3	0.0178
21	TM2	0.0165
22	SP3	0.0153
23	SQA3	0.0148
24	ADAC3	0.0134
25	SO1	0.0117
26	ADOC2	0.0113
27	ADOC3	0.0110
28	SK3	0.0101
29	SO3	0.0095
30	ISD1	0.0081
31	SQC3	0.0080
32	SQA5	0.0063
33	SQA2	0.0061
34	ADOC1	0.0059
35	ADAC1	0.0053
36	SP4	0.0048
37	SP1	0.0048
38	SK5	0.0044
39	SQC2	0.0043
40	SQA4	0.0033
41	SQC4	0.0021

5. Discussion and managerial implications

5.1. *Discussion*

Our study contributes to the TQM literature in general and the TQM 4.0 research stream in three significant ways. First, this study is an initial endeavour to determine the fulfilling indicators and main factors of the TQM 4.0 model for manufacturing enterprises by employing three rounds of the Delphi method. The study has identified 41 indicators for ten main factors, concluding five social and five technical components. In addition, this highlights some social factors that other studies have not paid attention to. For example, quality culture 4.0 was neglected in the previous studies. However, having a quality culture 4.0 is very important in organisations when implementing and spreading the new technology in TQM 4.0. It helps employees easily accept new tools and adapt to new technology in Industry 4.0.

Second, this study is the first attempt to rank the importance of indicators and factors in the TQM 4.0 model. After analysing by AHP technique, the results show three rankings, including (1) the rank of the importance of ten main factors in the TQM 4.0 model, (2) the rank of the importance of the indicators within each factor, and (3) the rank of the importance of the indicators in the TQM 4.0 model. This significant finding reveals that important indicators or factors should weigh more while less important indicators or factors should weigh less. Therefore, future researchers should consider the relative importance of TQM 4.0 factors and not assume that all factors have equal contribution when examining the TQM 4.0 model in the manufacturing industry in their studies. It is surprising that although TQM 4.0 is a combination of TQM and many tools of Industry 4.0, according to experts, the more important elements of TQM 4.0 are social aspects, not technical aspects, which have received attention from many scholars.

Specifically, top management was perceived as the most important of the ten domains in evaluating the TQM 4.0 application. This finding slightly conforms to Chiarini and Kumar's (2021) study, which indicated that top management is an important theme for the Quality 4.0 model in Italian manufacturing companies. The second important factor is Quality Culture 4.0, and the factor 'Integrating sustainable development' is ranked 3rd out of 10 factors. Fundin (2020) also emphasised integrating sustainable development in the 'Quality 2030: quality management for the future' study. TQM 4.0 must link quality and sustainability and serve society (Fundin, 2020). The remaining two factors of social approach are Skill 4.0 and Smart organisation that rank fourth and fifth respectively out of the ten factors. This result is supported by Chiarini and Kumar (2021) and Kupper et al. (2019), which show that Skill 4.0 is necessary for TQM 4.0 application. Another social factor mentioned in the TQM 4.0 model is Smart organisation, in which the two most strongly weight indicators are 'Lean structure organisation' and 'Adaptability in the fast-changing environment'.

Moreover, five factors belonging to technical aspects are assessed by experts as less important but indispensable for a TQM 4.0 system. This study confirms the factors that many authors have emphasised in previous studies. However, this paper adds more value by identifying the relative importance of each factor and each indicator. The most important technical factor is Smart Quality Control, in which the two most strongly weight indicators are 'Real-time quality inspection' and 'A new kind of SPC based on machine learning'. The TQM 4.0 model will allow real-time quality inspection (Sader et al., 2019) and a new kind of SPC based on machine learning predicts all sorts of defects during machining and gives feedback to the machine itself, automatically correcting its parameters without human interaction (Chiarini & Kumar, 2021). The next one is Smart Quality Assurance, in which the two most strongly weight indicators are 'Using AI software for prediction and prevention' and 'Big-data analysis'. The TQM 4.0 model will use AI software for predictive maintenance in advance and preventive intervention to avoid downtime or system failure (Chiarini & Kumar, 2021). In the TQM 4.0 model, a big-data analysis will collect real-time data generated during production and transform it into friendly useful information (Sader et al., 2019; Sader et al., 2021). The 'Smart product' factor ranks 8th in the ten factors, describing how smart technologies can significantly assist companies in identifying and tracking products and RFID technologies and smart sensors on products and packaging be used to identify and trace products (Chiarini

& Kumar, 2021). The two least important factors are 'Automated document control' and 'Automatic data collection'. In the TQM 4.0 model, many types of product-related data are to be automatically collected. The results of this study are supported by Chiarini & Kumar (2021), which indicates using electronic documentation for Quality Management System is necessary for the TQM 4.0 model. TQM 4.0 also provides digital standard operating procedures (SOPs) to ensure that workers have the most up-to-date instructions (Kupper et al., 2019).

Third, building upon the STS theory, this study explores the TQM 4.0 model balancing social and technical aspects. STS helps overcome the disadvantages of traditional TQM and Industry 4.0 to propose a TQM 4.0 framework with more flexibility, adaptability, and sustainability. This finding is in part consistent with a recent study by Sony & Naik (2020), which proposed the considered STS theory while designing the implementation of Industry 4.0. However, this study extends the QM literature by combining the STS theory into the TQM 4.0 model. While traditional TQM focuses more on external management and Industry 4.0 focuses on technical tools, the STS theory encourages organisations to focus on more internal management by enhancing employees' empowerment, improving employees' productivity, and supporting creativeness and innovativeness.

5.2. *Managerial implications*

Our research findings suggest that manufacturing organisations that apply the TQM 4.0 model need to employ both social and technical approaches. The calculation of global weight has helped rank the importance of 41 indicators and show that the indicators belonging to social factors are more important than those of technical elements. This result is remarkable for practitioners in the industry who will operate TQM 4.0 in companies. Our study indicates that the most important indicators include Top management commitment, Quality-driven mindfulness, Employee empowerment. Therefore, top managers in manufacturing organisations should be firmly committed to TQM 4.0 implementation to gain success. Moreover, managers should support quality-driven mindfulness and employee empowerment by encouraging employee self-leaders and actively solving problems instead of waiting for regular processes to minimise waste and reduce failure costs. Furthermore, managers should prioritise factors or indicators to apply and examine TQM 4.0 in the manufacturing industry, not assume that all factors have an equal contribution. This makes the implementation and evaluation of TQM 4.0 in the enterprise more accurate and efficient.

Finally, a note for managers is TQM 4.0 model not only meets customers' needs, improves performance, satisfies stockholders but also works towards sustainable development, meeting social needs. Therefore, manufacturing enterprises should operate more sustainably and integrate environmental management systems. Besides, with the integration of many new Industry 4.0 tools, employees need to have new skills, especially those related to analytics, AI, CPS, and quality staff need to have digital skills for problem-solving and preventive activities. Thus, manufacturing organisations should encourage employees to gain new skills through training. Especially, taking advantage of online courses can improve their digital skills conveniently.

6. Conclusion, limitations and future study

This study explores the 41 indicators and ten factors of the TQM 4.0 model based on STS theory. The results also indicate the weighted importance of indicators or factors, which researchers and practitioners can apply and examine TQM 4.0 implementation in manufacturing organisations.

Although this study provides significant contributions to the QM field, there are certain limitations. First, requiring respondents to participate in all Delphi–AHP survey rounds was practically a challenge because longitudinal surveys result in lower participation. Second, this study conducted a literature review and three rounds of Delphi sessions to thoroughly examine all of the TQM 4.0 indicators; nevertheless, some indicators of TQM 4.0 have not yet been identified in this study's conceptual framework. Therefore, it is recommended that future researchers identify other factors that may have been overlooked in this study. Third, it should also be considered that research was conducted in a developing country where the conscience about TQM 4.0 is in the growth stage; thus, confirmation from other geographical areas is needed. Future studies should, therefore, seek to examine TQM 4.0 in different regions or countries, as this may make it possible to compare TQM 4.0 based on experts' perceptions in different regions. Finally, this study is the first attempt in the literature to utilise AHP to develop TQM 4.0 indicators. Verifying this scale to assess TQM 4.0 implementations in enterprises is necessary for further studies. Moreover, the criteria adopted in the present study can link different variables such as customer satisfaction, digital transformation, sustainable excellence, etc. Examining the relationship between TQM 4.0 and other variables will help to aid future quality management research.

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References

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

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

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

Chiarini, A., & Kumar, M. (2021). What is quality 4.0? An exploratory sequential mixed methods study of Italian manufacturing companies? An exploratory sequential mixed methods study of Italian manufacturing companies. *International Journal of Production Research*. https://doi.org/10.1080/00207543.2021.1942285

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

Davis, M. C., Challenger, R., Jayewardene, D. N. W., & Clegg, C. W. (2014). Advancing socio-technical systems thinking: A call for bravery. *Applied Ergonomics*, *45*(2A), 171–180. https://doi.org/10.1016/j.apergo.2013.02.009

Fundin, A., Lilja, J., Lagrosen, Y., & Bergquist, B. (2020). Quality 2030: Quality management for the future. *Total Quality Management & 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 & Business Excellence*, 1–19. https://doi.org/10.1080/14783363.2020.1865793

Goetsch, D. L., & Davis, S. (2013). *Quality management for organisational excellence : Introduction to total quality*. Always Learning TA - TT - (Seventh Ed). Pearson Education Limited.

Isaksson, R. (2021). Excellence for sustainability – maintaining the license to operate. *Total Quality Management & Business Excellence*, *32*(56), 489–500. https://doi.org/10.1080/14783363.2019.1593044

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

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

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

Min, J. C. H. (2016). Guiding the guides: Developing indicators of tour guides' service quality. *Total Quality Management & Business Excellence*, *27*(910), 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

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 & Business Excellence*, *28*(9–10), 934–945. https://doi.org/10.1080/14783363.2017.1310703

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 & 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

Sony, M., Antony, J., & Douglas, J. A. (2020). Essential ingredients for the implementation of quality 4.0. *The 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

Wong, A. K. F., Kim, S., Lee, S., & Elliot, S. (2021). 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

Zhang, C., Moreira, M. R. A., & Sousa, P. S. A. (2021). A bibliometric view on the use of total quality management in services. *Total Quality Management & Business Excellence*, *32*(0), 1466–1493. https://doi.org/10.1080/14783363.2020.1732811