APPLICATION OF THE DELPHI TECHNIQUE FOR THE SUCCESSFUL ADOPTION OF QUALITY MANAGEMENT 4.0 IN THE SOUTH AFRICAN MANUFACTURING SECTOR

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ABSTRACT

Quality 4.0, an integration of traditional quality management and advanced Industry 4.0 technologies, is transforming manufacturing industries. Despite this, the application and impact of Quality 4.0 in developing nations, particularly in South Africa, has not been adequately explored. Ten experts were asked to use the Delphi technique to identify the critical factors that could lead to the successful adoption of Quality 4.0 in South Africa. Once the experts had reached a consensus, their recommendations were mapped on the Deming (PDCA) cycle. To enable a seamless transition, they emphasised top management support, workforce development, embedding a Quality 4.0 culture, integrating new technologies with legacy processes, and continual monitoring of key performance indicators. The study provides a guide for manufacturers successfully to embrace Quality 4.0, thereby enhancing competitiveness and contributing to the government’s goal of fully embracing Industry 4.0 by 2030, in line with the related United Nations sustainable development goal number 9 on industry, innovation, and infrastructure.

OPSOMMING

Kwaliteit 4.0, 'n integrasie van tradisionele gehaltebestuur en gevorderde Industrie 4.0-tegnologieë, is besig om vervaardigings-nywerhede te transformeer. Ten spyte hiervan is die toepassing en impak van Kwaliteit 4.0 in ontwikkelende lande, veral in Suid-Afrika, nie voldoende ondersoek nie. Tien kundiges is gevra om die Delphi-tegniek te gebruik om die kritieke faktore te identifiseer wat kan lei tot die suksesvolle aanvaarding van Kwaliteit 4.0 in Suid-Afrika. Sodra die kenners 'n konsensus bereik het, is hul aanbevelings op die Deming (PDCA)-siklus gekarteer. Om 'n naatlose oorgang moontlik te maak, het hulle klem gelê op topbestuurondersteuning, arbeidsmagontwikkeling, die inbedding van 'n Kwaliteit 4.0-kultuur, die integrasie van nuwe tegnologieë met erfenisprosesse, en deurlopende monitering van sleutelprestasie-aanwysers. Die studie verskaf 'n gids vir vervaardigers om Kwaliteit 4.0 suksesvol te omhels, en sodoende mededingendheid te verbeter en by te dra tot die regering se doelwit om Nywerheid 4.0 teen 2030 ten volle te omhels, in ooreenstemming met die verwante Verenigde Nasies se volhoubare ontwikkelingsdoelwit nommer 9 oor nywerheid, innovasie en infrastruktuur.

1. INTRODUCTION

Quality 4.0, representing the fusion of traditional quality management practices with cutting-edge Industry 4.0 technologies, has become a transformative force in the manufacturing industry worldwide [1], [2], [3]. Sony *et al.* [4], [5] claim that these Industry 4.0 technologies are a new wave of revolution in manufacturing. This viewpoint focuses on how manufacturing could use the latest developments in digitisation to maximise output while consuming the fewest resources possible. Industry 4.0, which was first developed in Germany to play a leading role in industries, has come to represent the start of the Fourth Industrial Revolution [2], [6]. Industry 4.0 makes use of cloud computing, cyber-physical systems (CPS), the Internet of Things (IoT), embedded systems, and semantic machine-to-machine communication to link what is known as the cyber world with physical systems [7].

The integration of these two systems creates a smart factory that uses a cyber-physical environment to handle the intricacies of the contemporary production system. It promises to realise Industry 4.0 by integrating manufacturing and network communication through CPS and IoT [8]. South African manufacturers, like their global counterparts, are seeking to embrace this technological revolution in order to enhance operational efficiency, improve product quality, and maintain competitiveness on the global stage [9], [10], [11], [12]. However, the journey towards the adoption of Quality 4.0 is fraught with difficulties, some unique to the South African context [9], [13].

Without embracing Industry 4.0 and its initiatives, South African manufacturing may lag behind its global competitors and lose its customers, which may weaken South Africa's already poor economic growth. Based on World Bank estimates referenced by Seery *et al.* [14] and Maisiri *et al.* [13], it is projected that, by 2030, 87% of the global population living in extreme poverty will be in Africa, unless the persistent economic problems on the continent are effectively addressed; and Shivdasani [15] noted that South Africa, like many other African nations, is already grappling with enduring issues such as poverty, unemployment, and inequality.

In response to this dilemma, President Cyril Ramaphosa introduced an ambitious national strategy to leverage technological innovation fully by 2030 [13], [15]. He has also advocated the adoption of the Fourth Industrial Revolution to tackle the persistent triple threat of poverty, unemployment, and inequality in the country [33], [13], [15]. The president estimated a R5 trillion return – the size of the current GDP – should South Africa successfully embrace Industry 4.0 initiatives [15], [16]. This study aims to investigate the critical success factors for and barriers to the successful adoption of Quality 4.0, with the ultimate goal of formulating a plan or strategy to migrate South African manufacturers successfully to Quality 4.0.

This study builds on the research undertaken by Dias *et al.* [6], Mhlongo and Nyembwe [10], and Sader *et al.* [17] on Quality 4.0 and its advantageous effect on the manufacturing industry by creating a guide to the Quality 4.0 transition. The articles outlined several factors that make Quality 4.0 in manufacturing necessary eradicate errors, guarantee customer satisfaction, and expand the market and, subsequently, of the economy. These factors included improved traceability and transparency, and the ability to make quick process adjustments [9]. The researchers believed that improving these factors would address the quality issues that South Africa currently experiences, as identified by TimesLIVE [18] and Pretorius *et al.* [19], which have resulted in repeated product recalls and, as a result, a decrease in this sector's output [9].

Maganga and Taifa [20], [21] established that there is currently no research on creating a guide to assist developing countries to make the transition to Quality 4.0, suggesting that very little work is being implemented on the crucial success factors for and barriers to the implementation of Quality 4.0. As a result, the current study focuses on three primary objectives: (1) to evaluate the critical success factors for Quality 4.0 implementation, (2) to evaluate potential barriers to Quality 4.0, and (3) to map out in a Deming cycle the measures and countermeasures required to ensure the successful implementation of Quality Management 4.0 in developing countries.

This study contributes to the body of knowledge on Quality 4.0 in manufacturing by identifying significant barriers to the adoption of the Quality Management 4.0 process and suggesting the defences against the hindrances identified by the experts who participated in the study. In addition, adoption of the experts' recommendations would ensure that the manufacturing sector readily adopts Quality Management 4.0 to optimise their production processes, improve quality, reduce time-to-market, and enhance organisational performance and thus economic growth.

2. LITERATURE REVIEW

2.1. Quality 4.0

According to Sony *et al.* [5], organisational digitisation presents unique prospects for the efficient administration of the quality of the goods and services offered. The dynamic nature of client expectations and the difficulties of maintaining high levels of quality have long been problems for traditional quality management approaches [22], [23], [24]. Numerous product recalls in sectors such as the automobile industry show that many businesses are still struggling with quality management [9], [11]. The degree to which cycle durations have been shortened, employee activities coordinated with changing customer desires, needs and expectations, and product development stages changed present significant problems for traditional quality management systems and procedures [2], [3].

Considering the body of research on total quality management (TQM), which includes the requirements for both soft and technical abilities [25], [26], it is critical to handle these factors well. The allocation of funds for research and innovation to create novel quality methods, the harmonisation of global quality standards in cases where businesses operate from different locations, and maintaining constant quality while customising products all continue to be difficulties [26]. To achieve new heights in operational excellence, performance, and innovation, traditional quality management techniques must be enhanced by technological breakthroughs in line with the digital age [2], [3].

The concept of Quality 4.0 is an extension of the broader Industry 4.0 paradigm, which is characterised by the integration of digital technologies, data analytics, and automation into processes in various sectors [27]. The application of Quality 4.0 principles is envisioned to bring about significant improvements in product quality, production efficiency, and operational decision-making [2], [28]. However, the realisation of these benefits hinges on the successful management of numerous problems and the formulation of effective strategies [5], [29].

Organisations may encounter various challenges when implementing Industry 4.0, such as the need to embrace new technologies and to ensure the seamless interoperability of digital subsystems to facilitate the efficient operation of production systems, according to Sony *et al.* [5] and Odubiyi *et al.* [29]. Another challenge is the significant shift in mindset required to embrace new technologies and methodologies, as some organisations perceive Quality 4.0 as costly and disruptive, leading to resistance to change and job security concerns [5], [29]. Furthermore, the diversity in firm size and resources complicates the implementation process, as smaller firms often struggle to match the capabilities of larger enterprises.

The increasing interconnectivity in Industry 4.0 also introduces cybersecurity risks that demand heightened vigilance. Moreover, the sheer volume of data generated by IoT-driven systems poses data management and analysis challenges [3], [28].

Last, integrating new Quality 4.0 technologies with existing systems can be complex owing to compatibility issues and technical differences [2], [3]. According to Antony *et al.* [4] and Cudney *et al.* [30], to overcome these global challenges, organisations must prioritise training, clear communication, collaboration, and strategic planning to transition successfully to Quality Management 4.0 in the evolving landscape of Industry 4.0. These challenges also differ between countries; so it is important to evaluate the scenario of each country in the supply chain [21].

2.2. Deming cycle

The PDCA (Plan-Do-Check-Act) cycle, also known as the Deming cycle or Deming wheel, is a renowned scientific framework for continuous improvement introduced by Walter Shewhart in the 1920s and improved by W. Edwards Deming, a distinguished figure in quality management in the 1950s [22]. This structured approach has been widely adopted by industries to enhance their processes, products, and services, as it offers a systematic way to manage change and improvement. By adopting the cyclical nature of PDCA, organisations can avoid chaotic or haphazard implementation of new initiatives.

While all phases in improvement initiatives are critical, the checking phase involves regular evaluations and facilitates continual learning, enabling insights, the identification of issues, and informed adjustments to enhance the effectiveness of initiatives [31]. Furthermore, embedding the PDCA cycle in an organisation's culture cultivates a mindset of continual improvement, fostering an environment in which employees are motivated to seek better ways to operate and to contribute to the overall success of the organisation. This scientific approach aligns with the principles of adaptability, risk management, and data-driven decision-making, making PDCA a valuable tool for the strategic introduction of new initiatives in organisations [1], [32].

3. RESEARCH METHODOLOGY

This study used the Delphi technique to identify critical success factors, barriers, and strategies of change management for Quality 4.0.

3.1. Delphi technique

The Delphi technique is a method of decision-making that, according to Habibi *et al.* [33], enables independent experts to collaborate without necessarily meeting one another. The main objective of the Delphi method is to gather expert viewpoints rather than to determine which answer is correct or incorrect [31]. This method is essential for developing and expanding areas of research, especially infant areas such as Quality 4.0.

The Delphi technique uses a process in which a group of experts individually assess their agreement with a series of statements through a multi-stage, iterative approach. This systematic method leverages the expertise of individuals in specific domains, and can offer guidance in a particular context. Delphi studies have traditionally found application in the development of content for quality-related programmes and new technology initiatives [31], [33], [34].

In the context of this study, the Delphi process was employed to identify the critical success factors of Quality 4.0, the hindrances to successful Quality 4.0 adoption, and recommendations for activities that would be required to ensure the successful implementation and adoption of Quality 4.0 in South African organisations.

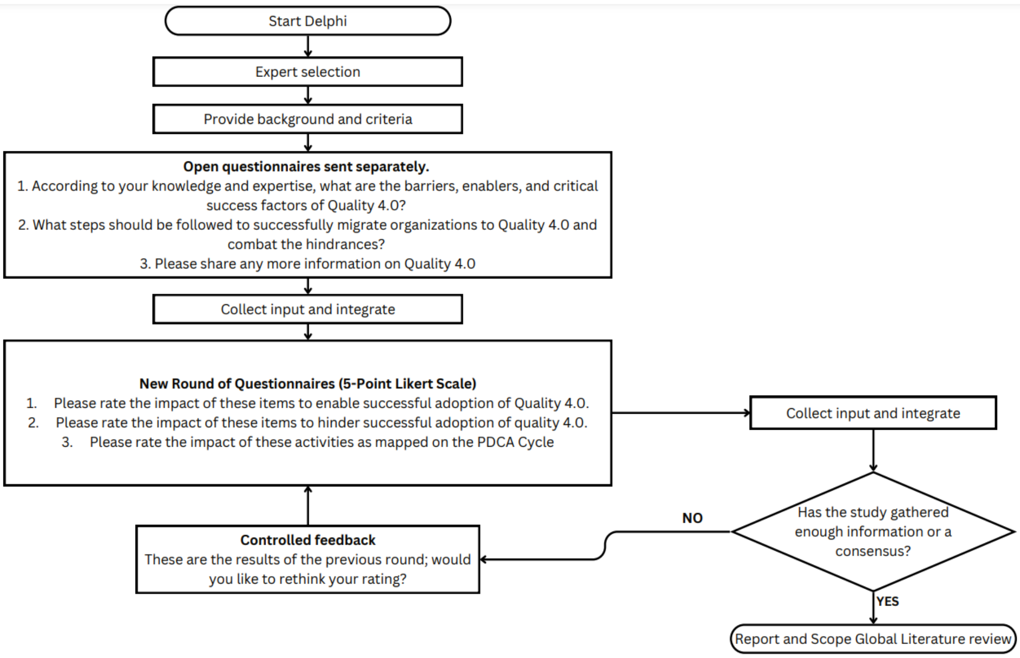

Figure 1: Research process

The research process laid out in Figure 1 was followed. Initially panel members were invited to pinpoint the factors that affect Quality 4.0 implementation; this constituted the brainstorming round. The researchers then collated the responses, identified the common factors, and created a survey questionnaire to be distributed to the experts electronically using Microsoft Forms. Informed consent was obtained from all the participants, as detailed in Table 1, ensuring that they were aware of their right to withdraw from the study at any point. After collecting data from each round, with some items failing to achieve consensus, the researchers sent controlled feedback to the participants, and a new round was started until enough information had been collected on which items to report and to draw conclusions.

3.2. Panel formation

Panel members were invited to participate in this study only if they had valuable knowledge on quality management, with relevant experience. These criteria were used:

A potential participant must:

a) Work for the manufacturing sector,
b) Have knowledge of quality management regimes and Industry 4.0,
c) Be willing to participate in the study,
d) Be involved in quality management planning and/or research activities.

3.3. Data collection and analysis

The purpose of the first iteration was to gather as much information from as many experts as possible. The information provided was based on open-ended questions, to which the expert panel was asked to react and to offer as much knowledge as they could. The information from this brainstorming round was then used to formulate the closed-ended questions in Delphi round 1, which were graded from 1 to 5 using a Likert scale with 1 representing very low; 2 = low; 3 = high; 4 = very high; and 5 = extremely high. The questions that reached consensus in the first round were not included in the second round of the Delphi iteration. The participants were asked whether they would like to rethink their responses, considering the input from the collective, and the first round's median was included in the second round. The factors that received an average of 'low' or 'very low' impact were dropped from the study.

Makhanya *et al.* [31] contended that it is crucial to decide on the number of iterations in advance and to alert potential participants to this. Although there is no agreement in the literature about how many iterations are necessary for Delphi research, in theory the iterations go on until the experts have come to an agreement. Habibi *et al.* [33] referenced research with one to ten iterations. According to Makhanya *et al.* [31], most studies use two to three rounds. An excessive number of iterations causes panellist fatigue and a high rate of drop-offs. This study used three rounds, as the panellists were starting to drop-off from the first round. Table 1 presents the results of the consensus building for this study.

Table 1: Consensus building

Parameters	Brainstorming round	Delphi round 1	Delphi round 2	Delphi round 3
Invitations	10	10	8	7
Responses	10	8	7	6
Number of items that reached consensus (IQR≤1)	N/A	30	17	6

With the Delphi technique, the first step in analysing the qualitative data thematically is followed by statistical methods [31], [34]. Data processing and interpreting the panel's comments are the fourth and fifth steps respectively. The panel members' comments were evaluated using descriptive statistics from the current study, specifically the median and the interquartile range. This study used the interquartile range (IQR) as the approach to gauge the degree of agreement among the panellists owing to its robustness and tolerance of outliers, as suggested by Ramos *et al.* [34]. Considering the range of the data set, the IQR aims to explain the distribution of the middle 50% of the data set [31], [34]. The IQR is calculated using Equation (3).

$$\text{First quartile}(Q1) = ((n+1)/4)\text{th} \quad \text{Equation (1)}$$

$$\text{Third quartile}(Q3) = (3(n+1)/4)\text{th} \quad \text{Equation (2)}$$

$$IQR = Q3 - Q1 \quad \text{Equation (3)}$$

where n represents the number of items.

If the IQR is less than or equal to 1, then the experts' ratings are almost unanimous. An IQR above 1 indicates that the responses from the experts are tightly clustered around the median. In this case, there is not much variability in the opinions, suggesting a high level of agreement or consensus among the experts. Conversely, a high IQR means that the responses are more spread out. This indicates a greater diversity of opinions among the experts, which may imply lower consensus on the topic. Note that an IQR of less than one indicates that the panellists agree with one another, not necessarily that they agree with the item. A high median indicates significant levels of relevance, and a low median indicates lower levels of significance. The median was used to quantify the amount of relevance/impact for each question or action. The formula for calculating the median is given in Equation (4).

$$\text{Median} = \{(n+1)/2\}\text{th} \quad \text{Equation (4)}$$

where n represents the number of items.

In order to understand the similarities between South African and global manufacturing, the final results were presented and compared with views on Quality 4.0 in the global literature.

4. RESULTS AND DISCUSSION

4.1. Demographics

This section outlines the demographics of the experts who took part in the Delphi study. As shown in Figure 2, 40% of the participants held a Bachelor's degree, and another 40% had a doctoral degree. The remaining 20% had a Master's degree. None of the participants had only a national diploma or a matric certificate.

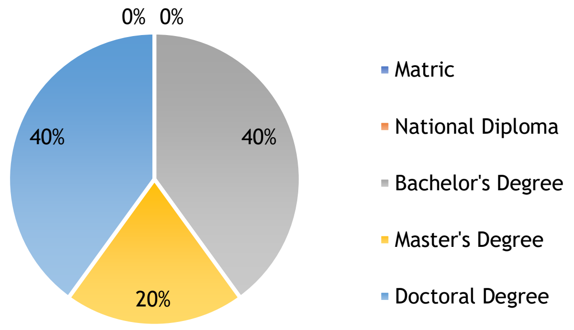

Figure 2: Level of education

Figure 3 depicts the employment levels of the participants. The majority were at intermediate or senior management levels, each level making up 30% of the total. Middle management accounted for 20%, while only 10% of the participants were at entry or executive levels.

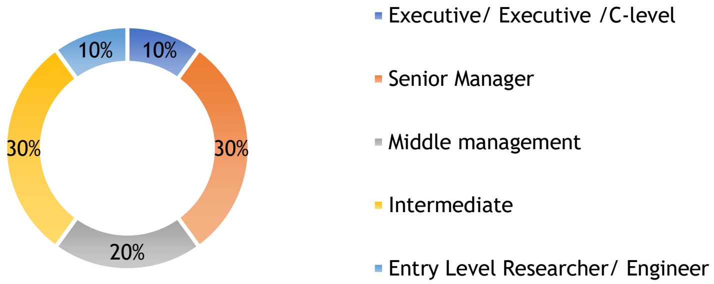

Figure 3: Level of employment

Figure 4 illustrates the participants' years of experience. The majority, 40%, had between 11 and 15 years of experience. Those with 16 to 20 years and 6 to 10 years of experience each made up 20%. A minority, 10%, had either one to five years or more than 20 years of experience. These demographics suggest that the experts had diverse levels of education, employment, and experience, which contributed to the credibility of their inputs.

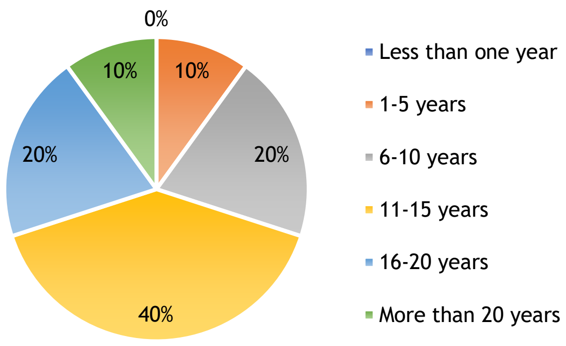

Figure 4: Years of experience

The next section presents the results of the Delphi study, which aimed first to identify the critical factors for the successful adoption of Quality 4.0 and the hindrances to the successful adoption and sustainability of Quality 4.0 by South African organisations. The second aim was to map the activities in respect of the Deming cycle that were required to combat the hindrances and to ensure a successful migration to Quality 4.0.

4.2. Quality 4.0 critical success factors

The brainstorming session with the experts found 15 critical success factors of Quality 4.0, which are presented in Table 2 and Figure 5.

Table 2 presents both the consensus-based factors and the factors on which the experts did not agree, the IQR, and the median. Figure 5 presents the distribution of opinions per critical success factor for Quality 4.0 adoption. It may be noted that most of the CSFs (eight) were considered to have a very high impact (median = 4). Only three of the fifteen CSFs had a median score of 3 or 3.5, indicating a high impact, while the other four were deemed to have an extremely high impact (median ≥ 4.5). Notably, CSF4, CSF7, CSF8, and CSF10 were identified as having an extremely high impact on Quality 4.0 success. Eleven items had an IQR of 1 or less, meaning that the panel had achieved consensus.

Table 2: Critical success factors

#Code	Critical success factors of Quality 4.0	Median	IQR	Consensus
CSF1	Enhanced data-driven decision-making (data integration and analytics)	3	2	No
CSF2	Real-time monitoring and control	4	1	Yes
CSF3	Interconnected systems	4	1	Yes
CSF4	Digital twin technology	4.5	1	Yes
CSF5	Leadership support	4	1	Yes
CSF6	Supplier collaboration	4	2	No
CSF7	Employee training and engagement	4.5	3	No
CSF8	Cybersecurity	4.5	0.5	Yes
CSF9	Process optimisation	4	1	Yes
CSF10	Continual improvement culture	5	0	Yes
CSF11	Customer-centric approach/Greater customer satisfaction	4	1	Yes
CSF12	Sustainability and environmental responsibility	4	1	Yes
CSF13	Regulatory compliance and risk management	4	1	Yes
CSF14	Measurable metrics	3.5	2	No
CSF15	Scalability and flexibility	3	1	Yes

In the literature, Sader *et al.* [17] and Dias *et al.* [6] corroborated these experts' views, stating that successful implementation would rely on twin digital technologies that had the capability to simulate different production scenarios and pick the defect-less one (improving the quality of the product), increase employee engagement and individual development because of complete integration between all stakeholders (even between top managers and employees), and continual improvement. In these items, there was consensus among the participants, denoted by an interquartile range (IQR) of ≤ 1 on three of the items. The high IQR score of 3 for CSF7 is indicative of the fact that the experts felt that the importance of employee engagement as a success factor of Quality 4.0 would vary with each organisation.

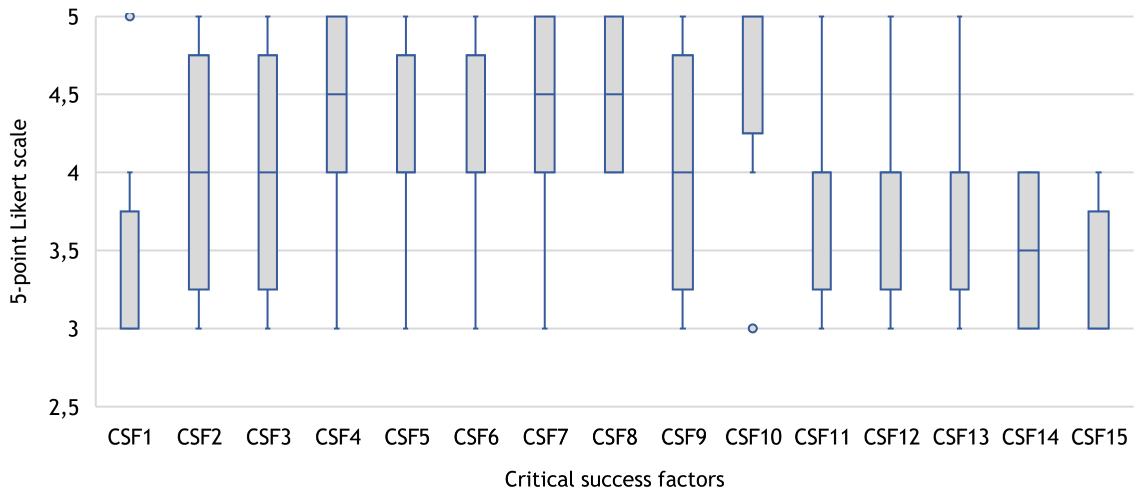

Figure 5: Visual representation of expert opinions on Quality 4.0 critical success factors

CSF2, CSF3, CSF5, CSF6, CSF9, CSF11, CSF12, and CSF13 were collectively recognised as having a very high impact on facilitating the successful implementation of Quality 4.0 in organisations. The literature corroborates this: according to Sader *et al.* [2], [3], Rowlands and Milligan [1], and Forero *et al.* [35], the success of Quality 4.0 would depend on real-time monitoring and control capabilities, total integration and interconnectedness, leadership support, process optimisation, and supplier collaboration.

In addition to these factors, Zonnenshain and Kenett [36] also suggested that Quality 4.0 success would depend on the customisation of products and the assurance that risk is minimised on production floors. However, it would be important to note that consensus was not reached among the participants on CSF6 (IQR > 1). This implies that, while supplier collaboration ensures success (median = 4), its impact and importance may vary from one company to another. CSF1 and CSF14, although considered to have a high impact, showed an IQR of 2, indicating a lack of unanimous agreement among the participants about its significance.

The above results suggest that the impact of data integration, analytics, and measurable metrics would differ from one company to another – although Sader *et al.* [17] mentioned a big data capability and its ability to predict future failures and market demands as one of the most important features of Quality 4.0. Researchers have also concluded that Quality 4.0 would improve efficiency and quality, reduce production costs, and aid customisation, which would ensure customer satisfaction and improve sector performance [1], [17], [37].

4.3. Hindrances to successful implementation of Quality 4.0

The brainstorming session with the experts found seven factors that hinder Quality 4.0 initiatives, which are presented in Table 3 and Figure 6.

Table 3 presents the consensus-based items, the IQRs, the medians, and the items that failed to reach consensus, while Figure 6 presents a visual distribution of the opinions per item on possible hindrances to successful Quality 4.0 adoption. As can be observed, a total of seven items were listed as possible barriers or hindrances to Quality 4.0 implementation.

Table 3: Hindrances to successful implementation of Quality 4.0

#	Hindrances to Quality 4.0	Median	IQR	Consensus
H1	Inadequate infrastructure and technology readiness (reliable electricity and internet, modern technologies)	5	1	Yes
H2	Financial constraints (economic factors)	4	1	Yes
H3	Skill gaps	4	0	Yes
H4	Lack of data security and privacy	4	1	Yes
H5	Lack of top management support (resources, guidance and change management)	5	1	Yes
H6	Inadequacy to integrate with legacy processes	4.5	1	Yes
H7	Firms' resistance (owing to lack of awareness/Quality 4.0 culture and socioeconomic factors)	4	0.5	Yes

It can be observed that H1, H5 and H6 were identified as extremely obstructive to the successful implementation of Quality 4.0 (median ≥ 4.5). There was unanimity among the participants on this matter, reflected in IQRs of ≤ 1 for these factors.

This indicates that the experts believed that unreliable infrastructure, lack of acquiring top management support, and the inability to integrate modern technologies with legacy processes would hinder a firm's ability to embrace and sustain Quality 4.0. According to Olaitan *et al.* [38], an intermittent electricity supply, including that caused by load shedding by Eskom, impedes South African companies' ability to embrace and use new technologies.

The above finding is corroborated in the global literature. For example, Sony and Naik [39] and Antony *et al*. [7] found that reliable infrastructure, including internet and electricity, is essential to embracing Quality 4.0. According to Cudney *et al*. [30], one of the main hindrances to the adoption of Quality 4.0 is the cost and complexity of integrating it into existing processes.

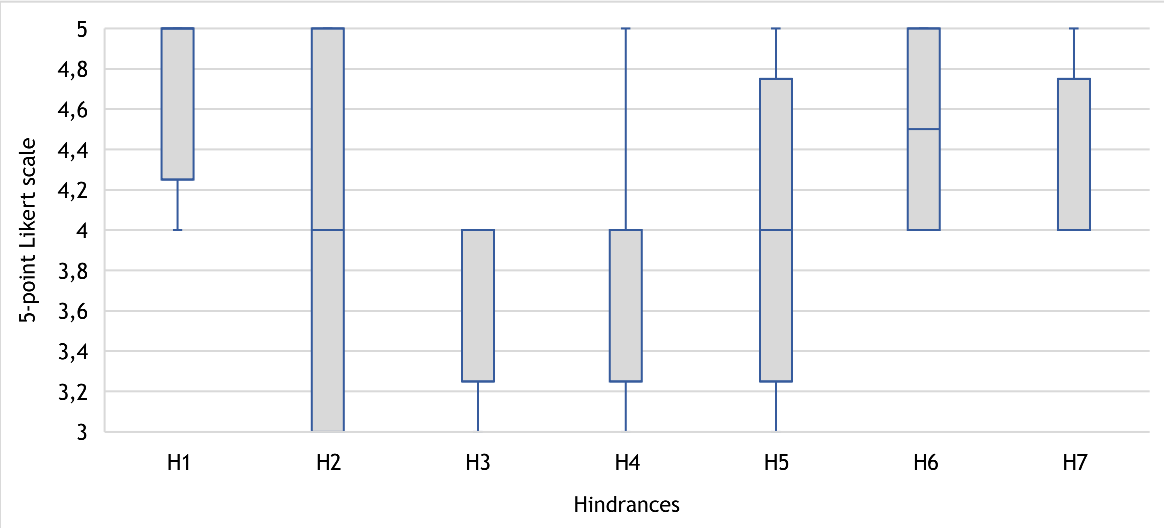

Figure 6: Visual representation of expert opinions on hindrances to the adoption of Quality 4.0

Factors H2 to H4 and H7 were collectively recognised as having a very high impact on impeding the successful integration of Quality 4.0 in organisations (median = 4). The experts arrived at a consensus on all these hindrances, signifying their shared belief that these economic constraints, lack of Industry 4.0 skills, inadequate cyber security, and resistance from employees would all be strong hindrances to organisations' effectively embracing Quality 4.0. Lindelani *et al*. [40] found that an ignorant management and the lack of an improvement culture would impede the power to embrace new technologies.

Researchers have also found that the substantial capital investments that are necessary to overhaul internal processes and IT infrastructure could be daunting for many organisations [2]. According to Olaitan *et al*. [38], South Africa's lack of economic growth and productivity is impeding its preparedness for the transition to Industry 4.0 initiatives. The country is currently facing an economic recession, which has been worsened by the severe impact of COVID-19, making it difficult to invest adequately in new technologies. according to Cudney *et al*. [30] and Sony *et al*. [8], [39], without the right skills, resources, and adequate cybersecurity measures, Quality 4.0 initiatives globally will fail. Lindelani *et al*. [40] detailed how theft and vandalism (both socioeconomic issues), which are unique to countries such as South Africa, would impede the success of Industry 4.0 initiatives in the country.

4.4. PDCA mapping of activities required for successful adoption of Quality 4.0

This section presents the Deming cycle as mapped by the experts. They were then asked to recommend activities, according to their Deming cycle, that would counter the hindrances and ensure the successful adoption and implementation of Quality 4.0, and so achieve maximum benefits. Figure 7 shows the 31 activities mapped in the Deming cycle. This cycle suggests that, for organisations to adopt Quality 4.0, reap all its benefits, and sustain it, they would need constantly to follow all those improvement activities.

PLAN

Technology:
- **Plan 1-** Assess the existing infrastructure and technological capabilities.
- **Plan 2-** Plan the budget for Quality 4.0 initiatives, considering potential financial constraints. Explore cost-effective solutions and prioritise initiatives, based on their impact and feasibility.
- **Plan 3-** Develop a plan to upgrade or integrate new technologies required for Quality 4.0.

People:
- **Plan 4-** Develop a vision to be presented to top management (to obtain management buy-in)
- **Plan 5-** Identify the skill gaps in the organisation.
- **Plan 6-** Plan training programmes to enhance employee skills in alignment with the new technologies to foster engagement.
- **Plan 7-** Develop a training plan or collaboration with external partners to address these skill gaps and to build the necessary expertise.

Processes:
- **Plan 8-** Identify processing bottlenecks, areas of waste, and areas for improvement.
- **Plan 9-** Develop a plan to modify processes to integrate modern technology with legacy systems (e.g., incorporating artificial intelligence and machine learning into processes for improved decision-making and efficiency).
- **Plan 10-** Develop a comprehensive plan for ensuring data security and privacy for the implementation of Quality 4.0 (defining protocols and encryption methods, and compliance with relevant regulations & standards).
- **Plan 11-** Develop a risk management plan to identify, assess, and mitigate potential risks associated with technology adoption (incl. anti-vandalism measures).
- **Plan 12-** Establish measurement indicators.

DO

Technology:
- **Do 13-** Adopt and leverage modern technologies.
- **Do 14-** Execute plans to integrate new technologies with existing legacy processes. This may require phased implementation and careful consideration of interoperability.
- **Do 15-** Execute plans to interconnect systems and create a seamless flow of data throughout the organisation.

People:
- **Do 16-** Develop a vision to be presented to top management (acquire management buy-in).
- **Do 17-** In workforce recruitment, be sure to address country's social and political processes. This also ensures that Quality 4.0 is not just for economic competitiveness but also for local inclusive growth.
- **Do 18-** Upskill the workforce.
- **Do 19-** Actively address both firm's interest and resistance within the organisation. Communicate the benefits of Quality 4.0, involve key stakeholders, and manage resistance through change management strategies.
- **Do 20-** Actively promote and cultivate a culture of continuous improvement among employees.

Processes:
- **Do 21-** Modify processes to integrate modern technologies into legacy processes. (This may require phased implementations and careful consideration of interoperability).
- **Do 22-** Implement cybersecurity measures to protect digital assets and sensitive information.
- **Do 23-** Implement risk management strategies.

CHECK

- **Check 24-** Collect available data after deploying technology, developing the workforce, and modifying processes to see whether the results are as expected. (Did the new and modern systems integrate seamlessly, did the training improve human capabilities, did the workshops eliminate employee/stakeholder resistance, are the deployed cybersecurity measures effective, and are the data processes compliant with the standards and regulations?)
- **Check 25-** Review documentation to measure the success of the project. (Is Quality 4.0 in action and yielding positive results as expected?)
- **Check 26-** Identify areas for improvement.
  - ✓ Continually monitor and enhance cybersecurity measures to address evolving threats.
  - ✓ Adjust financial plans as needed, and seek alternative funding sources if necessary.
  - ✓ Make training adjustments as necessary.
  - ✓ Engage employees, and act on feedback to foster a culture of continual improvement.

ACT

If migration was a success:
- **Act 27-** Standardise and expand.
- **Act 28-** Communicate the changes to stakeholders.

If migration was not a success:
- **Act 29-** Identify and analyse what went right and what was missed.
- **Act 30-** Identify gaps between success and what went wrong.
- **Act 31-** Start the process again with new actions aimed at mitigating unsatisfactory performance.

Figure 7: Deming cycle for successfully implementing Quality 4.0

The activities mapped in the PDCA cycle were listed and given codes (which are used in Figure 8). Figure 8 presents the distribution of experts' opinions per activity required to facilitate the successful adoption and implementation of Quality 4.0 in South African manufacturing firms. The respondents agreed that all the activities would have an impact that was high, very high, or extremely high (median ≥ 3) on the successful adoption and implementation of Quality 4.0. They reached a consensus on all the activities, as reflected in an IQR of ≤ 1.

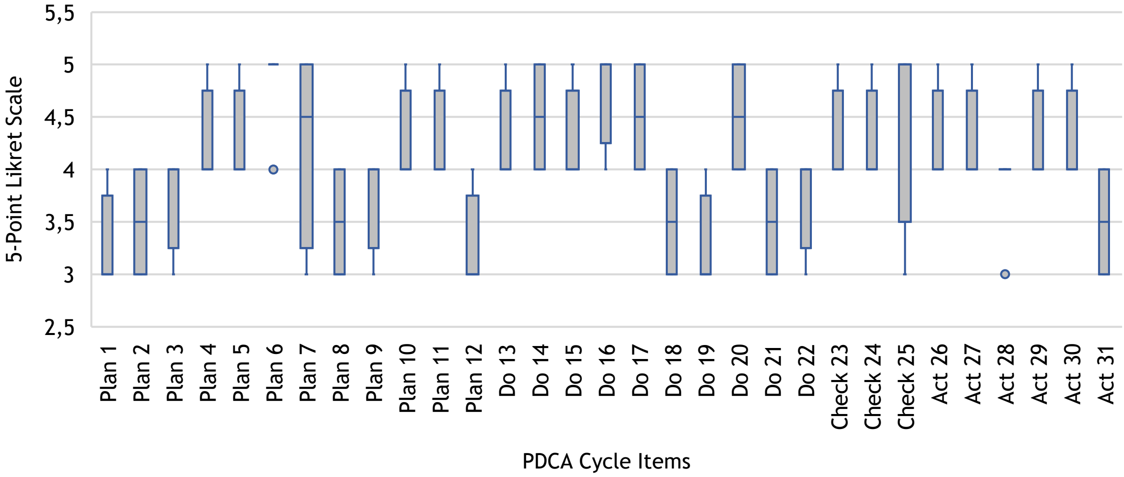

Figure 8: Expert opinions on the PDCA cycle items

Figure 8 also shows that, although all the activities were considered highly influential for a successful transition to Quality 4.0, activities such as Plan 6, Plan 7, Do 14, Do 17, Do 20, and Check 25 were identified as having an extremely high influence on ensuring the successful adoption and implementation of Quality 4.0 (median ≥ 4.5). This indicates that the experts believed that planning training programmes for employees, recruiting new talent, collaborating with industry bodies and institutions of higher learning for workforce development, and ensuring a continual Quality 4.0 culture among employees would ensure their readiness and eliminate the resistance caused by a lack of skills and awareness. Also, according to the experts, it was equally important to execute plans to integrate new technologies with existing legacy processes, and continually to monitor the key performance indicators to analyse project success.

4.5. Discussion

The study suggests that the benefits of adopting Quality 4.0 regimes would not come without difficulties. However, the study also shows that steps and strategies could be employed to combat these challenges and to ensure a successful implementation of Quality 4.0. The identified hindrances were linked to the people, the processes, the plant, and the financial resources required to make Quality 4.0 a success. For example, the study revealed that challenges relating to people included a lack of training and skills, a lack of managerial buy-in, and employee resistance (owing to different factors such as a lack of awareness and the fear of losing jobs). The research also revealed the hindrances linked to processes, such as a lack of knowledge, a lack of processes to integrate modern technologies with legacy systems and processes, and bottlenecks in ensuring data security. Last, the problems linked to the plant were identified as an unreliable electricity supply (owing to power outages and persistent loadshedding), poor internet access, modern technologies not being leveraged fully, and traditional technologies not being prepared to pair with new ones. South Africa is also regarded as undergoing a recession and as struggling to survive after the Covid-19 pandemic, which has increasingly put a strain on firms' financial resources and thereby impeded their chances of embracing Quality 4.0.

This Delphi study conducted in South Africa validated the conclusions of global studies on the enablers of and barriers to Quality 4.0. Additional challenges that were discovered and that are peculiar to the South African setting were socioeconomic in nature, such as theft and vandalism, which inhibit firms' ability to invest further in technologies. Employee resistance was also identified as caused by socioeconomic issues, because employees resist new technologies for fear that they would be retrenched. The study then formulated a plan/strategy of implementation, mapped on the PDCA cycle, which gives a step-by-step guide to how organisations could embrace Quality 4.0 projects successfully.

5. CONCLUSION

Quality 4.0 represents a paradigm shift in manufacturing, combining traditional quality management with Industry 4.0 technologies to enhance product quality, operational efficiency, and competitiveness. For South African manufacturers, embracing Quality 4.0 would present unique challenges owing to their context of poor economic conditions, infrastructure, and workforce readiness. This Delphi study engaged a panel of ten quality management experts in South African manufacturing to identify the challenges and to propose strategies for a smooth Quality 4.0 adoption. The participants had diverse levels of education, employment, and experience, which contributed to the diversity and credibility of their inputs.

The study found that data-driven decision-making, interconnected systems, real-time monitoring and control, supplier collaboration, customer-centric approaches, and employee training and engagement would be critical factors for the successful adoption of Quality 4.0.

In addition, the study found that South African manufacturers face a range of challenges, including financial constraints, data security and privacy concerns, skill gaps in the workforce, and issues related to integration and interoperability. Financial constraints were identified as the most critical problem, underscoring the need for a collaborative approach between the government and industry stakeholders to provide financial support. These factors were corroborated by the global views mentioned in the literature. However, additional factors that hinder adoption, such as loadshedding, unreliable internet access, and socioeconomic issues such as poverty (influencing resistance because of a fear of job losses) and theft/vandalism were found to be specific to South Africa (and possibly to other underdeveloped countries).

The study also mapped on the PDCA/Deming cycle the activities needed to combat the adoption difficulties and to ensure the successful implementation of Quality 4.0. The items emphasised activities such as acquiring partnerships with educational institutions and facilitating workforce development, and ensuring top management support; they also identified the significance of robust data security measures, among other activities, to ensure the success and sustainability of Quality 4.0. The adoption of industry-wide integration standards and rigorous testing were also highlighted as essential to ensure seamless system interaction.

6. RECOMMENDATIONS AND FUTURE RESEARCH

The study aimed to make manufacturers aware that, while Quality 4.0 might revolutionise their manufacturing processes, it would not be without challenges. Before migrating, it would be critical to conduct research, analyse potential risks and obstacles, and plan accordingly. It would also be critical to have measuring metrics and to refer continually to them in order to assess the project's effectiveness and so guarantee that the benefits were realised. Future research endeavours could explore the practical implications of these strategies, and assess their impact in real-world manufacturing scenarios.

This study offers insights and recommendations to navigate the challenges and embrace the opportunities presented by Quality 4.0, ultimately positioning South African manufacturing for a more competitive and technologically advanced future. This in turn would ensure that the goal of the South African president and government, of embracing Industry 4.0 for economic growth, was fulfilled.

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