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RESEARCH ARTICLE:

The Convergence of Quality and Digitalisation in a Changing World: Implications for Developing Nations such as the BRICS Group

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Abstract

The emergence of digitalisation and the Fourth Industrial Revolution has resulted in a significant shift in practices, resulting in a disconnection among organisations, employees, and technology, particularly affecting developing nations like the BRICS group which have faced disproportionate challenges due to the COVID-19 pandemic. The aim of this paper is to explore the role of quality in the context of intelligent and automated systems operating in a technologically advanced environment. The study employs a systematic literature review methodology, which encompassed a rigorous process of identifying and selecting 38 articles, followed by a comprehensive thematic analysis. The findings highlight that organisations need to adapt their quality systems to effectively operate in a world dominated by intelligent and automated systems. The implication is that by leveraging digital technologies, organisations can embrace the integration of quality with machine learning, programmable logic controllers, adaptive feedback loops, automated information collection, and blockchain technology to develop a value-based, transparent, and secure quality system. The proposed roadmap and model derived from this study affords organisations the opportunity to establish an intelligent quality ecosystem that aptly aligns with the requisites of the technologically advanced era, thereby ensuring the attainment of excellence in quality during the digital era.

Keywords*: Quality 4.0; digitalisation; smart manufacturing; industry 4.0*

Introduction

Digitalisation is defined as the convergence of digital information and digital technologies to produce organisational models that promote efficiencies and increase profit (Parviainen *et al*., 2017). Through this definition, it has forced organisations in the direction of automation, cyber-physical systems and cloud computing (Cohen *et al*., 2019; Morakanyane *et al*., 2020). There is consensus that digitalisation has emerged as the most significant technological trend of the twenty first century (Parviainen *et al*., 2017; Gebayew *et al*., 2018; Reis *et al*., 2020; Cohen *et al*., 2019; Morakanyane *et al*., 2020; Urbinati *et al*., 2020). Moreover, digitalisation has played a significant role in ushering in the Fourth Industrial Revolution (4IR). Ramos *et al*. (2019) as well as Jeon *et al*. (2020) and Botlikova *et al*. (2020) advise that digitalisation has already had a tremendous impact on organisations regarding organisational efficiencies and transformation. However, organisations and employees, particularly in developing nations such as the BRICS group, are significantly behind in the digitalisation era, which is substantially limiting economic growth in these countries. Furthermore, the Corona Virus disease from 2019 (COVID-19) has exacerbated this situation.

Xu *et al*. (2018), Mahmood and Mubarik (2020), Kimani *et al*. (2020) and Botlikova and Botlik (2020) tout the 4IR as the convergence of digitalisation with artificial intelligence, robotics, 3D printing, advanced wireless technologies, and physical and biological innovations. The 4IR extends beyond the third revolution by merging the digital world with the biological and physical world. Therefore, it can be perceived that the 4IR will cause systematic change that will tremendously influence and transform organisations across all sectors. Although significant

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developments have been made towards the 4IR, it still requires substantial evolution and support from society and organisations when viewed as a nascent idea.

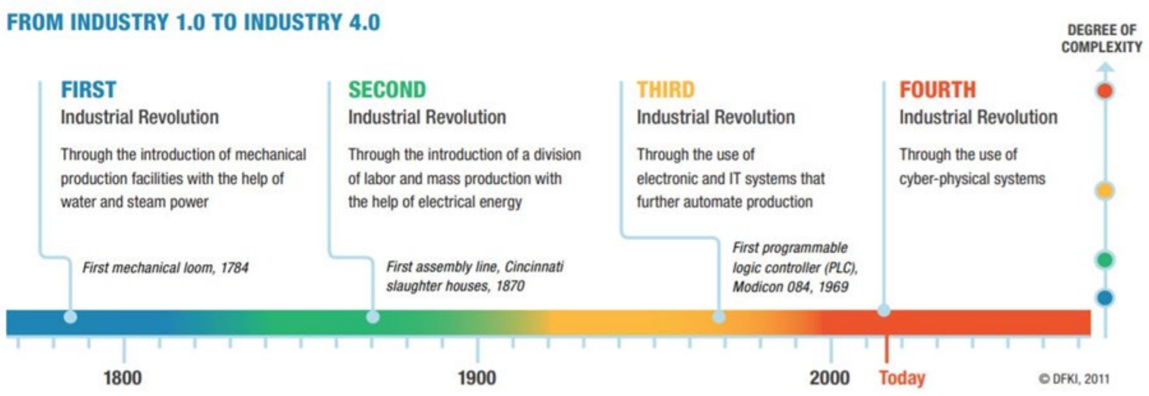

Figure 1: Image depicting the four industrial revolutions with descriptions and timelines (Jacob, 2017)

Arsovski (2019), Zonnenshain and Kennet (2020), and Chiarini (2020) report that in conjunction to the impact that digital transformation has had on organisations; it has also had a significant impact on quality. Quality 4.0 is the term that has been coined to describe the digitalisation of quality in the 4IR (Arsovski, 2019). Quality has become an essential component in ensuring an organisation can sustain financial growth accompanied with maintaining competitiveness. It might be useful to recognise how quality is embedded throughout the industrial revolutions and to learn from its evolution to inform quality in 4IR. Figure 1 depicts a summary from the first to the fourth industrial revolution. The American Society of Quality (n.d) highlights some of these roles. For instance, during the first industrial revolution, the concept of quality first emerged as 'self-inspection' in production plants. Through the course of the second industrial revolution, there was a shift towards quality control and inspection. Noteworthy, throughout the third industrial revolution quality had materialised as a simple system that required basic planning and documentation. Following this, there have been major advancements in the field of quality, namely the development of the International Organisation for Standardisation (ISO) and, for example, the introduction of organisational wide quality control in Japan which was influenced by quality gurus such as Edwards Deming and Joseph Juran. The ISO later began developing different quality standards that are used today.

The evolution of quality accentuates that it has adapted to technological changes and scientific advancements throughout the first three industrial revolutions. Therefore, it can be perceived that the advancements of quality in the 4IR are vital and crucial for organisational success in the Industry 4.0 milieu. Quality in the age of digitalisation presents promising opportunities, such as the possibility to revolutionise traditional quality control and assurance systems and significantly expand the access to financial markets for organisations (Rowlands and Milligan, 2021). Of importance, Piccarozzi *et al*. (2018); Sader *et al*. (2019); Frank *et al*. (2019); and Elg *et al*. (2020) express that quality in the age of digitalisation is not just isolated to the technological advancements of the 4IR but also to the ability of organisations to utilise that technology to reduce inefficiencies, improve access of information, and increase profit. It is imperative that developing nations urgently accelerate digitalisation transformation in organisations to improve economic growth and heighten the competitive edge in line with the rest of the world.

Arising from the need for organisational transformation to adapt to the 4IR, Alcácer and Cruz-Machada (2019) and Chiarini (2020) report that although organisations are aware of the urgent need to embrace the 4IR and move towards digitalisation, there is limited research conducted on the connection between digitalisation and quality. These gaps in knowledge have led to a number of organisations misunderstanding the shift towards digitalisation. Additionally, many organisations have misinterpreted customer requirements concerning digitalisation that has led to a misuse of capital expenditure and labour. In order to ensure that organisations are not excluded from the swift expansion of digitalisation, the aforementioned authors add that there needs to be a roadmap on the steps required for an organisation to transition towards a digitalised quality management system. These gaps in knowledge are further highlighted by a case study from Ramezani and Jassbi (2020) in Portugal, which accentuates that a lack of digital quality systems and a failure to integrate management systems are a major hindrance in implementing Quality 4.0. They argue that integrating traditional software systems with intelligent software systems could overcome these issues. The software systems they advise should be developed to include Statistical Process Control (SPC) tools such as x-bar and r charts and Cpk calculations. Cognisant of this, these recommendations will be explored throughout this paper. Concomitantly, the lack of research on steps that organisations can take to transform their quality systems has provided the impetus to investigate the current trajectory of quality, vis-a-vis its integration with the 4IR as Industry 4.0 rapidly moves towards digitalisation. This will inform the development of a roadmap with pathways which organisations can follow to digitalise their quality systems.

Of importance, Sezer *et al*. (2018) purport that there are several base components in developing smart factories. These base components could possibly serve as a pathway in which organisations can follow to achieve digitalisation of their quality system. The first of these components is The Internet of Things (IoT), which refers to the internet connections between physical items such as computers, digital equipment, and scanners. This is the foundational step for developing a smart factory. It is recommended that all organisations have access to a basic internet connection, software, and computers as a starting point. The second component is Cloud Computing (CC), which alludes to the storage of data, programmes, and information on the internet. This is to ensure that critical data can be accessed remotely and is backed-up in the event of an emergency. This further assist organisations that do not have the funds to acquire expensive digital servers. The next component is Cyber-Physical Systems (CPS), which can be described as digital systems that control the physical mechanics in a process with computer-based algorithms. Cyber-Physical Systems involve intense collaboration across computer software systems, physical process, and communication programmes. The purpose of CPS is to integrate all physical processes and systems in an organisation with cyber-digital technology.

The fourth component is Machine Learning, which refers to the software regarding artificial intelligence or predictive learning. The aim of Machine Learning is for computer software to be able to recognise patterns among data and have the ability to adjust the process if it falls outside of the control limits. Based on the discourse presented thus far, this component will be one of the major contributing components towards a digitalised quality system. The last component is Condition Based Maintenance (CBM), which is a maintenance plan that involves analysing previous maintenance reports and downtime with the aim of developing predictive maintenance patterns. Once this is established, maintenance and production costs caused by downtime, poor maintenance scheduling, and constant repairs can be avoided. In reviewing these components, a possible pathway towards the digital transformation of quality systems can be realised and will be reiterated during the construction of the proposed roadmap.

Literature Review

This section will first, illustrate the evolution of quality to ascertain why and how quality has evolved though the decades to meet organisational needs. The section will then highlight possible concerns relating to digitalisation to underscore any possible impact it may have on Quality 4.0. The third part of this section will portray possible links between sustainability, digitalisation, and quality. It is evident that the evolution of quality throughout the four industrial revolutions has provided insight in the transformation of industry in response to technological changes. This section will further explore the evolution of quality and the development of international quality standards with the intention of ascertaining pertinent information concerning plausible routes towards quality in the 4IR. Rybski *et al*., (2017), Fonseca and Domingues (2018), and Galli (2019) attest that the development of international Quality standards has become paramount for an organisation to be profitable and maintain sustainability. The ISO 9001:2015 is the latest version of the ISO quality management systems standard. When the first version of the standard was released in 1984, it provided the basic organisational structure for documentation and processes that organisations could implement. In the succeeding years, the standard was updated four times. The changes were due to evolving customer and regulatory requirements. The first revision was made in 1994 to highlight preventative action.

The second revision of the standard occurred in the year 2000. The change was primarily made in order for the standard to begin alignment with ISO 14001:1996. This was to aid organisations which were running parallel management systems. The next version published was ISO 9000:2008. The third revision began the harmonisation of generic Quality management systems and supporting technologies that were presented in TC 176 - Quality Management and Quality Assurance. The last updated revision was in the year 2015. The main change in this revision was the substitution of preventive action with risk management and the employment of the Plan-Do-Check-Act (PDCA) cycle at all levels of an organisation. Yang (2020) reports that Deming's Continuous Improvement Model, the PDCA cycle, has evolved throughout the decades and has become an integral part of the ISO 9000 series. Recognising, the evolution of the ISO 9000 series over the years highlights the ever-changing notion of traditional quality concepts, such as process quality control, product design, and customer service. Based on the evolution, it can be perceived that the use of international quality standards, such as ISO 9001:2015, could form a vital part of digitalised quality systems as that is the next step in the progression of quality.

Zaborovskaia *et al*. (2020) suggest that in order for an organisation to achieve sustained successes, there are three pillars that need to be fundamental to sustainability. These are economic growth, environmental considerations, and social cohesion. They further add that, in order to maintain these pillars in the age of the 4IR, it is paramount to include digitalisation in an organisation's operations and systems. Given these requirements, the emergence of operating multiple systems has become the norm in many organisations. Bernardo *et al*. (2018) posit that due the level of difficulty associated with operating multiple systems such as administrative and audits costs, cumbersome documentation, and repetitive processes, integrating management systems are recommended as an alternative to stand alone quality systems. Zimon *et al*. (2020) are of the view that the integration of different management systems is vital for the developmental and economic growth of organisations. In order to maintain this growth in the age of digitalisation it can be concluded that the integration of management systems has become a necessity to achieve the optimum structure for different organisations. This is in corroboration with findings from Ramezani and Jassbi (2020). In view of the evolution of quality over the various industrial revolutions, integration and digitalisation of management systems and standards appears to be a natural progression and it can be argued that quality must adapt to keep up with the emergence of the 4IR, making integrated management systems a vital part of the digitalisation in organisations.

Wilson and Campbell (2018), Carrillo-Labella *et al*., (2020), and Zimon *et al.* (2020) highlight that in order to identify overall inefficiencies in organisations and ensure a limited loss of competition in the global market, which is now driven by the 4IR, the different tools offered by quality systems can be pursued to minimise these inefficiencies and losses. For example, the possible use of ISO 9001:2015 to guide the process of digitalisation in organisations and the use of SPC to develop automated responses to non-conformances (Sengöz, 2018; Sader *et al.,* 2019; Özdağoğlu *et al*., 2019). Although several advantages of digitalisation have been discussed thus far, it is also important to consider the disadvantages associated with digitalisation. Royakkers *et al*. (2018), Dimitrieska *et al*. (2018), Kaur (2019), and Reis *et al.* (2020) report that even though there are numerous benefits associated with the shift towards digitalisation and embracing the 4IR, there are two main negatives which have emerged. The first being cyber security, which encompasses several major problems. For instance, cyber criminals are able to collect sensitive and private personal information about people, which opens the possibility for identity fraud. Therefore, organisations will have to ensure that they have extensive and encrypted software security systems to avoid this type of threat. Secondly is the disruption of the labour market. The main problem is a lack of training and awareness in the field of communication and digital technology. These areas include information technology, computer application technology, software development, biotechnology, and nanotechnology. The lack of training and awareness has also caused resistance to new technologies among employees.

There are two prime insights that can be drawn from these negatives. The first being that there is a lack of understating on how to go about planning, using, and implementing digital technologies. The second insight that can be exacted is that there is an internal mind-set among the employees that is difficult to change. Halawi and Haydar (2018) express that training is one of the most effective tools to overcome employee resistance. To overcome these problems, it is recommended that organisations offer training and professional development to employees prior to introducing new digital technologies and systems. For example, in South Africa the South African Qualifications Authority (n.d) reports that governmental programmes, such as the South African Skills Development Levy and Sector Education Training Authority (SETA) Programmes, are available for basic digital technology training for those organisations that do not have the financial capacity to commit to new training programmes.

Müller *et al*. (2018); Bressanelli *et al*. (2018); Parida *et al*. (2019); Reza *et al*. (2021); and Bag *et al*. (2021) describe the link between sustainability and digitalisation. Sustainability through digitalisation can occur in the form of improving product and process design, thereby moving organisations towards zero waste. This can be achieved through predictive maintenance programmes and product/process tracking based on available digital data streams such as work rate, rejection rate and other quality performance checks. This also allows organisations to lower their carbon footprint by reducing energy and minimising negative environmental impacts by cutting down on waste. Some positive attributes of digitalisation are that it encourages the use of different digital platforms to promote value-creating opportunities and to provide new revenue streams. These findings call attention to the various advantage's digitalisation has for both the organisation and the environment. Additionally, the positive effects that digitalisation has on the environment can form a key component of ISO 14001:2015 which further highlights the possible use of digital integrated management systems.

Methodology

Peters *et al*. (2015), Dewey and Drahota (2016), and Xiao and Watson (2019) express that following a systematic review process is an effective method to search, select, and critically evaluate literature. They further add that it is one of the most constructive and functional methods for reviewing literature. Hence, this paper will follow a systematic review process to get a sense of direction of present published research concerning Quality 4.0 and digitalisation.

The methodology employed in this research article followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) data screening process, which is a systematic approach to identify and select relevant literature (PRISMA, 2020). The initial step involved selecting multiple databases, namely Web of Science, Emerald, Scopus, Taylor and Francis, and Google Scholar, to conduct a literature search. The search was conducted using a combination of keywords, including "Quality 4.0", "Industry 4.0", "Digitalisation of Quality", "Smart Manufacturing", "Integrated Management Systems", and "Statistical Process Control". Boolean Operators were utilised to separate and refine the keywords for improved search accuracy. A date range from 2016 to 2021 was specified to encompass a wide variety of relevant sources and only peer-reviewed articles were flagged to maintain a high standard of scholarly rigour. The initial search results from each database are summarised in Table 1. Subsequently, the articles were imported into Endnote software for screening.

Table 1: Number of articles

Database	**Number of articles (initial search)**	**Number of articles selected for quality evaluation**
Web of Science	17	3
Emerald	28	7
Scopus	46	2
Taylor and Francis	41	4
Google Scholar	63	22

In the first phase of the screening process, duplicate articles (13 in total) were removed. Following this, the titles of the remaining articles were evaluated to assess their relevance to the research topic. Thereafter, the abstracts of journal articles were analysed and only those papers that exhibited alignment with the subject matter were selected for further investigation. The selected research articles were then thoroughly examined and their contents were scrutinised to identify pertinent information for this study. In total, 38 journal articles met the rigorous selection criteria and were included in this research, ensuring a robust and comprehensive review of the literature.

From a trend analysis, it can be witnessed that there is an increase in publications concerning digitalisation in quality and industry. The graphs below will depict pertinent information on journal articles where the information was available.

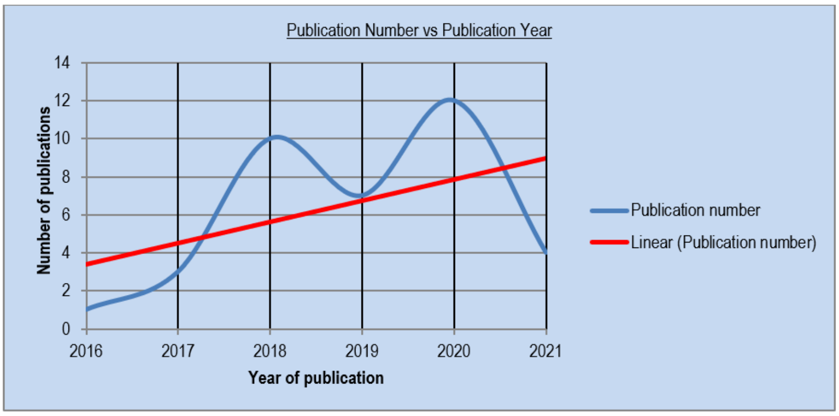

Figure 2: Graph depicting the number of publications versus the publication year

Figure 2 indicates that over the past five years there has been a significant increase in the number of publications concerning the digitalisation of quality and Industry 4.0. Based on the results of the linear trend analysis, it can be perceived that in the coming years there will be a rapid increase in publications as the 4IR continues to permeate into organisations.

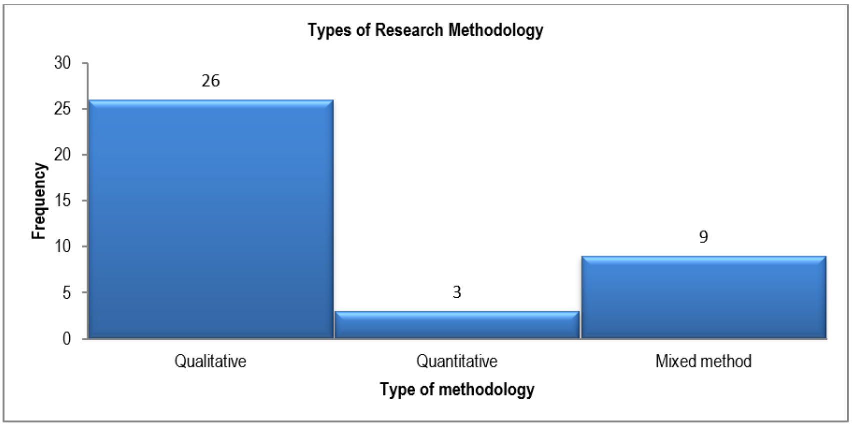

Figure 3: Graph depicting different types of data analysis

Figure 3 highlights the data analysis of the different journal articles that were used in this paper. The majority of articles that were examined followed a qualitative research analysis. This falls in line with the analysis that was used in this research paper. However, a few articles that follow a mixed method approach were scrutinised in order to inform the use of Statistical Process Control tools in this paper.

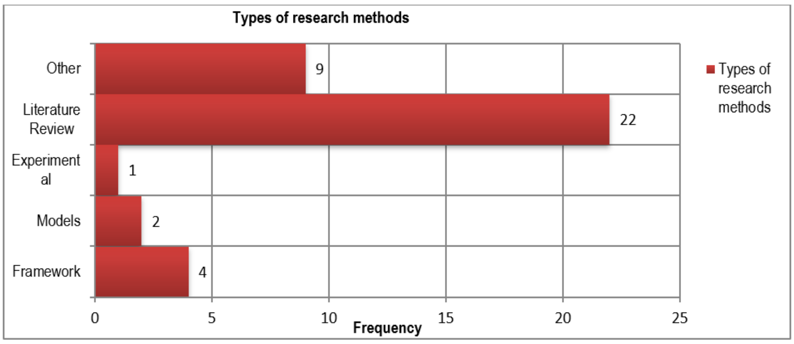

Figure 4: Graph depicting different types of research methodology

The last graph calls attention to the different types of research methodologies that the journal articles which were used in this research paper followed. Literature reviewed accounted for the majority of journal articles that were used. Six of the articles that were used in this paper were not included in Figure 4 because they did not follow any of the specific types of research methodologies listed above.

Results and Discussion

Sader *et al.* (2019) posit that digitalisation can be used in the implementation of the seven mandatory clauses in ISO 9001:2015. For example, digitalisation can be used in the planning clause by transferring data from processes onto digital systems and analysing the data thereby enabling predictive maintenance to occur. This can result in less downtime and reductions in defects. Another example can be seen in the leadership clause, where they argue that management are able to allocate resources more successfully due to evaluation of digital information such as intelligent quality control systems and early prediction of failures. Zonnenshain and Kennet (2020) propose that another route towards Quality 4.0, from an engineering perspective, is by combining Information technology and operations management, enabling digital transformation to occur. This entails transferring operations management principles onto digital platforms. For example, moving planning and scheduling into digital platforms ensures maximum availability of employees and efficient use of their time.

Another view, from Illa and Padhi (2019), is to introduce Quality 4.0 in the context of developing a 'smart factory'. They argue that total quality management can be divided into four main components that will drive digitalisation. The first category is integrated system architecture, which entails that all quality related data and daily checks needs to be integrated with an online system. The second category is automated data processing, where all quality related data needs to be automated. The penultimate category is increased levels of autonomy, which entails that operations are not dependant on people to function after defects occur. The last category is predictive analysis which requires the ability of data to automatically pre-empt defects and non-conformances. Fernández-Caramés and Fraga-Lamas (2019) and Buchi *et al*. (2020) had similar findings in their research. Piccarozzi *et al.* (2018) and Frank *et al*. (2019) posit the concept of Industry 4.0 or 'smart manufacturing' as the amalgamation of processes, systems, and operations with digitalisation and automation. Wiktorsson *et al*. (2018) highlight an example of this in Sweden, where a large bus and truck manufacturing organisation with the philosophy of continuous digital improvement has created a special internal smart factory laboratory. The laboratory is designated to conduct trials on emerging digitalisation with production and logistics and ensures that production and processing capabilities are at their optimum. An encouraging upshot of initiatives similar to this is that organisations can create or develop new departments that can research and develop digitalised systems and processes.

Lee *et al*. (2019) present an ideal example of the interrelation between quality and the 4IR and report a case study on establishing predictive maintenance using the international organisation, Rolls-Royce. They report that the sequence for establishing predictive maintenance was initiated by uploading all the data and information onto an internal digital network for ease of access and analysis. This resulted in the organisation being able to generate new information and communication technologies based on data analysis. Thereafter, they were able to develop predictive maintenance and quality control techniques to detect errors and monitor processes continuously. The key technological advancement that they used to monitor processes were nanobots equipped with cameras and sensors. Nanobots are microscopic sized robots with cameras and sensors that quality controllers insert into engines and other parts of Rolls-Royce products, where they can monitor and access products and processes continuously. A theme that has emerged from these authors is that organisations must be encouraged to move their quality systems online, with the underscoring aim of being able to eventually pre-empt operational defects and non-conformances. It can be deduced that once this is complete, organisations can then develop pre-determined corrective actions for different types of non-conformances that may occur, thus, reducing downtime, waste, and defects.

Prester *et al*. (2018) and Sremcev *et al*. (2018) encourage the use of quality tools when developing digital quality systems. One of these tools is Poke Yoke. Malega (2018) and Widjajanto *et al*. (2020) describe Poke Yoke as the Japanese term for 'mistake proofing'. Poke Yoke is an important quality tool that removes mistakes from processes, tools, or equipment and replaces it with a step that ensures that errors do not occur. Given that predictive analysis and pre-emptive maintenance have emerged as strong themes from literature, it can be perceived that Poke Yoke can be used as an important quality tool. Some of the commonalities between Poke Yoke and digitalisation are building a new system that is data driven, early detection of non-conformances, and an immediate response to non-conformances/downtime. Dutta *et al*. (2021) report that SPC has emerged as one of the most significant quality tools in the age of digitalisation. Statistical Process Control can be described as a method that employs statistical analysis to monitor and control processes with the aim of optimising processes and reducing waste. Some of the tools used in SPC include control charts and the design of experiments developed by Shewart in 1924.

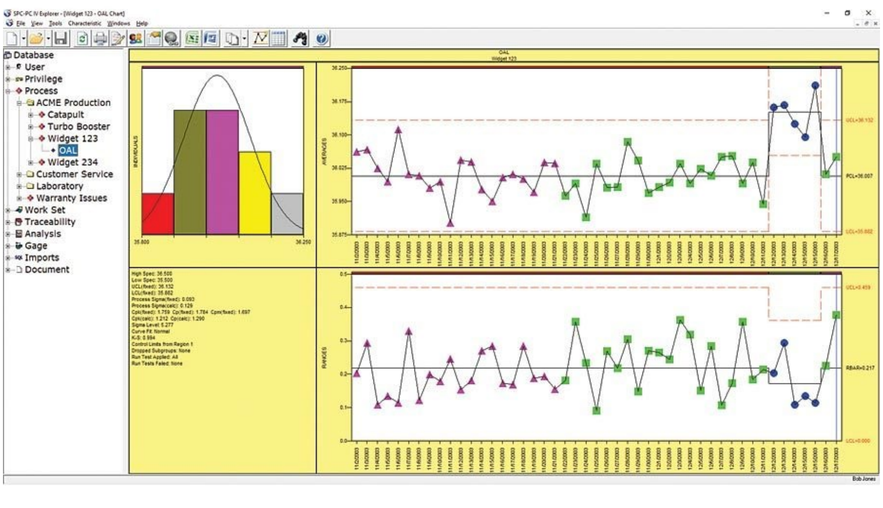

Figure 5: Visual representation of digital statistical processes control chart (Keller, 2019)

Sengöz (2018), Özdağoğlu *et al.* (2019), and Anuali and Venkatesan (2019) explain that control charts (Figure 5) are one of the main techniques used in SPC to enhance quality. They further allege that it is possible that additional information could be extrapolated from digitalised control charts; for instance, they could indicate when there are deviations from the control limits, thereby allowing pre-determined corrective actions to take place. The aim of this is to assist with real-time system diagnosis. A case study by Ramezani and Jassbi (2020) in Portugal attests that a lack of decisive quality control charts and a failure to integrate management systems are major hindrances in implementing Quality 4.0. They argue that integrating traditional software systems with intelligent software systems could overcome these issues. The results of this case study fortify the need for integrated management systems and the importance of SPC tools towards embracing the digitalisation concept. Ferreiro *et al*. (2016) posit a scenario for predictive maintenance where the focus is on physical-cyber systems. They attest that in order for an organisation to operate at its optimum, there needs to be predictive maintenance software for machines and physical mechanics. They add that organisational data needs to be analysed to develop different computer algorithms to ascertain degradation levels of machines and physical mechanics, thus, supporting the aim of establishing condition-based maintenance. This further substantiates the themes that have emerged from literature.

Leible *et al*. (2019) and Xu *et al*. (2019) call attention to the use of Block Chain Technology (BCT) in digital systems. Block Chain Technology has gained prominence in recent years because it is the underlying technology used in crypto currencies such as Bitcoin. Block Chain Technologies can be described as disruptive core technology in that it can change the way systems and organisations operate. Block Chain Technology collects information then embeds a digital code in each piece of data and stores it in transparent and shared databases, where the information is protected from deletion or revision. Other advantages of BTC include the decentralisation of information, transparency, immutability, and improved efficiency. The different clauses of ISO standards require increased transparency, access to information, traceability, and preventing tampering of information. Therefore, it can be deduced that these key advantages of BCT could be applied to Digital Quality Systems. The implications of this could foster another possible component that could be integrated in a digital quality system.

This section presented the argument that digitalisation has created the opportunity to use SPC and Poke Yoke as mechanisms to create predictive maintenance performance software for digital quality control systems. The software needs to establish clear decision-making rules in the event of non-conformance or downtime and create systems to eliminate the different possibilities of errors. This can be achieved by automating a predetermined response once a process falls out of the acceptable limits. The need to have predetermined and automated responses falls in alignment with research conducted by Sader *et al.* (2019), Illa and Padhi (2019), and Ramezani and Jassbi (2020). Moreover, given that predictive analysis and maintenance has gained steady endorsement in extant literature, and by extension this research paper, it stands to reason that this component can play a pivotal role in the digitalisation of Quality.

Recommendations

This section recommends the best practices and way forward for organisations to begin implementing Quality 4.0 based on the deductions and recommendations from the literature review.

Rybski *et al.* (2017), Fonseca and Domingues (2018), and Galli (2019) posit that the PDCA cycle is a feasible mechanism to guide research and integrate different management systems. The cyclic model allows for faster streamlining of processes and methods that are more efficient to track progress and continuous improvement. Therefore, the PDCA cycle will be used as the underlying concept for the road map that will be presented.

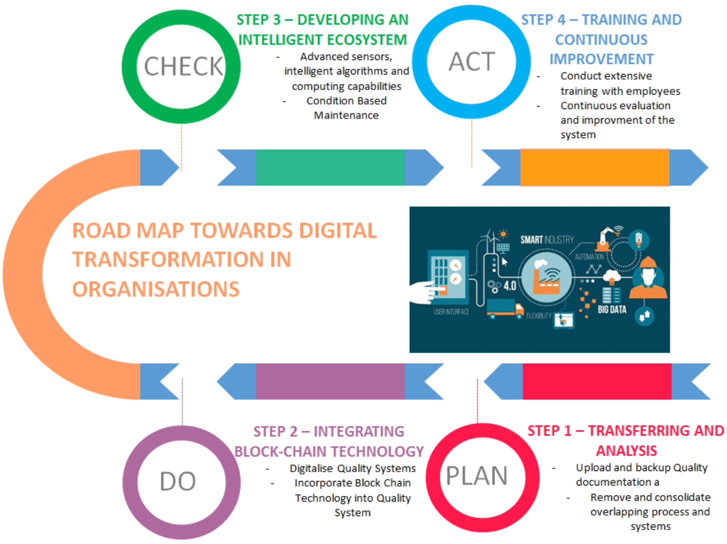

Figure 6: Visual representation of Road Map towards digital Quality transformation in organisations

Transferring and Analysis (Step 1): In order to develop a solid foundation of a digital quality system, it is first recommended that all documents, policies, and information concerning quality be digitally uploaded onto an internet storage database or a server. Following this, it is recommended that organisations begin assessing and analysing their systems and processes. After this analysis is completed, redundant processes must be removed and processes that overlap must be consolidated. This falls in line with the requirements of implementing digitalisation in organisations and integrated management systems.

Integrating Block Chain Technology (BTC) in Digitalised Quality Control (Step 2): The process of quality checks and inspections must first be digitalised. Initially, if the checks and inspections are conducted manually, the data must be inserted into a digital programme immediately. This can occur in two ways; for example, computers stationed at quality checkpoints or quality controllers being assigned digital tablets. Block Chain Technology can then be incorporated into the digital quality control systems. Block Chain Technology is a type of database that collects information together in groups and stores them as blocks. A key advantage of incorporating BCT in a digital quality system is that the system provides an irreversible timeline of data captured. This also removes duplication of records, reduces upload times, and accelerates processing of data.Additionally, BCT aids in transparency because any attempted changes or effected changes to data streams are visible to whoever is using the system.

Developing Intelligent Ecosystems (Step 3): Once quality control data is digitalised, then organisations can use computer-based algorithms to develop statistical control charts for each process with predetermined control limits. Organisations can begin incorporating advanced sensors into their processes; for example, using sensors with intelligent algorithms to detect products that have deviated from specifications. Quality control tracking systems can also be used for individual components of a product. For example, Židek *et al.* (2020) posit the use of, radio-frequency identification (RFID) systems. This system uses electromagnetic waves to track individual components of a product. After control limits are established, automated responses can be programmed to occur when a process falls out of the control limits. The process must automatically stop or adjust itself to predetermined levels depending on the type of process. This will aid in minimising financial obligations such as waste, errors, and downtime. Furthermore, this data can also be used to establish condition-based maintenance. By analysing the digital data and control charts, organisations can be able to identify processes that are frequently deviating from the specifications. This draws attention to equipment or physical mechanics that may need attention.

Training Step 4: Training must form an integral part of digital transformation. This is to ensure that employees are motivated and feel secure in their positions. Finally, continuous monitoring and improvement of the system is recommended to ensure the organisation is up to date with technological trends.

Taking cognisance of the tremendous impact that digitalisation has had on organisations, it is, therefore, of paramount importance that organisations immediately embark upon the process of digitalising their quality systems. This is to ensure that organisations minimise inefficiencies and ensure limited loss of competition in the global market. The recommendations above provide a roadmap that organisations can follow to begin the digitalisation of the internal quality systems. It is envisaged that once an organisation follows these steps as represented in the PDCA cycle, they will make significant progress towards preparing themselves for the convergence of quality and digitalisation in a changing world. This study carries substantial implications for both the academic and practical spheres. In academia, it serves as a valuable resource for instructing on the subject of quality and digitalisation, exploring its multifaceted elements that exert influence on both the organisation and its customers. From a practical perspective, the study holds considerable economic implications as a proposed roadmap and model facilitate the integration of diverse elements to establish an intelligent quality ecosystem, enabling the development of a transparent, secure, and value-based quality system. These advancements have the potential to optimise resource utilisation, reduce waste, and mitigate environmental impact (Müller *et al.,* 2018; Bressanelli *et al.*, 2018; Parida *et al.,* 2019; Reza *et al.,* 2021; Bag *et al.*, 2021). Simultaneously, the advancements contribute to heightened operational efficiency, improves decision-making processes, and enhanced competitiveness for organisations navigating the digital era.

Conclusion

By embracing digital solutions and prioritising quality improvement, organisations can navigate the complexities of the modern business landscape. They can achieve greater resource efficiency, reduce their environmental footprint, and even contribute to the development of a circular economy. The findings of this study highlight the critical role that quality and digitalisation play in shaping the future of organisations across sectors. Moving forward, it becomes evident that the integration of digital technologies and quality-driven practices is essential for organisations aiming to thrive in an increasingly interconnected and competitive global market. Future research and practical implementations should continue to explore and harness the potential of these synergies, driving innovation, sustainable growth, and positive societal impact. A possible avenue of exploration could be the development of frameworks and standards that promote the seamless integration and compatibility of data and systems related to quality.

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