Developing a Quality 4.0 Maturity Index for Improved Business Operational Efficiency and Performance

DOI: 10.12776/QIP.V26I2.1718

Matolwandile Mzuvukile Mtotywa

Received: 2022-07-08 Accepted: 2022-07-15 Published: 2022-07-31

ABSTRACT

Purpose: Technological advances and increased environmental turbulence require a transition in quality management. The study aimed at developing a Quality 4.0 maturity index for improved business operational efficiency and performance.

Methodology/Approach: This conceptual paper introduces a theoretical business evaluative model that allows an integrated analysis of technology-driven, quality management dimensions. The model is based on theoretical and empirical information and describes Quality 4.0 business analysis by a theoretical central business dimensional concept, formal statistical analytical methods and uses these data to assign a maturity index score to the business.

Findings: The study builds the Quality 4.0 maturity index following the analysis of seven continuous quality improvement dimensions. The maturity of these dimensions in the business is assessed with a five-point maturity level. The effectiveness of the index should be confirmed with fit as covariation and a composite score for the level of Quality 4.0 maturity.

Research Limitation/Implication: The research is based on theory and has not been validated with empirical data. It is recommended that a validation study be conducted based on the approach and guidelines provided in the paper.

Originality/Value of paper: The study helped develop a theoretical aspect of total quality management during an era of the fourth industrial revolution. It also aimed at practically benefiting a business by focussing on improved business capacity and capability to mitigate the environmental turbulence associated with pandemics. The paper provides novel work, as it describes one of the first Quality 4.0 maturity index models that may be used to improve business.

Category: Conceptual paper

Keywords: quality 4.0; maturity index; operational efficiency; performance

1 INTRODUCTION

Customer requirements are constantly changing, making it challenging to maintain a high standard of quality service provision and customer satisfaction (Gold and Pray, 1999; Bergman and Klefsjö, 2010; Felix, 2015). Changes in socio-economic conditions drive this higher expectation of customisation, technological change and changing societal imperatives (Mihajlović and Koncul, 2016). This requires firms to analyse the deployment of new customer requirements, solutions and behaviour and assess the competitive landscape and the focal business relationships with other customers and suppliers in the value chain (Biggemann et al., 2013). This highlights how the forces that drive customer and supplier interests and incentives to collaborate on customer solutions can change over time, altering the purpose and scope of solutions and increasing the risk of service failure. Customers identify problems and suppliers respond based not only on the viability of the customer-specific solution but also on their assessment of future solutions in a broader market allowing suppliers to then seek standardised, successful solutions across markets. Numerous firms still suffer from quality issues critical to meeting this changing demand, as evidenced by numerous product recalls across several industries (Magno, 2012; Bernon et al., 2018; Gunasekaran, Subramanian and Ngai, 2019). Chang, Ellinger and Blackhurst (2015) argued that these recalls can negatively impact a business' performance, erode brand equity, tarnish its reputation, create panic among customers to result in revenue and market share losses. This can have a short-term impact on shareholder wealth and long-term effects on supply chain disruptions (Zhao, Li and Flynn, 2013). This has created a continuous debate on whether the traditional quality management strategies and methodologies respond effectively to changes in product development stages, cycle time shortening and staff efforts to meet demand and consumer expectations (Gunasekaran, Subramanian and Ngai, 2019).

Research on Quality 4.0 has gained traction in the last five years, driven by technological advances which increased the accessibility of the Fourth Industrial Revolution (4IR) technologies, as well as the COVID-19 pandemic which changed the face of society and the workplace (Sony and Aithal, 2020; Broday, 2022). Together with such research, it is critical to also develop a Quality 4.0 maturity assessment model that can be employed to help improve operational efficiency and business performance. This is particularly important within developing countries such as South Africa, where there are several barriers to the implementation of the 4IR (Mtotywa et al., 2022).

2 EVOLUTION OF QUALITY MANAGEMENT TO QUALITY 4.0

Quality management has evolved over decades with four major paradigm shifts together with incremental changes observed during these periods (Weckenmann, Akkasoglu and Werner, 2015; Carnerud and Bäckström, 2021). Initially, the focus for quality management was on inspections to detect a defect or deficiency in the product, after which it evolved to include quality control, where efforts were made to eliminate the cause of the defects. With the development in quality management driven by some of the quality gurus such as Deming, Juran, Ishikawa, Crosby and others, the quality management focused on quality assurance and then total quality management (Evans, 2017) focussing on quality for the whole firm (Sader, Husti and Daroczi, 2022).

2.1 Contextualising Total Quality Management

Total quality management (TQM) was developed over several decades, with authors such as Deming, Juran and Crosby providing much of the seminal work to significantly impact development with regards to, amongst others, the focus and approach to the customer, TQM measurement and leadership commitment (Zairi, 2013; Evans, 2017).

Total quality management is used in all areas to improve processes and optimise business and is a recognised, sustainable application for competitive advantage (Talib, 2013). The TQM is a quality-focused management method based on the engagement of all employees and it's aim is for long-term success by prioritising the customer and offering benefits to the organisation and society. Goetsch and Davis (2014) contextualised total quality as a three-legged stool with a customer focus as the 'seat' and the 'legs' being measures, people and processes. The measures are statistical processes, benchmarking and quality tools, while people constitute the base upon which the quality is built, expected and empowered to effectively ensure total quality in the firm, while the processes aimed at continual improvement and are driven by the principle of 'good enough is never good enough' due to changing demand and requirements of customers. This highlights that, over the years, quality management has demonstrated an exceptional ability to update and evolve in response to the context and the needs of customers, firms and the operating environment (Fundin et al., 2020).

Literature shows that six to ten dimensions of TQM are associated with improving efficiency and performance in organisations. These dimensions include customer focus, committed leadership or management commitment, continuous process and systems improvement, participation of all employees, training, communication, supplier relationship, management by facts, strategic focus on quality as a source of competitive advantage as well as benchmarking (Bergman and Klefsjö, 2010; Psomas and Fotopoulos, 2010; Agus and Hassan, 2011; Aquilani et al., 2017; Evans, 2017; Bouranta et al., 2019; Fayyaz, 2021).

Traditionally, TQM was developed as an organisational measure (Prajogo and Hong, 2008; Mosadeghrad, 2013; Deshpande, 2019). However, research has shown the applicability of the TQM at the level of the individual with in-depth knowledge of process or organisation such as subject matter experts, process owners, internal or external consultants with relevant expertise as well as senior management (Prajogo and Cooper, 2017; Alweteed, 2018). This is possible as TQM is essentially a way of organising and involving the whole organisation;

every department, every activity, every single person at every level (Oakland, 1989). This was further explained by Morgan and Murgatroyd (1997) who noted that the "total" element of TQM indicates that every organisational member is active in quality improvement processes.

2.2 Development of Quality 4.0

With the technological advances and the advent of the 4IR, the focus on quality shifted toward Quality 4.0. While "Quality 4.0" is still in its infancy and no standard has been established, some authors have already addressed its implications within an industry and business firm context (Efimova and Briš, 2021). Several studies on Quality 4.0 have associated it with the impact of technology on TQM (Sader, Husti and Daróczi, 2019; Chiarini, 2020; Nenadál, 2020; Carvalho et al., 2021). Quality 4.0 is founded on empirical learning, empirical knowledge discovery as well as real-time data generation, collection and analysis to enable intelligent operations decisions (Nenadál, 2020; Rifqi et al., 2021; Broday, 2022). Quality 4.0 ensures that pertinent information is communicated continuously via the system. Thus, a delicate balance of digital confidence is essential to assure data protection and customer identity confidentiality. Regarding validation, artificial intelligence (AI) and machine learning is utilised to reflect beneficial effects on industrial operations (Javaid et al., 2021). It is applicable at different levels, from an individual level to the operations and business level, as well as the external operating environment.

3 QUALITY 4.0 MATURITY ASSESSMENT MODEL

The Quality 4.0 maturity assessment model builds the Quality 4.0 maturity index upon seven continuous, quality improvement dimensions. These seven dimensions are assessed using a 28-item scale. The maturity of these dimensions in the business is assessed and the effectiveness of the index is confirmed with fit as covariation and and a composite score for the level of Quality 4.0 maturity.

3.1 Dimensions of Quality 4.0

The dimensions of the Quality 4.0 model are grounded on total quality within the context of industry 4.0 and are enhanced by other quality tools and approaches such as lean-six sigma. Quality 4.0 should comprise not only quality digitalisation but also quality technologies, processes as well as people who influence digitisation. In the past, quality management was conducted through data-driven decision-making, but today, evidence-based decision-making is increasingly significant and the role of analysts is highlighted due to the collection of massive data in real-time (Jacob, 2017; Lee, Lee and Kim, 2019). As such, there are seven dimensions that were developed in this conceptual paper which are critical for improved operational efficiency and business performance of the Quality 4.0 model. These are management commitment to technology and innovation-driven operations, customer focus that enhances the voice of the customer, quality for strategy and competitive advantage, operational environment benchmarking, forecasting and future prediction, employee involvement and empowerment, process and systems integration and management and root cause analysis of operations disturbances and sustainable solution.

3.1.1 Management commitment to technology and innovation

The first dimenson is management commitment to technology and innovation (MC). There is general consensus within the quality management sphere that management commitment to quality management is critical. This is evident from the approaches proposed by Deming, Juran and Crosby, amongst others (Goestch and Davis, 2014; Evans, 2017). The management role remains critical with the changing quality environment and the implementation of Quality 4.0. With Quality 4.0 grounded on the technologies of the 4IR (Rifqi et al., 2021; Broday, 2022), management must be committed to technology and innovation, with this journey demanding a mental and cultural shift. Thus, top management is a crucial enabler of Quality 4.0 and individuals must be receptive to external ideas and willing to share their knowledge. By displaying dedication and support, senior management is vital to overcoming the opposition of individuals who oppose the implementation of innovation (Igartua, Garrigós and Hervas-Oliver, 2010).

Management must drive technology and innovation strategy and culture, clarify how the value will be developed, supply the innovation implementation team with a budget and assistance and monitor and evaluate results (Mortara et al., 2009; Huizingh, 2011). The importance of top management commitment and support is because it affects innovation, product as well as and process innovation (Al Shaar et al., 2015). Moreover, top management support influences the organisational structure and information technology (IT) synergy to directly affect the company's technology adoption and operational performance. Fernaldi, Hotlan and Selvie (2020) concluded that top management commitment has an impact on operational performance using information technology and supply chain management practices. This is because management has shown its commitment by providing the human resources needed to support the use of technology, which is provided according to the company's needs to maximise technological use and function in providing data and information to top management and the rest of the business, as part of the strategy to facilitate business functions.

3.1.2 Customised Customer focus (Voice of the customer)

The second dimension is customed customer focus. Customer focus (CF) remains the main pillar of quality management. Goetsch and Davis (2014) compared customer focus to a driver's seat, which is the final arbiter of the journey as the customer determines the acceptable level of quality. Gaskin et al. (2010) termed the voice of a customer as a business phrase used to describe the process of eliciting customer requirements. It helps to generate a comprehensive list of

ISSN 1335-1745 (print) ISSN 1338-984X (online)

customer wants and requirements that are grouped hierarchically and ranked according to their relative relevance and importance, as well as the level of satisfaction. Efimova and Briš (2021) posited that innovative technologies are advantageous to quality management processes and customer satisfaction. This is mainly driven by the amount of customer data that these technologies are capable of providing for decision-making and competitive advantage. This results from creating a customised customer when efforts are made to establish an environment that prioritises streamlined efficiency and customisation. Using big data, robots, machine learning and artificial intelligence facilitates efficiency and the development of solutions to significantly enhance customer performance (Mtotywa, Seabi and Moitse, 2021). In addition to customised customers, 4IR technologies enhance customer-relationship management (CRM) and penalty-reward contrast analysis. Studies generally demonstrate that customer-relationship management has a substantial impact on customer satisfaction and that the two variables are positively related (Hassan et al., 2015; Santouridis and Veraki, 2017). This means that if a business makes its CRM as robust and trustworthy as possible, its customers will more likely be satisfied and remain loyal. This was supported by Cavaliere et al. (2021) who found a correlation between CRM technology implementation and customer satisfaction, with a higher customer satisfaction rate correlating with increased CRM technology implementation. This can be complemented with an effective penalty-reward-contrast analysis (PRCA) that can be used to uncover asymmetric influences of product/service qualities on total customer satisfaction (Albayrak and Caber, 2013).

3.1.3 Technology-driven employee involvement and empowerment

The third dimension is technology-driven employee involvement and empowerment (EE). Technologies can be used in Quality 4.0 to improve employees' baseline skills and to increase their skills scale-up. Javaid et al. (2021) argued that social media, artificial intelligence, machine learning and virtual reality, among others, can be used to help with training and capacity building in the firm. Antony et al. (2022) highlighted that implementing Quality 4.0 would necessitate continual training and retraining of staff to pose a social problem. Furthermore, the societal consequences of Quality 4.0 will transform society into a knowledge-based society so that as repetitive operations are automated, a higher level of expertise will be required of quality specialists. In addition, Quality 4.0 will increase skills, including data science, programming, configuring and managing modern systems. Creativity, conflict resolution and emotional intelligence will be needed in the digital age.

3.1.4 Process and systems integration and management

The fourth dimension is the process and systems integration and management (PS). The TQM places a premium on process quality (Nguyeni and Nagase, 2019) as there is a cohesive link between the quality of the product or service, the quality of the process and the dimensional aspect of processes leading to an effective quality outcome for customer satisfaction. The quality management system is made up of interconnected procedures and an understanding of how this system produces outcomes allows an organisation to optimise the system and its performance. Sadikoglu and Olcay (2014) emphasised the importance of process management as it ensures activities through a collection of strategies, including preventive and proactive approaches. The technologies from the 4IR, especially enabling technologies such as the internet of things (IoT), cloud computing, integrated systems and virtual reality (VR), big data and blockchain (Carvalho et al., 2021) that enhance the quality of process and systems integration and management to help ensures that there is transparency and self-learning that optimise efficiency and performance. This also allows for early prediction of errors and less downtime by predicting early maintenance.

3.1.5 Knowledge for decision-making and future prediction

The fifth dimension is the knowledge for decision-making and future prediction (KP). Effective knowledge has long been at the forefront of planning and decision-making. It helps to minimise uncertainty which can create difficulties in businesses, with individuals and organisations attempting to minimise risks and maximise benefits (Petropoulos et al., 2022). Numerous business applications necessitate a variety of techniques to address real-world issues. This has become more critical with the increasing environmental turbulence that is experienced in the operating environment. Chatterjee and Chaudhuri (2021) highlighted such turbulence, which includes market turbulence, competitive intensity, technological turbulence and pandemic turbulence.

Fundin et al. (2020) reported that stability in change forms a component of the Quality 2030 agenda. This stability in change symbol emphasises the need to develop knowledge of the dynamics between stability and change through new knowledge that could lead to improvements in frameworks and management models to, in turn, lead and govern through rapid change. It may also boost the ability to drive both change and stability, both seen as possible synergistic allies. Honarpour, Jusoh and Nor (2012) posited that TQM practices improve knowledge creation and transformation. Utilising information effectively in quality management boosts the success of quality improvement operations. Within the scope of quality management, organisational processes should be addressed that ensure synergistic coupling of data and information tracking to innovative to capacity development of the workforce. Such knowledge transfer guarantees ongoing augmentation of complete quality management (Long et al., 2016).

3.1.6 Root cause analysis of operations disturbances and sustainable solution

The sixth dimension involves root cause analysis of operational disturbances and sustainable solutions (RC). Root cause analysis (RCA) is a very successful methodology for product design teams and production managers to engage in creative solutions that leverage instruments of the 4IR – Industry 4.0. This problem-solving method, launched as part of a bigger continuous improvement initiative, also includes the exploitation of digital applications and smart devices to communicate data across the firm in real-time (Vo, Kongar and Suárez-Barraza, 2020). While RCA is an excellent technique for determining the remote and immediate causes of events, it is ineffective in establishing effective preventative measures (Martin-Delgado et al., 2020). As such, it is important to move beyond RCA, and focus on the approach as provided by Lean Six Sigma, Theory of Constraints and Lean methodologies., which emphasise sustainable solutions. This solution can be tested with design of experiment (DOE) and simulation so as to obtain feasible solutions that satisfy all constraints and optimise yields and best value (Taha, 2017). Technology driven route cause analysis in operations disturbances using technologies such as the IoT focus on the data these devices collect, analyse, review and automate rather than on the cutting-edge, smart devices themselves (Guan et al., 2022). This knowledge, problem solving and root cause analysis can be handled more appropriately based on the acquired data. Managers can encourage staff to utilise these insights for good decision-making. Technology can also remove duplicate or tedious processes, thus streamlining the data necessary to conduct root cause analysis of operations disturbances, and in the process increasing the efficiency of a business.

3.1.7 Operational environment benchmarking

The last dimension is operational environment benchmarking (OB). Benchmarking is a quality management tool (Milosevic et al., 2013) that is part of breakthrough improvement involving discontinuous rather than gradual change. Operational environmental benchmarking includes competitive benchmarking of processes and products or service performance of competitors, process benchmarking of key work processes and strategic benchmarking, both strategies aimed at providing competitive advantage (Evans, 2017). Büyüközkan and Maire (1998) and Bhutta and Huq (1999) argued that benchmarking is a never-ending process of discovery and learning that finds and assesses the best practices and performance, so that it should be integrated into an organisation’s current activities to boost effectiveness, efficiency and flexibility. Because benchmarking is a continuous activity, this approach is aligned with Deming’s Plan-Do-Check-Act (PDCA) cycle (Moriarty and Smallman, 2009; Kailong, 2019). The defining characteristic of benchmarking is it’s incorporation into a comprehensive and inclusive policy for continual quality improvement (CQI). Conditions for successful benchmarking centre primarily on process planning, relevant indicator monitoring, staff participation and inter-organisational visits (Ettorchi-Tardy, Levif and Michel, 2012). Benchmarking may help improve quality and other interventions (Willmington et al., 2022).

3.2 Quality 4.0 Index Scale

As indicated in Figure 1, each of the seven dimensions has four items and so the developed Quality 4.0 maturity index is comprised of 28 items that together focus on understanding Quality 4.0 maturity within a business to improve its efficiency and performance.

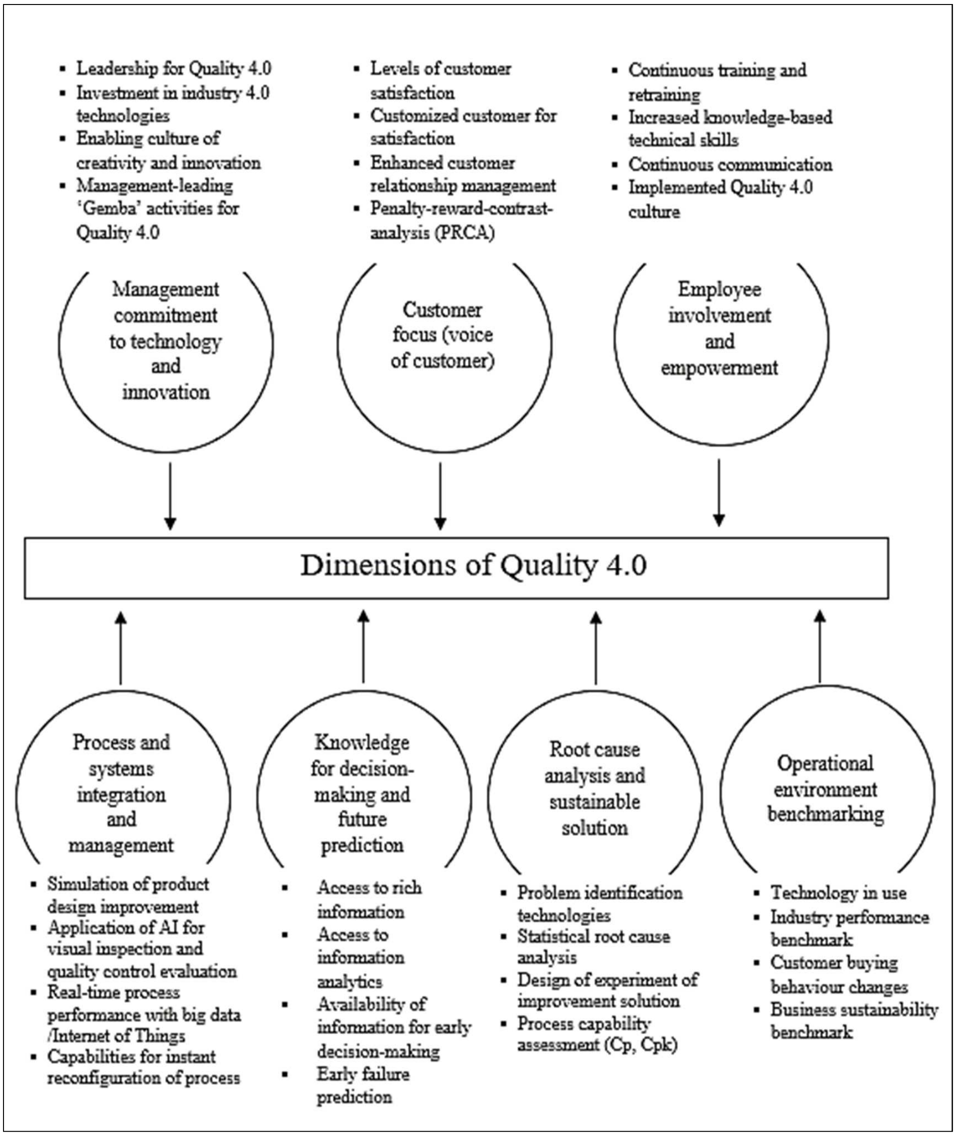

Figure 1 – Dimensions of Quality 4.0

3.3 Assessment of the Maturity Index

Assessment of the maturity index for each of the 28 items is evaluated using a 5-point scale from Level 1 to Level 5. Level 1 assesses the awareness of the business concerning quality management and the use of technology in quality management. Level 2 involves the initial or ad hoc use of technology for quality management. Level 3 is achieved when the business has established and is focused on improving critical business operations. Level 4 is achieved when there is confirmed efficiency and operational performance from an established process and effectively measured efficiency. In Level 5, the business shows a level of maturity and realises a return on investment (ROI) from the use of Quality 4.0 through cost saving, market share growth, safety improvements, profitability, improved customer satisfaction, customer-repurchase or competitive advantage. The investment can be quantified with established financial instruments such as net present value (NPV), internal rate of return (IRR) or payback. These index assess each of the seven dimensions (MC, CF, EE, PS, KP, RC, OB) developed in this Quality 4.0 model (Appendix, Table A1).

3.4 Business Maturity Level

3.4.1 Fit for covariation

It is crucial to verify the comparability of Quality 4.0 dimension measures, since respondents from two different settings may view these dimensions differently (Malhotra et al., 2013). This may be developed using the concept of fit as covariation as described by Venkatraman (1989) that is based on the view that underlying theoretical variables are related and require consistent attention across all of them. Venkatraman (1989) further argued that in this perspective, there is a requirement for high precision in the patterns of logical consistency among the dimensions. The covariation can be modelled with exploratory and confirmatory factor analysis (EFA).

Such EFA is based on the model of common factors with variables expressed as a function of common factors, unique factors and measurement errors (Watkins, 2018; Mtotywa, 2019). Each distinct factor affects a single manifest variable and cannot account for correlations between variables. The factor structure involves sphericity and KMO measurement to determine the feasibility of conducting factor analysis (Dziuban and Shirkey, 1974; Asadollahfardi et al., 2015).

The Kaiser, Meyer, Olkin (KMO) measure of sampling adequacy (MSA) quantifies the degree to which each variable in a set is accurately predicted by the other variables (Kaiser, 1974). The Kaiser-Meyer-Olkin (KMO) statistic ranges from 0 to 1 where a value of 0 indicates that the sum of partial correlations is significantly larger than the sum of correlations, implying that factor analysis is likely ineffective. A KMO value near unity indicates that the sum of partial correlations is small compared to the sum of correlations, suggesting that factor analysis should produce distinct and reliable factors. Performing factor analysis requires specifying the number of retained or extracted components (or latent variables). This choice is frequently motivated or justified by statistical indices and procedures that aim to determine the optimal number of factors. The number of retained factors is based on an Eigen value ($\psi \geq 1.0$) and/or Scree plot.

The Bartlett's Sphericity Test determines whether a matrix (of correlations) deviates significantly from the identity matrix. The test indicates the likelihood that the correlation matrix contains significant correlations between at least some of the variables in a dataset, a condition necessary for factor analysis to work. In other words, before beginning factor analysis, one must determine the significance of Bartlett's Test of Sphericity.

The confirmatory factors analysis can then be used to validate the constructs with structural equation modelling (SEM), either covariant (SEM-CB) or partial least square (PLS-SEM). The convergent validity is evaluated with average variance extracted (AVE) using equation 1:

$$AVE = \frac{\sum \lambda^2}{n} \tag{1}$$

where λ is the factor loading while n is the indicator in the factor. Using equation 2, discriminant validity (DV) can then be determined using the square-root value of AVE to compare with inter-construct correlation values where the square root of AVE should be higher than inter-construct correlation values:

$$DV = \sqrt{AVE} \tag{2}$$

DV is the discriminant value and there is discriminant validity if:

$$AVE > MSV \tag{3}$$

$$AVE > ASV \tag{4}$$

where MSV is the Maximum Shared Variance, while ASV is the Average Squared Shared Variance.

In PLS-SEM, the Heterotrait-Monotrait criterion ($HTMT$) is used to determine the discriminant (Hair et al., 2018):

$$HTMT_{ij} = \frac{W}{\sqrt{R \ x \ Q}} \tag{5}$$

where W is the average heterotrait-heteromethod correlations, which is the average of all pairwise correlations between items of the first construct and the second construct. R is the average monotrait-heteromethod correlations, which are means of all pairwise correlations between items of the first construct. Q is the average monotrait-heteromethod correlation which are all pairwise correlation between items of the second construct. The reliability is determined using composite reliability:

$$CR = \frac{(\sum \lambda)^2}{(\sum \lambda)^2 + (\sum \varepsilon)} \tag{6}$$

where ε = 1- λ. The development of the valid and reliable Quality 4.0 constructs confirms results that indicate support for measure equivalence, which permits appropriate comparisons and interpretation of the results when characterising the quality of a maturity model (Byrne, 2004; Asdecker and Felch, 2018).

3.4.2 Composite score for the level of Quality 4.0 maturity

The next step is to conduct a Quality 4.0 business maturity level. The relative score is then translated into a maturity stage, with the five steps describing a route to maturity, *i.e.,* excellence in leveraging Quality 4.0 for efficiency and performance in the business. The MID is the quality maturity index score of the individual dimensions (*MC, CF, EE, PS, KP, RC, OB)* that were indicated in Figure 1, in the operational process, *j* in the organisation:

$$MID_j = \frac{\sum_{i=1}^{4} QI_{ij}}{4} \tag{7}$$

where QI_1, QI_2, QI_3,QI_4 are items used for assessing Quality 4.0 maturity. For the total composite score for all items, CC:

$$CC_j = \frac{MC_{ij} + CF_{ij} + EE_{ij} + PS_{ij} + KP_{ij} + RC_{ij} + OB_{ij}}{7} \tag{8}$$

With the the overall quality maturity index score for the process, QMI_j:

$$QMI_j = \frac{CC_j}{5} X100\% \tag{9}$$

AWR (≤ 0.20), AWR – ADH (0.20 ≤ QMI ≤ 0.40), EFP (0.40 ≤ QMI ≤ 0.60), EFP-IMP (0.60 ≤ QMI ≤ 0.80), ROV (≥ 0.80). Zero to 1 is 0% to 100%.

3.5 Operationalisation of the Quality 4.0 Maturity Index

The operationalisation of the Quality 4.0 maturity index would work in the following manner using a fictitious set of data as indicated in Table 1.

This index is applicable in processes, a business unit or organisation and group of experts or people with in-depth knowledge of an area of investigation. These individuals must be selected carefully and should be limited to subject matter experts, process owners, internal or external consultants with relevant expertise and senior management. The fit for covariance will mainly be applicable in the analysis group of experts or people with in-depth knowledge of process or organisation, as there should be sufficient data for accumulation.

In this theoretical example, the measure will be the mean scores ($\check{Q}$). The MID is computed based on equation 7 and on this fictitious data and the overall MID_j = 25.75. Based on equation 8, CC_j = 3.679 and using equation 9, QMI_j = 73.57%. The maturity index based on the guidelines provided is EFP-IMP (60.0% ≤ QMI ≤ 80.0%). In this scheme, a high score closes to 1 (100%) indicates higher maturity in leveraging the advantages of Quality 4.0 for improved efficiency and organisational performance, while a lower score shows the opposite potential.

Table 1 – A Numerical Illustration of Operationalisation of the Maturity Index in Implementing Quality 4.0 in the Business

Maturity index dimension	Measured Score $(QI_1,)$*	Measured Score (QI_2)*	Measured Score (QI_3)*	Measured Score (QI_4)*	Number of items per dimension	MID
MID_1	1	5	4	3	4	3.25
MID_2	4	5	3	3	4	3.75
MID_3	5	3	2	5	4	3.75
MID_4	2	5	2	3	4	3.00
MID_5	5	5	3	5	4	4.50
MID_6	4	5	3	4	4	4.00
MID_7	5	2	5	2	4	3.50
						25.75
CC_j						3.679
QMI_j						73.57%

Notes: * - fictitious data.

4 CONCLUSION

Quality 4.0 is regarded as an expanded approach to quality management in which new technologies are combined with established quality techniques (QC, QA, TQM) in order to broaden the scope of quality management and to improve quality operations (Sader, Husti and Daroczi, 2022). Developing a Quality 4.0 maturity index for improved operational efficiency and performance is critical for businesses as they are faced with adapting to environmental turbulence from changes in customer behaviour and preferences as well as recovery from the COVID-19 pandemic, which has hugely disrupted industries (Nicola et al., 2020).

The Quality 4.0 maturity index was constructed in the study based on seven different characteristics of ongoing quality improvement. These include a management commitment to technology and innovation-driven operations, a customer focus that enhances the voice of the customer, employee involvement and empowerment, integration and management of processes and systems, root cause analysis of operational disturbances and sustainable solutions, knowledge for decision-making and future prediction as well as benchmarking of the operating environment.

In addition, the level of maturity of various aspects of the company is evaluated using a scale with five levels, beginning with the stage of awareness (Level 1) and progressing all the way up to an optimised process with evidence of return on investment (Level 5). Whether or not the index is helpful is determined through the use of fit as covariation and a composite score for the level of Quality 4.0 maturity.

4.1 Theoretical Implications of the Study

Quality 4.0 analytical strategies add to the body of knowledge to enhance total quality management already enhanced by technologies associated with the fourth industrial revolution. As Efimova and Briš (2021) highlighted that Quality 4.0 is still in its infancy and no standard has been established, use of such strategies can help to improve the business and industry base surrounding Quality 4.0,. Thus, this study has also contributed to the quality 2030 agenda which focuses on quality management of the future, in particular the "stability in change" which relates to the idea that organisations require not only continuity or stability, but also change, including disruptive change involving technologies (Fundin et al., 2020).

4.2 Practical Implications for Management

Management in businesses should make an effort to create an enabling environment that will allow for effective implementation of Quality 4.0. Quality 4.0 provides numerous benefits to quality management, including increased speed and transparency, increased adaptability to new situations and continual improvement across businesses plus increased awareness, skills and intelligence. It helps with industrial transformation and has a direct effect on customer service and satisfaction, or its product or service customisation (Milunovic Koprivica et al., 2019). Adopting a novel quality paradigm necessitates changes at every level of the business, along with societal and technological changes that are required to adapt to Quality 4.0 – thus, important adjustments to management models and systems are also required (Dias, Carvalho and Sampaio, 2021). The study also aimed at practically benefiting a business by focussing on improved business capacity and capability to mitigate the environmental turbulence associated with pandemics, geopolitical instabilities and other turbulence.

4.3 Strength and Limitations of the Research

The strenght of the research model is dependent on the depth of theory on TQM and the continued development of Quality 4.0, factors that are synthesised and presented in this paper. The development follows an approach towards effective development of a maturity index (Venkatraman, 1989; Schumacher, Erol and Sihn, 2016; Asdecker and Felch, 2018). Despite this, the research is theoretical and has not been validated by empirical evidence. This means that the maturity index model should be optimised following the incorporation of empirical data, a limitation of the research.

4.4 Direction for Future Research

Quality 4.0 is still in its infancy and necessary improvements to it will demand resources. Nonetheless, the benefits of technologies in quality management could offer industrial businesses a competitive advantage (Efimova and Briš, 2021). It is suggested that a validation study be done using the methodology and principles outlined in the article. This can be done across different business value chains. Although the model is potentially applicable across all business sections and operations where it is used, the greater the comprehensive nature of its testing should provide increased validation for the model.

REFERENCES

Agus, A. and Hassan, Z., 2011. Enhancing production performance and customer performance through Total Quality Management (TQM): Strategies for competitive advantage. *Procedia—Social and Behavioral Sciences*, 24, pp.1650-1662.

Al Shaar, E.Q., Khattab, S.A., Alkaied, R.N. and Manna, A.Q., 2015. The effect of top management support on innovation: the mediating role of synergy between organizational structure and information technology. *International Review of Management and Business Research*, 4(2), pp. 499-513.

Albayrak, T. and Caber, M., 2013. Penalty–Reward-Contrast Analysis: a review of its application in customer satisfaction research. *Total Quality Management & Business Excellence*, [e-journal] 24(11-12), pp.1288-1300. DOI: 10.1080/14783363.2013.776757.

Alweteed, N., 2018. The Impact of Total Quality Management on the Organization Performance. *European Journal of Business and Management*, 10(34), pp.69-71.

Antony, J., Sony, M., Furterer, S., McDermott, O. and Pepper, M., 2022. Quality 4.0 and it's impact on organizational performance: An intergrative viewpoint. *The TQM Journal*, [e-journal] (ahead-of-print). DOI: 10.1108/TQM-08-2021-0242.

Aquilani, B., Silvestri, C., Ruggieri, A. and Gatti, C., 2017. A systematic literature review on total quality management critical success factors and the identification of new avenues of research. *The TQM Journal*, [e-journal] 29(1), pp.184-213. DOI: 10.1108/TQM-01-2016-0003.

Asadollahfardi, G., Zamanian, M., Mirmohammadi, M., Asadi, M. and Tameh, F.I., 2015. Air pollution study using factor analysis and univariate Box-Jenkins modeling for the northwest of Tehran. *Advances in Environmental Research*, [e-journal] 4(4), pp.233-246. DOI: 10.12989/aer.2015.4.4.233.

Asdecker, B. and Felch,V., 2018. Development of an Industry 4.0 maturity model for the delivery process in supply chains. *Journal of Modelling in Management*, [e-journal] 13(4), pp.840-883. DOI: 10.1108/JM2-03-2018-0042.

Bergman, B. and Klefsjö, B., 2010. *Quality from customer needs to customer satisfaction*. Studentlitteratur AB. Lund University.

Bernon, M., Bastl, M., Zhang, W. and Johnson, M. 2018. Product recalls: The effects of industry, recall strategy and hazard, on shareholder wealth. *International Journal of Business Science and Applied Management*, 13, pp.1-14.

Bhutta, K. and Huq, F., 1999. Benchmarking – Best Practices: an Integrated Approach. *Benchmarking for Quality Management & Technology*, [e-journal] 6(3), pp.254-268. DOI: 10.1108/14635779910289261.

Biggemann, S., Kowalkowski, C., Maley, J. and Brege, S., 2013. Development and implementation of customer solutions: A study of process dynamics and market shaping. *Industrial Marketing Management*, [e-journal] 42(7), pp.1083-1092. DOI: 10.1016/j.indmarman.2013.07.026.

Bouranta, N., Psomas, E., Suárez-Barraza, M.F. and Jaca, C., 2019. The key factors of total quality management in the service sector: a cross-cultural study. *Benchmarking: An International Journal*, [e-journal] 26(6), pp.1-31. DOI: 10.1108/BIJ-09-2017-0240.

Broday, E.E., 2022. The evolution of quality: from inspection to quality 4.0. International *Journal of Quality and Service Sciences*, [e-journal] (ahead-of-print). DOI: 10.1108/IJQSS-09-2021-0121.

Büyüközkan, G. and Maire, J.L., 1998. Benchmarking Process Formalization and a Case Study. *Benchmarking for Quality Management & Technology*, [e-journal] 5(2), pp.101-125. DOI: 10.1108/14635779810212356.

Byrne, B.M., 2004. Testing for multi-group invariance using AMOS graphics: A road less travelled. *Structural Equation Modelling*, [e-journal] 11(2), pp.272-300. DOI: 10.1207/s15328007sem1102_8.

Carnerud, D. and Bäckström, I., 2021. Four decades of research on quality: summarising, Trendspotting and looking ahead. *Total Quality Management & Business Excellence,* [e-journal] 32(9-10), pp.1023-1045. DOI: 10.1080/14783363.2019.1655397.

Carvalho, A.V., Enrique D.V., Chouchenea, A. and Charrua-Santos, F., 2021. Quality 4.0: An Overview. *Procedia Computer Science*, 181, pp.341-346.

Cavaliere, L.P.L., Khan, R., Sundram, S., Jainani, K., Bagale, G., Chakravarthi, M.K., Regin, R. and Rajest, S.S., 2021. The Impact Of Customer Relationship Management On Customer Satisfaction And Retention: The Mediation Of Service Quality. *Turkish Journal of Physiotherapy and Rehabilitation*, 32(3), pp.22107-22121.

Chang, W., Ellinger, A.E. and Blackhurst, J., 2015. A contextual approach to supply chain risk mitigation. *The International Journal of Logistics Management*, [e-journal] 26(3), pp.642-656. DOI: 10.1108/IJLM-02-2014-0026

Chatterjee, S. and Chaudhuri, R., 2021. Supply chain sustainability during turbulent environment: Examining the role of firm capabilities and government regulation. *Oper Manag Res*, [e-journal] (ahead-of-print). DOI: 10.1007/s12063-021-00203-1.

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*, [e-journal] 32(4), pp.603-616. DOI: 10.1108/TQM-04-2020-0082.

Deshpande, A., 2019. Total Quality Management, Concurrent Engineering and Manufacturing Performance: An Empirical Investigation. *Journal of Operations and Strategic Planning*, [e-journal] 2(1), pp.35-64. DOI: 10.1177/ 2516600X19845230.

Dias, M.A., Carvalho, A.M. and Sampaio, P., 2021. Quality 4.0: literature review analysis, definition and impacts of the digital transformation process on quality. *International Journal of Quality & Reliability Management*, [e-journal] 39(6), pp.1312-1335. DOI: 10.1108/IJQRM-07-2021-0247.

Dziuban, C.D. and Shirkey, E.S., 1974. When is a correlation matrix appropriate for factor analysis? Some decision rules. *Psychology Bulletin*, 81, pp.358-361.

Efimova, A. and Briš, P., 2021. Quality 4.0 for Processes and Customers. *Quality Innovation Prosperity*, [e-journal] 25(3), pp.33-47. DOI: 10.12776/qip.v25i3.1609.

Ettorchi-Tardy, A., Levif, M. and Michel, P., 2012. Benchmarking: a method for continuous quality improvement in health. *Healthcare policy = Politiques de sante*, 7(4), e101–e119.

Evans, J.R., 2017. *Quality and Performance Excellence: Management, Organization and Strategy.* 8th ed. Boston: Cengage Learning.

Fayyaz, A., 2021. Total Quality Management and its Implementation in the Context of Pakistan. *Theory Methodology Practice*, 17(2), pp. 45-51.

Felix, E., 2015. Marketing Challenges of Satisfying Consumers Changing Expectations and Preferences in a Competitive Market. *International Journal of Marketing Studies*, [e-journal] 7(5), pp.41-52. DOI: 10.5539/ijms.v7n5p41.

Fernaldi, D.L., Hotlan, S. and Selvie, J.O., 2020. The Effects of Top Management Commitment on Operational Performance Through the Use of Information Technology and Supply Chain Management Practices. ICSH. *SHS Web of Conferences*, [e-journal] 79, pp.1-12. DOI: 10.1051/shsconf/20207601009.

Fundin, A., Lilja, J., Lagrosen, Y. and Bergquist, B., 2020. Quality 2030: quality management for the future. *Total Quality Management & Business Excellence*, [e-journal], pp.1-17. DOI: 10.1080/14783363.2020.1863778.

Gaskin, S.P., Griffin, A., Hauser, J.R., Katz, G.M. and Klein, R.L., 2010. *Voice of Customer*. John Wiley & Sons Ltd.

Goetsch, D.L. and Davis, S.B., 2014. *Quality Management for Organizational Excellence.* Upper Saddle River: Pearson.

Gold, S.C. and Pray, T.F., 1999. Changing Customer Preferences and Product Characteristics in the Design of Demand Functions. *Simulation & Gaming*, [e-journal] 30(3), pp.264-282. DOI: 10.1177/104687819903000303.

Guan, A.L.C., Manavalan, M., Ahmed, A.A.A., Azad, M.M. and Miah, S., 2022. Role of internet of things (IoT) in enabling productive work from home (wfh) for environmental volatiles. *Academy of Marketing Studies Journal*, 26(1), pp. 1-11.

Gunasekaran, A., Subramanian, N. and Ngai, W.T.E., 2019. Quality management in the 21st century enterprises: Research pathway towards Industry 4.0. *International Journal of Production Economics*, [e-journal] 207, pp.125-129. DOI: 10.1016/j.ijpe.2018.09.005.

Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E., 2018. *Multivariate Data Analysis*. 8th ed. United Kingdom: Cengage Learning.

Hassan, R.S., Nawaz, A., Lashari, M.N. and Zafar, F., 2015. Effect of Customer Relationship Management on Customer Satisfaction. *Procedia Economics and Finance*, [e-journal] 23, pp.563-567. DOI: 10.1016/S2212-5671(15)00513-4.

Honarpour, A., Jusoh, A. and Nor, K., 2012. Knowledge Management, Total Quality Management and Innovation: A New Look. *Journal of Technology Management and Innovation*, [e-journal] 7(3), pp.22-31. DOI: 10.4067/S0718-27242012000300003.

Huizingh, E., 2011. Open innovation: State of the art and future perspectives. *Technovation*, [e-journal] 31(1), pp.2-9. DOI: 10.1016/j.technovation.2010.10.002.

Igartua, J.I., Garrigós, J.A. and Hervas-Oliver, J.L., 2010. How innovation management techniques support an open innovation strategy. *Research Technology Management*, [e-journal] 53, pp.41-52. DOI: 10.1080/08956308.2010.11657630.

Jacob, D., 2017. *Quality 4.0 impact and strategy handbook: getting digitally connected to transform quality management*. Cambridge: LNS Research.

Javaid, M., Haleem, A., Singh, R.P. and Suman, R., 2021. Significance of Quality 4.0 towards comprehensive enhancement in manufacturing sector. *Sensors International*, [e-journal] 2, pp.1-13. DOI: 10.1016/j.sintl.2021.100109.

Kailong, E.K., 2019. Application of Demings cycle in benchmarking and performance in public Secondary schools in Keiyo sub-county, Kenya. *International Journal of Advanced Research*, 7(4), pp.991-999.

Kaiser, H.F., 1974. An index of factorial simplicity. *Psychometrika*, 39, pp.31-36.

Lee, S.M., Lee, D. and Kim, Y.S., 2019. The quality management ecosystem for predictive maintenance in the Industry 4.0 era. *International Journal of Quality Innovation*, [e-journal] 5(4), pp.1-11. DOI: 10.1186/s40887-019-0029-5.

Long, C.S., Kowang, T.O., Fei, G.C. and Mang, H.P., 2016. Importance of Knowledge Management on Total Quality Management: A Review. *World Applied Sciences Journal*, [e-journal] 34(12), pp.1829-1833. DOI: 10.5829/idosi.wasj.2016.1829.1833.

Magno, F., 2012. Managing product recalls: The effects of time, responsible vs. Opportunistic recall management and blame on consumer‘s attitudes. *Procedia – Social and Behavioral Sciences*, [e-journal] 58, pp.1309-1315. DOI: 10.1016/j.sbspro.2012.09.1114.

Malhotra, N., Mavondo, F., Mukherjee, A. and Hooley, G., 2013. Service quality of frontline employees: A profile deviation analysis. *Journal of Business Research*, [e-journal] 66(9), pp.1338-1344. DOI: 10.1016/j.jbusres.2012.02.034.

Martin-Delgado, J., Martínez-García, A., Aranaz, J.M., Valencia-Martín, J.L. and Mira, J.J., 2020. How Much of Root Cause Analysis Translates into Improved Patient Safety: A Systematic Review. *Medical Principles and Practice*, [e-journal] 29(6), pp.524-531. DOI: 10.1159/000508677.

Mihajlović, I. and Koncul, N., 2016. Changes in consumer behaviour – the challenges for providers of tourist services in the destination. *Economic Research-Ekonomska Istraživanja,* [e-journal] 29(1), pp. 914-937. DOI: 10.1080 /1331677X.2016.1206683.

Milosevic, D., Djuric, M., Filipovic, J. and Ristic, S., 2013. Benchmarking as a Quality Management Tool in Public Administration. *Inzinerine Ekonomika-Engineering Economics*, [e-journal] 24(4), pp.364-372. DOI: 10.5755/j01.ee.24.4.2785.

Milunovic Koprivica, S., Maric, A., Ristic, O. and Arsovski, S., 2019. Social oriented quality: from quality 4.0 towards quality, and 5.0. *Proceedings on Engineering Sciences*, [e-journal] 1(2), pp.405-410. DOI: 10.24874/PES01.02.038.

Morgan, C. and Murgatroyd, S., 1997. *Total quality management in the public sector*. Buckingham, UK: Open University Press.

Moriarty, J.P. and Smallman, C., 2009. En route to a theory of benchmarking. *Benchmarking: An International Journal*, [e-journal] 16(4), pp.484-503. DOI: 10.1108/14635770910972423.

Mortara, L., Kerr, C.I.V., Phaal, R. and Probert, D.R., 2009. Technology Intelligence Practice in UK Technology-Based Companies. *International Journal of Technology Management*, [e-journal] 48(1), pp.115-135. DOI: 10.1504/IJTM.2009.024603.

Mosadeghrad, A.M., 2013. Obstacles to TQM success in health care systems. *International Journal of Health Care Quality Assurance*, [e-journal] 26(2), pp.147-173. DOI: 10.1108/09526861311297352.

Mtotywa, M.M., 2019. *Conversations with Novice Researchers*. East London: AndsM.

Mtotywa, M.M., Manqele, S.P., Mthethwa, N., Seabi, M.A. and Moitse, M., 2022. Barriers to Effectively Leveraging Opportunities within the Fourth Industrial Revolution in South Africa. *African Journal of Developmental Studies*, [e-journal] 2, pp.213-236. DOI: 10.31920/2634-3649/2022/sin1a10.

Mtotywa, M.M., Seabi, M.A. and Moitse, M., 2021. South African citizens‘ self-assessed knowledge about the fourth industrial revolution. *African Journal of Science, Technology, Innovation and Development*, [e-journal], pp.1-10. DOI: 10.1080/20421338.2021.1961358.

Nenadál, J., 2020. The New EFQM: what is really new and could be considered as a suitable tool with respect to quality 4.0. *Quality Innovation Prosperity*, [e-journal] 24(1), pp.17-28. DOI: 10.12776/qip.v24i1.1415.

Nguyeni, L. and Nagase, K., 2019. The influences of total quality management on consumer satisfaction. *International Journal of Healthcare Management*, [e-journal] 12(4), pp.277-285. DOI: 10.1080/20479700.2019.1647378 .

Nicola, M., Zaid, A., Sohrabi, C., Kerwan, A., Al-Jabir, A., Iosifidis, C., Agha, M. and Agha, R., 2020. The socio-economic implication of the coronavirus pandemic (COVID-19): A Review. *International. Journal of Surgery*, [e-journal] 78, pp.185-193. DOI: 10.1016/j.ijsu.2020.04.018.

Oakland, J., 1989. *Total quality management*. Oxford, UK: Heinemann.

Petropoulos, F., Apiletti, D., Assimakopoulos, V. and Yusupova, A., Ziel, F., 2022. Forecasting: theory and practice. *International Journal of Forecasting*, [e-journal] 38(3), pp.705-871. DOI: 10.1016/j.ijforecast.2021.11.001.

Prajogo, D.I. and Cooper, B., 2017. The individual and organizational level effects of TQM practices on job satisfaction. *International Journal of Manpower*, [e-journal] 38(2), pp.215-225. DOI: 10.1108/IJM-12-2014-0240.

Prajogo, D.I. and Hong, S.W., 2008. The effect of TQM performance in R&D environments: A perspective from South Korean firms. *Technovation*, [e-journal] 28(12), pp.855-863. DOI: 10.1016/j.technovation.2008.06.001.

Psomas, E. and Fotopoulos, C., 2010. Total quality management practices and results in food companies. *International Journal of Productivity and Performance Management*, 59(7), pp.688-687.

Rifqi, H., Zamma, A., Souda, B. and Hansali, M., 2021. Lean Manufacturing Implementation through DMAIC Approach: A case study in the automotive industry. *Quality Innovation Prosperity*, [e-journal] 25(2), pp.54-77. DOI: 10.12776/qip.v25i2.1576.

Sader, S., Husti, I. and Daróczi, M., 2019. Industry 4.0 as a Key Enabler toward Successful Implementation of Total Quality Management Practices. *Periodica Polytechnica Social and Management Sciences*, [e-journal] 27(2), pp.131-140. DOI: DOI:10.3311/PPso.12675.

Sader, S., Husti, I and Daroczi, M., 2022. A review of quality 4.0: definitions, features, technologies, applications and challenges. *Total Quality Management & Business Excellence*, [e-journal] 33(9-10), pp.1164-1182. DOI: 10.1080/14783363.2021.1944082.

Sadikoglu, E. and Olcay, H., 2014. The Effects of Total Quality Management Practices on Performance and the Reasons of and the Barriers to TQM Practices in Turkey. *Advances in Decision Sciences*, [e-journal] 2014, pp.1-17. DOI: DOI:10.1155/2014/537605.

Santouridis, I. and Veraki, A., 2017. Customer relationship management and customer satisfaction: the mediating role of relationship quality. *Total Quality Management & Business Excellence*, [e-journal] 28(9-10), pp.1122-1133. DOI: 10.1080/14783363.2017.1303889.

Schumacher, A., Erol, S. and Sihn, W., 2016. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP*, [e-journal] 52, pp.161-166. DOI: 10.1016/j.procir.2016.07.040.

Sony, M. and Aithal, P.S., 2020. Practical lessons for engineers to adapt towards Industry 4.0. *International Journal of Case Studies in Business, I.T. and Education*, [e-journal] 4(2), pp.86-97. DOI: 10.5281/zenodo.

Taha, H., 2017. *Operations Reseach An Itroduction*. Essex, England: Pearson.

Talib, F., 2013. An overview of total quality management: understanding the fundamentals in service organization. *International Journal of Advanced Quality Management*, 1(1), pp.1-20.

Venkatraman, N., 1989. Strategic Orientation of Business Enterprises: The Construct, Dimensionality and Measurement. *Management Science*, [e-journal] 35(8), pp.942-962. DOI: 10.1287/mnsc.35.8.942.

Vo, B., Kongar, E. and Suárez-Barraza, M.F., 2020. Root-Cause Problem Solving in an Industry 4.0 Context. *IEEE Engineering Management Review*, 48, pp.48-56.

Watkins, W., 2018. Exploratory factor Analysis: A guide to best practice. *Journal of Black Psychology*, [e-journal] 44(3), pp.219-246. DOI: 10.1177/0095798418771807.

Weckenmann, A., Akkasoglu, G. and Werner, T., 2015. Quality management–history and trends. *The TQM Journal*, 27(3), pp.281-293. DOI: 10.1108/TQM-11-2013-0125.

Willmington, C., Belardi, P., Murante, A.M. and Vainieri, M., 2022. The contribution of benchmarking to quality improvement in healthcare. A systematic literature review. *BMC Health Services Research*, [e-journal] 22(1), pp.1-20. DOI: 10.1186/s12913-022-07467-8.

Zairi, M., 2013. The TQM legasy – Gurus' contributions and theoretical impact. *The TQM Journal*, [e-journal] 25(6), pp.659-679. DOI: 10.1108/TQM-06-2013-0069.

Zhao, X., Li, Y. and Flynn, B.B., 2013. The financial impact of product recall announcements in China. *International Journal of Production Economics*, [e-journal] 142, pp.115-123. DOI: 10.1016/j.ijpe.2012.10.018.

ABOUT THE AUTHOR

Matolwandile Mzuvukile Mtotywa[0000-0003-2835-1841] – PhD Adjunct Lecturer, Tshwane School for Business and Society, Tshwane University of Technology, Pretoria, South Africa; Director, Business and Social Research Institute, Pretoria, South Africa, e-mail: andile@bsri.co.za.

CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

APPENDIX

Table A1 – Quality 4.0 Assessment of Maturity Index

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Dimensions: Management commitment to technology and innovation					
Leadership for quality 4.0	Leaders not aware of Quality 4.0	*Ad hoc* activities by leaders on Quality 4.0	Leaders have vision and implemented Quality 4.0 in the firm	Quality 4.0 implemented across operations with benefits driven by leaders	Firm quantifying return on investment from Quality 4.0
Investment in industry 4.0 technologies	No firm investment in 4IR technologies	*Ad hoc* investment in 4IR technologies	Firm investment in 4IR technologies part of strategy linked resource allocation	Optimised investment for all critical and interlinked 4IR technologies for operations	Positive NPV/IRR/ payback for optimised investment on 4IR technologies for operations
Enabling culture of creativity and innovation	No technology-driven creativity and innovation culture	*Ad hoc* technology-driven creativity and innovation culture	Established technology-driven creativity and innovation culture	Organisation-wide established and managed technology-driven creativity and innovation culture	Improved efficiencies and performance from optimally managed technology-driven creativity and innovation culture
Management leading 'Gemba' activities for Quality 4.0	No ‘Gemba’ activity on Quality 4.0	Initial ‘Gemba’ activity on Quality 4.0	Established focused ‘Gemba’ activity on Quality 4.0	Improved and managed process ‘Gemba’ activity on Quality 4.0	Evidence of return on investment ‘Gemba’ activity on Quality 4.0
Dimensions: Customer focus (voice of customer)					
Levels of customer satisfaction	Customer satisfaction not measured	*Ad hoc* measurement of customer satisfaction	Established Customer satisfaction	Technology-driven continuous customer satisfaction assessment	Re-purchase and loyalty from customer satisfaction
Customised customer for satisfaction	No customised customer activities in place	*Ad hoc* customised customer activities in place	Established customised customer activities	Managed customised customer activities in place	ROI from customised customer activities

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Enhanced customer relationship management	No customer relationship management in use	*Ad hoc* use of customer relationship management system	Established technology-driven customer relationship management	Continuous technology-driven customer relationship management	ROI from customer relationship management
Penalty-reward contrast analysis (PRCA)	No awareness of PRCA	Awareness and initial use of PRCA	Established and focused use of PRCA	Improved and managed process of PRCA	Firm quantifying return on investment from PRCA
Dimensions: Employee involvement and empowerment					
Continuous training and retraining	No technology-based training	*Ad hoc* technology-based training	Established technology-based training	Advanced technology-based training	ROI on technology-based training
Increase knowledge-based technical skills	No technology-based technical skills	Low technology-based technical skills	Established technology based technical skills	High technology-based technical skills	ROI from high technology-based technical skills
Continuous communication	Non-existent communication in firm	*Ad hoc* technology-driven communication	Established technology-driven communication	Technology-driven internal and external communication	Financial or non-financial ROI on communication
Quality 4.0 firm culture	No total quality culture in firm	*Ad hoc* implementation of total quality culture in the firm	Established focused culture of quality 4.0	Organisation-wide established quality 4.0 culture	Improved efficiencies and performance from Quality 4.0 culture
Dimensions: Process and systems integration and management					
Simulation of product design improvement	No Simulation in use in firm	*Ad hoc* use of simulation technology	Established simulation technology in use	Operations wide simulation in use in firm	ROI from simulation in use in firm
Application of AI for visual inspection and / quality control	No AI or other VR technology in use for inspection/ control	*Ad hoc* technology use in inspection/ control	Established AI or other VR technology in use for inspection / control	Operations wide AI or other VR technology in use for inspection / control	ROI from AI or other VR technology in use for inspection / control

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Real-time process performance monitoring with big data / IoT	No real time process performance monitoring	*Ad hoc* process performance monitoring	Technology driven real time process performance monitoring	Operations wide real time process performance monitoring	ROI from real time process performance monitoring
Capabilities of instant reconfiguration of process	No capabilities of instant reconfiguration of process	Initial capabilities of instant reconfiguration of process	Established capabilities of instant reconfiguration of process	Operations wide capabilities for instant reconfiguration of process	ROI on capabilities and outcomes of instant reconfiguration of process
Dimensions: Knowledge for decision-making and future prediction					
Access to rich information	Operations information not available	*Ad hoc* availability of operations information	Established technology-driven operations information	Operations wide technology-driven information availability	ROI from Operations wide technology-driven information availability
Access to information analytics	No access to information analytics	*Ad hoc* access to information analytics	Established access to information analytics	Operations wide technology-driven access to information analytics	ROI from Operations wide technology-driven access to information analytics
Availability of information for early decision-making	No available information for early decision-making	*Ad hoc* availability of information for early decision-making	Established available information for early decision-making	Operations wide technology-driven information for early decision-making	ROI from Operations wide technology-driven information for early decision-making
Early failure prediction	No early failure prediction	*Ad hoc* early failure prediction	Established early failure prediction technology in use	Operations wide technology-driven early failure prediction	ROI on Operations wide technology-driven early failure prediction

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Dimensions: Root cause analysis and sustainable solution					
Problem identification technologies	No problem identification technology in use	Initial or *Ad hoc* use problem identification technology	Established problem identification technology in use	Real-time/on-line problem identification technology in operations	Quantified return on investment from Real-time/on-line problem identification technology in operations
Statistical root-cause analysis	No route-cause analysis process	*Ad hoc* route cause analysis process	Established technology-driven root cause analysis process	Operations interconnected technology-driven root cause analysis	Financial and non-financial return on investment from root cause analysis
DOE for improvement solution	DOE not in use for improvement solution	DOE in use for improvement solution at ad hoc basis	Established DOE in use for improvement solutions	DOE improves design or processing of product or services	DOE result in costs saving/eliminating waste / increase profitability/ customer satisfaction
Process capability assessment	Process capabilities not assessed	*Ad hoc* process capabilities assessed	Established procedure and implementation of capabilities assessment	Process capabilities assessment leveraged for improved design or processing of product or services	Process capabilities saving costs/eliminating waste/increase in profitability/customer satisfaction
Dimensions: Operational environment benchmarking					
Technology in use	No Technology in use	*Ad hoc* technology use in operation	Established use of technology in operation	Improved and managed process technology across operations	Financial or non-financial returns from technology across operations

Items	**Awareness stage (1) – AWR**	**Initial or *Ad hoc* activity stage (2) - ADH**	**Established focused process (3) - EFP**	**Improved and managed process (4) - IMP**	**Optimised process with evidence of ROI (5) - ROV**
Industry performance benchmark	No Industry performance benchmark	*Ad hoc* industry performance benchmark	Technology-based industry performance benchmark implemented	Comprehensive firm strategy aligned to industry performance benchmark	Return on investment on performance benchmark with improved competitive advantage/ profitability
Customers buying behaviour changes	No monitoring of customer buying behaviour changes	*Ad hoc* monitoring of customer buying behaviour changes	Technology monitoring of customer buying behaviour changes	Effectively managed process of monitoring customer buying behaviour changes	Return on investment (cost saving or market share growth) from strategy culminating from monitoring customer buying behaviour changes
Business sustainability benchmark	No sustainability plan	*Ad hoc* sustainability activities, with aid of technology	Technology-driven sustainability plan in place and implemented	Technology-driven continuous sustainability benchmark	Firm leveraging technology-driven sustainability for competitive advantage and future growth

ISSN 1335-1745 (print) ISSN 1338-984X (online)