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RESEARCH ARTICLE

Benefits, challenges, critical success factors and motivations of Quality 4.0 – A qualitative global study

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Purpose – Quality 4.0 (Q4.0) is nascent, but many organisations have started their journeys on Q4.0. This study seeks to investigate the real-time organisational benefits and motivations for deploying Q4.0 and understand current Q4.0 initiatives along with the skills, challenges, and critical success factors required to implement Q4.0.
Design/methodology/approach – A qualitative interview approach was utilised by interviewing a global panel of senior management, and operational excellence professionals from leading companies deploying Q4.0.
Findings – This study provides a theoretical base for the organisational adoption of Q4.0 and understanding the benefits, challenges, critical success factors, motivations, and skillsets required. The challenges to Q4.0 identified include gaining management commitment to invest in technology and guide the organisational strategy to implement Q4.0. The skillset required for Q4.0 includes data science, data analysis, and knowledge of Industry 4.0 technology in order adapt to the increased world of digitalisation and smart factories.
Research limitations – Most of the interviewees who participated in this study represent four continents. There is an opportunity for a detailed longitudinal study, analysis, and case studies in individual organisations.
Originality/value – This is the first global study on Q4.0 that captures the viewpoints of senior management professionals deploying Q4.0.

Keywords: Q4.0; Challenges; Benefits; Critical Success Factors; Organisational Readiness; Leadership; Q4.0 Skills

1. Introduction

With the advent of Industry 4.0, modern organisations are undergoing transformation changes with increased digitalisation and automation. Digitalisation creates new opportunities for organisations to incorporate technological advances to achieve superior operational excellence, performance, and innovation (Santos et al., 2021; Sony et al., 2020). The term Quality 4.0 (Q4.0) was first put forward by Jacob (2017), who stated that Q4.0 connects new technologies with traditional quality methods. However, various

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authors have since proposed different definitions of Q4.0 (Sader et al., 2021; Watson, 2019). Q4.0, in simple terms, is managing quality in the modern era of Industry 4.0. Therefore, Q4.0 can be thought of as combining the new technologies of Industry 4.0 and traditional quality management systems, tools, and methods to achieve superior performance, a higher level of operational excellence, and optimal innovation (Antony et al., 2021a; Radziwill, 2018). However, a global study by the Boston Consulting Group found that few organisations had a clear and detailed strategy on Q4.0 and had yet to launch an implementation programme (Kupper et al., 2019).

Q4.0 deployment and the concept itself are still nascent within organisations (Antony et al., 2021a; Chiarini and Kumar, 2021). A practical and theoretical understanding of Q4.0 are important to ensure successful implementation and deployment of Q4.0. Visualisation and conceptualising Q4.0 are important to understand the concept (Sony et al., 2021a). Hence, there is a need to capture practitioners' real-time viewpoints and experiences during the implementation of Q4.0. The practical experience of Q4.0 practitioners can be analysed to develop the theoretical understanding further. Except for Antony et al. (2020) and Antony et al. (2021a), very few studies have conceptualised Q4.0 from a practitioner and current implementation point of view. Thus, the first main research question for this study is to understand the benefits and motivations for Q4.0 from a practitioner viewpoint to develop the theoretical understanding. The second main research question for this study is to further the understanding of the concept of Q4.0 from a practitioner viewpoint in organisations where Q4.0 is currently being implemented and is an ongoing project. This study expands the current understanding of the various components of Q4.0 as a concept based on practical examples from practitioners. As such, the following sub-research questions for this research project are as follows:

1. What are the benefits and motivations for adopting Q4.0?
2. What are the critical success factors (CSFs), challenges, organisational readiness factors, and skills of Q4.0?
3. What types of Q4.0 projects are deployed in organisations and why?

2. Literature review

2.1 *Q4.0 definitions and characteristics*

The International Academy for Quality (IAQ) and the American Society of Quality (ASQ) have both put forward definitions for Q4.0 and how Q4.0 will change the quality profession (Ramanathan and Watson, 2021; Watson, 2019). According to ASQ, 'Q4.0 brings together Industry 4.0's advanced digital technologies with quality excellence to drive substantial performance and effectiveness improvements' (ASQ, 2021). Per Sader et al. (2021), 'Q4.0 is the new generation, evolution, or revolution of quality management, resulting in conjunction with the emergence of Industry 4.0 due to the advancement in ICT and Industry 4.0'. Antony et al. (2021a) defines it as 'the use of advanced technologies such as IoT, CPS, cloud computing to design, operate and maintain adaptive, predictive, self-corrective, automated quality systems along with improved human interaction through quality planning, quality assurance, quality control and quality improvement to achieve new optimums in performance and operational excellence'. While Dias et al. (2021) describe Q4.0 as 'the delivery of superior quality, using modern technology to augment the capabilities of both people and quality tools and methods'. More specifically, Q4.0

can be described as the 'Digital empowerment of all the stakeholders of the process for dynamic quality enhancement and sustainment' (Radziwill, 2020).

The literature highlights that Q4.0 leverages the potentials of disruptive technologies of Industry 4.0. Q4.0 will ensure quality decisions are taken with less human intervention, which leads to mistakes or errors and more technology interference. Q4.0 evolved from all the previous quality approaches and methodologies from the past four to five decades. It is a fusion of people, processes, and technology (ASQ, 2021). More specifically, it has roots in managerial, statistical, and Industry 4.0 technologies. In addition, Q4.0 depends on a dynamic ecosystem that fosters learning, unlearning, and relearning with dynamic data analysis and decision making for quality improvement and sustainment (Escobar et al., 2021). This can be achieved through technologies such as artificial intelligence, Internet of Things (IoT), big data, block-chain, deep learning, machine learning, and data science to achieve defect-free processes, smart, and speedy decision making (Radziwill, 2020). However, technology is just one component of the Q4.0 quality transformation. The traditional quality aspects reinforced with technology will be the new paradigm. Also, the operation excellence division will continue to be an integral part of the Q4.0 transformation (Sureshchandar, 2021).

2.3 *Q4.0 motivators*

Ever-changing customer preferences, the intervention of disruptive technology, emphasis on the circular economy, high stakeholder expectations, sustainable production/service goals, and Industry 4.0 requirements are persuading organisations to adopt Q4.0. Further, the expectation of quality has changed from continual quality improvement and sustainment to dynamic product and service innovation. In addition, reliable information, data-driven decision making, customer satisfaction, stakeholder satisfaction, and cost and time savings are the real motivators for the adoption of Q4.0 (Antony et al., 2021a; Sony et al., 2021a). According to Antony et al. (2021a, 2021b), Q4.0 impacts key performance indicators of the organisation such as financial performance, environmental sustainability, customer value proposition, social performance, and internal and external business growth. Q4.0 ensures superior quality and performance due to its adaptive capacity of a product or service at any point of its life cycle to increase customer satisfaction and stakeholder interest in the value chain (Salimova et al., 2020; Dias et al., 2021). Moreover, Q4.0 reduces the cost of redesign and rework by reducing the turnaround time to launch the product or service to the market due to dynamic data-based decisions. This leads to empowered internal and external customers with effective collaboration, connectivity, and co-creation (Zairi, 2020; Dias et al., 2021)

2.4 *Q4.0 benefits*

The new tools and techniques of Q4.0 enhance the quality of decisions by reinforcing human intelligence, ensuring transparency, and traceability. Further, it assists in robust prediction, unearthing the bias, and dynamically providing feedback with potential solutions. Q4.0 also helps in auditability and provides evidence of compliance to specifications (Radziwill, 2018). The opportunities to utilise technology to predict when equipment in manufacturing or the customer arena will fail aids in the reduction of downtime, increase reactivity and response time, and reduction of warranty claims (Santos et al., 2021). Q4.0 will considerably reduce the cost of poor quality by reducing quality assurance, inspection, and field reliability issues (Antony et al., 2021ab).

Therefore, Q4.0 can yield many benefits for organisations, which provides strong motivation for an organisation to embark on Q4.0 implementation. Recent technologies such as blockchain have improved data quality and traceability, enabling efficient recall of products if quality issues arise (Saggin et al., 2019). Organisations currently implementing Q4.0 are reaping the benefits and adjusting to the challenges. The benefits of increased productivity, improved operational efficiency, reduced costs of quality, enhanced product quality, and increased customer satisfaction are motivating factors for the adoption of Q4.0. According to Javaid et al. (2021), Q4.0 has significant applications in the manufacturing sector as it automates inspection processes, reduces the cost of quality, assists in dynamic quality control, increases performance of the product, enhances business culture and partnership, re-aligns quality functions, reshapes production procedures, streamlines productions of new products, automatically detect defects, and helps in proper operations of finished goods. Moreover, it ensures environmental quality and green production by helping operators track and maintain temperature, moisture, air, and water quality (Javaid et al., 2021).

2.5 *Q4.0 challenges*

Nevertheless, the deployment of Q4.0 has several challenges. It demands systems thinking approach, quality information, reliable data, innovation ecosystem, learning organisation, and socio-cultural and socio-technical transformation. In addition, the non-availability of resources, lack of synchronisation of Q4.0 with corporate strategy, lack of awareness about benefits, high initial investment, and effectiveness of current continual improvement strategies compared to Q4.0 limit the adoption of Q4.0 across organisations (Antony et al., 2021a; Sony et al., 2020). Further, digital empowerment, digitalisation, and dynamic quality enhancement are essential to ensure Q4.0 deployment. Moreover, cultural transformation is vital to reinforce the digital transformation of quality (Sureshchandar, 2021). The greatest challenge of Q4.0 does not lie in automation or technology. Instead, it relies on the people who use the technology. Thus, the challenge is to enhance the technical abilities and capability of the people to solve the problem based on reliable data and scientific methodology (Balouei et al., 2022).

2.6 *Q4.0 Readiness factors*

Organisations must prepare their workforce for the automated inspection process and data analytics skills. Also, the integration value chain for data quality is essential for reliable and quality data (Sader et al., 2021). The handling of big data in quality management is the most important factor for adopting Q4.0, irrespective of the size and nature of the organisation. Small and medium-sized enterprises (SMEs) reported that costs and time savings over the long run were not high with Q4.0. Thus, it is essential to perform critical analysis before full-scale implementation. An organisation must be prepared for cultural transformation towards Q4.0, establish a roadmap for Q4.0 deployment with a clear vision and strategy, promote knowledge and awareness on Q4.0 among the stakeholders, and ensure customer and supplier focus across the value chain (Antony et al., 2021a). From the perspective of technology, big data, connectivity, collaboration, and data presentation across the system must be integrated for Q4.0 deployment (Sader et al., 2021). Also, from the operational point of view, it is necessary to ensure business objectives are aligned with Q4.0 project selection and prioritisation criteria. In addition, effective management of resistance

to change, horizontal, vertical, and end-to-end system integration with Q4.0, and training on Q4.0 are vital to initiate the Q4.0 transformation (Escobar et al., 2021; Sony et al., 2020).

2.7 *Q4.0 skill factors*

There will be an increased focus on data science and data mining in Q4.0 (Ramanathan and Watson, 2021). Traditional quality managers have valuable soft skills that can include communication, teamwork, time management, assessment and analysis, leadership, and customer focus, amongst many more skills (Garad, 2007). However, organisations implementing Q4.0 need to be well versed in the use of technology and the development of those technologies (Cudney and Keim, 2017; Gunasekaran et al., 2019a; Kannan and Garad, 2020). Sony et al. (2020) highlighted a shortage of digital skills, slowing Q4.0 implementation. Santos et al. (2021) and Escobar et al. (2021) recommended skills for quality professionals in the Q4.0 world. These skills include combining new technologies with quality management practices and enhanced decision making by utilising smart and reliable data (Küpper et al., 2019). Sureshchandar (2021) highlights that problem-solving is one of the essential skills for quality improvement in addition to technical skills. Moreover, sound statistical and analytical skills are essential for making an informed decision. Chiarini and Kumar (2021) highlight that leadership and digital literacy of quality staff are essential skills for Q4.0.

2.8 *Q.4.0 critical success factors*

CSFs for implementing Q4.0 in an organisation include increased availability of data and ability to analyse it, linking the Q4.0 initiative to organisational strategy, having leadership commitment and support, providing adequate training, and having a receptive organisational culture for Q4.0 (Sony et al., 2020). However, Kupper et al. (2019) found that few organisations had a plan or strategy for Q4.0. Moreover, as Q4.0 is still nascent and evolving (Gunasekaran et al., 2019b), there is little evidence of a successful implementation of Q4.0. The CSFs of implementing Q4.0 is aligned with Industry 4.0. The investment in technology, appropriate skill sets, proper training and knowledge, resolving issues with cybersecurity, management support, organisational culture, effective management of resistance to change are critical for Q4.0 deployment. Antony et al. (2021b) highlight commonality between the CSFs of Q4.0 and Lean Six Sigma.

3. Methodology

A qualitative study was carried out utilising interviews for data collection. Senior managers with expertise in Q4.0 and quality roles working in a wide range and diversity of industries were chosen in this study. A purposive sampling study was carried out (Etikan et al., 2015; Charmaz and Belgrave, 2007). An exploratory qualitative design was utilised to capture the views of senior organisational personnel on their practical understanding and their views of Q4.0. This study included participants from seven different countries and four continents.

Countries such as Germany, the UK, USA, and Italy are dominating Industry 4.0 research (Brandenburger et al., 2021; Chiarini and Kumar, 2021; Yurin et al., 2021).

The professional interviews were chosen from different industry types, including aerospace, information technology, power industry, and digital security, to name a few. This selection was chosen to establish a wide range of viewpoints and concepts concerning Q4.0. All participants have over 10 years of experience and were involved in some level in management and strategic roles. The participant's details and backgrounds are elucidated in Table 1.

Participants details were found from LinkedIn, as it is the most up to date source of professional networking (s-Shpigel et al., 2015). Online interviews using Zoom or MS teams were conducted. The interviews consisted of general questions to start the process about demographic information about the interviewees and their experience working within quality management or continuous improvement disciplines, followed by twelve open-ended questions. The same questions were intended to be asked of all respondents to ensure consistency and comparability of the qualitative study. The themes of the questions were centred around benefits, motivations, leaderships role, CSF's, challenges, and readiness factors for Q4.0 implementation.

Other more analytical questions were subsequently asked concerning Q4.0 depending on the information and opinions expressed by the respondents during the study. The interview results were transcribed once the recordings were available and identified, documented, and uploaded to ATLAS Ti9 software using participant numbers (P numbers) to maintain anonymity. Following Gupta et al. (2020) and Saunders et al. (2018), a sample size of eleven was judged appropriate as saturation was achieved and no new themes emerged. Participants in the interview process had more than 10 years of experience and were senior provisional and senior managers within their organisations with experience in Q4.0 project implementation.

The grounded theory methodology was used to perform qualitative analysis (Hussein et al., 2020). Open coding was utilised to identify individual meaning units or similar themes; in axial coding, these were categorised or sub-categorised, and selective master themes or selective coding were linked (Charmaz and Belgrave, 2007). Finally, memoing was utilised to verify the data and keep track of the Q4.0 themes while coding with triangulation by multiple research team members (Creswell, 1999).

The following themes of Q4.0 were researched in the interviews: defining Q4.0, benefits and motivations for Q4.0, measures of success, organisational readiness factors for Q4.0, the role of leadership in Q4.0, and challenges and CSFs for Q4.0 implementation.

Table 1. Participant information by industry/organisation type, location, and role.

Participant	Role	Organisation Type	Location
1	Head of Quality Management	Digital Security	Netherlands
2	Global Head of Operational Excellence	Digital Technology	India
3	Director of Quality	Aerospace	USA
4	Head of Operational Excellence	Engineering Services	UK
5	Associate Director	Management Consultancy	USA
6	Global Customer Quality Leader	Sustainable Technologies	UK
7	Quality Manager	Power Industry	UK
8	Director of Quality	Manufacturing Services	Belgium
9	Director of Quality	Industrial Automation	Denmark
10	Global Engineering Director	Transport Refrigeration	Canada
11	Executive Director	Accountancy Consultancy	India

In addition, the types and tools of Industry 4.0 that can be utilised in Q4.0 were also investigated. Another important part of the research was to investigate the topics for a future curriculum of Q4.0 along with the hard and soft skills required and examples of implementation or application of Q4.0 projects.

4. Results & discussion

4.1 *Defining Q4.0 from a practitioners' perspective*

One of the first thematic questions ascertained how the interviewees understood or defined Q4.0. The responses are summarized in Table 2. A word cloud as a simple visualisation technique was used to summarise the responses to defining Q4.0 and demonstrate the most frequent words of a text in a circular spatial layout. The font sizes of the words indicate their relevance or occurrence frequency, while other visual properties (e.g. colour, position, orientation) are often varied for aesthetic reasons or to visually encode additional information. Keywords featured included quality, 4.0, technology, industry, process, automation, and intelligence, to describe a few.

Many respondents referred to Q4.0 as the 'digitalisation of quality' or 'Industry 4.0 plus Quality'. The interview participants echoed this theme of the 'integration', 'linking', and 'alignment' of Industry 4.0 and Q4.0. As defined by Antony et al. (2021a) and echoed by the interviewees, Q4.0 can be thought of as combining new technologies and standard quality tools and methods to achieve superior performance, a higher level of operational excellence, and optimal innovation. A summary of the definitions of Q4.0 as put forward by the participants is demonstrated in Table 1. A strong theme of how Industry 4.0 technology can help improve quality through better technology, automation, and new techniques and achieving organisational strategy was echoed by all the participants.

The respondents in this study also explicitly stated the importance of integrating technology with human aspects to implement Q4.0 to meet the key strategic objectives of an organisation. Thus, pragmatically Q4.0 can be defined 'as the systematic integration of Industry 4.0 technologies with existing quality tools and methods using a meaningful framework and also incorporating human factors, to achieve superior quality performance and higher levels of operational excellence'. (Table 2)

Table 2. Definitions of Q4.0: responses from research participants.

'Q4.0 is the way robotics or computerisation is used in industry to facilitate processes' **P7**
'It is optimising existing quality processes by applying new technology and applying the principles of industry 4.0 to quality thus improving the business model' **P9**
'Q4.0 is linking quality to Industry 4.0' **P10**
'Q4.0 is the translation of Industry 4.0' **P11**
'Q4.0 is to utilise these new techniques or these new tools that are the result of Industry 4.0 and put them in the Quality frame-of-work, meaning using or building on the existing techniques or methodologies that have been there for decades for quality … and inserting them into a meaningful framework' **P1**
'Alignment with industry 4.0 enabling a connected organisation. Intelligent investment with automation playing its part, thereby creating space for human beings to do a lot more creative and innovative solutions in the space for quality' **P2**
'So, Q4.0 would align with the business model of the company, not just limited only to product quality. It is about driving total quality across organisations' **P3**

4.2 *Benefits of Q4.0*

The next question, 'What are the benefits of Q4.0 to your organisation?' was asked. There are major benefits if one can implement it correctly, particularly in manufacturing. The research question responses were analyzed to get a practical understanding of why Q4.0 is important in an organisation. As described by Antony et al. (2021a), Q4.0 is closely aligning quality management with Industry 4.0, which will help organisations in enterprise efficiency, performance, and improved business models.

While many interviewees outlined the benefits of Q4.0 in terms of increased customer satisfaction and improved product quality, the themes of how Industry 4.0 technology will help deliver Q4.0 and enable quality professionals for success were reoccurring. Q4.0 implementation within an organisation improves customer satisfaction, ensures better and superior quality products and services, and delivers a competitive advantage.

'We will get it right the first time', and 'we can reduce inspection and where we need it, we can ensure its effectiveness'. Another respondent stated, 'Using sensors, we can track producers and highlight when these products need servicing'. In a McKinsey report, Carpintero et al. highlighted similar benefits of 'smart' Quality. These benefits included optimised quality control plans, deviation and nonconformance prevention, and rapid issue resolution, which can accelerate production and release cycle times. In particular, they highlighted the benefits to Pharma and Medtech industries with highly regulated environments by utilising technology to integrate compliance documentation and using data to make decisions, thereby reducing the compliance burden. The benefits highlighted by the participants are highlighted in Table 3.

4.3 *The challenges of Q4.0*

The respondents were asked the research question concerning the challenges of Q4.0 to understand it from a practical perspective. The participants cited many examples of the challenges of implementing Q4.0, including gaining management commitment for investing in technology and guiding the organisational strategy to implement Q4.0. 'That is that it has to be committed to, from the top management and then down in the organisations'

Table 3. Benefits of Q4.0: responses from research participants.

'There are benefits because of the quicker decisions enabled by better vision systems, data and connectivity. Producing with small variation in products, cheaper and quicker inspection' **P2**
'Q4.0 will reduce the operational costs of quality assurance and inspection' **P3**
'There are major benefits if you can implement it correctly, and in particular in manufacturing. I think that is where you find synergies with industry 4.0 as well, of course, and that the two are related to each other' **P4**
'Q4.0 is a cost reduction because you can have much quicker responses to deviations in processes by putting the right sensors in place' **P5**
'Efficient use of resources and saving time' **P6**
'In the Q4.0 world, if I have got sensors, AI and machine learning with analytics capability; I won't need to sample and inspect at all' **P7**.
'Q4.0 will give me a constant data feed to analyse, use for root causing and enable decision making' **P11.**
'Performing inspection day in and day out with a ruler or calliper. Writing up defect reports or performing a routine audit. You know these types of manual, repetitive jobs -robots can do' **P10**.
'When I look at how many aircraft we build a year or over the next 30 years … . The seconds and minutes really add up, so there is a huge ROI to be reaped by applying Q4.0 technology' **P3**

was a comment stated by one participant indicative of the theme of management support. In addition, the cost of Q4.0 in terms of implementation was a strong theme from every participant.

The interview participants reported significant challenges in adopting Q4.0 to be lack of resources in terms of financial, people, and time resources. Also, the lack of understanding the relationship of Q4.0 with the organisational strategy and goals, actual benefits of Q4.0, or definition of Q4.0. One comment captured this confusion as 'we do not know the benefits until we see the change and implement the technology, but we cannot implement the technology and see the change without visionary leadership, understanding of the technology, the benefits and high investments'. A summary of the responses from the participants is provided in Table 4.

4.4 *Core skills for Q4.0*

In order to prepare for Q4.0, quality professionals will need to develop different skills than they currently have to support the evolution to Q4.0. Therefore, the participants were asked to provide the core skills required of quality professionals for Q4.0 evolution, preparedness, and maintenance. The responses are outlined in Table 5.

The participants discussed the different hard and soft skills related to the current role of quality professionals versus the future role within Q4.0. Themes of data analysis the availability of new, better, and larger amounts of data was a recurring theme. The importance of data science can be viewed as 'asking the right questions and analysing the data to get answers' (P6). The importance of data science, analysis, and data analytics was seen as vital to the skillset of the future quality professional. These skills in data science have been highlighted by several others, including Ramanathan and Watson (2021), and Antony et al. (2021a).

Santos et al. (2021) and Sony et al. (2021a) highlighted that shortages of digital skills and challenges with technology and data are barriers to Q4.0 implementation. Other soft skills such as teamwork, communication, decision making problem solving, and enhanced project management skills were deemed important by the interviews. These skills have been discussed as just as important as data analytics by Watson (2019) and Küpper

Table 4. Challenges of Q4.0: responses from research participants.

'Not all organisations and countries can afford or possess the same readiness.' **P1**
'Data management and an over-reliance on the cloud can threaten cyber security.' **P2**
'A big challenge is the willingness and capacity to change.' **P3**
'Aging workforce is with new computing/communication systems will be a challenge.' **P4**
'Have to overcome the fear that a robot will take my job.' **P5**
'Lack of commitment from the leadership is going to be the biggest challenge. It is not something that can be delegated down the line.' **P6**
'Need to look at the return on investment, be ready to experiment with different technologies because new technologies are coming through.' **P7**
'Carefully evaluate some of the technologies in the market and see what this can be done to reach out to those technology.' **P8**
'If you do not have that courage to invest in Q4.0, that is the biggest challenge.' **P9**
'Q4.0 should not be seen as an initiative by the quality department. It is an organisational initiative, so it has to be brought in right from day one with the business owners.' **P10**
'If we are going to take a collective and cohesive approach towards quality – this is not going to be the responsibility of the quality department.' **P11**

Table 5. Core skills for Q4.0: responses from research participants.

'Analytical skills – How to deal with the new technologies/ machine learning/ read and analyse data? There will be tonnes of data and info produced per minute and transmitted to a central location. We need reskilling/upskilling on how to handle this within the quality dept.' **P2**
'Soft skills: Communication and leadership: need to be better able to explain these processes to suppliers/customers.' **P3**
'Quality professionals are in a good position to acquire new techniques and skills as they have already been trained to be analytical thinkers. Some jobs, however, will become obsolete, e.g. Inspector.' **P6**
'Quality traditionally has been more focused on, you know, checklist-based activities or procedural based activities compliance perspective. But now Q4.0 will do this with automation that will take care of all the checklist compliance paths.' **P7**
'Quality will now focus on performance improvement; cognitive thinking, critical thinking, and other important soft skills as well as technological literacy and digital literacy.' **P8**
'So being quality professionals, we need soft skills and to possess the ability to solve a business problem using structured methodology with techniques as well as the ability to embrace technology swiftly to solve a business complex business problem in record time.' **P10**
'To use technology and software to empower the machines so that it will give the quality professional enough bandwidth and space to focus on structured problem solving.' **P11**

et al. (2019). Further, employers expect graduates to have generic skills and the ability to learn, which needs to be incorporated into the curriculum for quality professionals of the future.

4.5 *CSFs for the implementation of Q4.0*

To gain a complete understanding of Q4.0, in addition to motivations, the respondents were asked what the CSFs for the adoption of Q4.0 in organisations were. Several CSFs have been described for implementing Q4.0, including having top management support, a good organisational culture, support of leadership, and a vision for Q4.0 aligned with strategy, as well as a training programme of support Q4.0 need*s* (Sony et al., 2021a; Sony et al., 2020).

The participants comments echoed the CSFs concerning management support in the literature. P1 stated, 'Top management support is very important', while P2 noted, 'management engagement and commitment'. In addition, P3 remarked that, 'reluctance is inevitable, so management needs to have been bought into the process of transition'. Training, good infrastructure, and investment were all deemed CSFs as highlighted by comments such as the following from P8, 'We need infrastructure readiness within the organisation: How much investment will give us a return and results?'. Similarly, P9 stated, 'We need to be prepared. Are our workforce educated enough on the digitalisation of quality? HR and management need to collaborate for success in identifying skills shortages; is there apt training?'

4.6 *Motivations for Q4.0*

The responses to the research question, 'what are the motivations for implementing Q4.0?' were analysed based on how many respondents gave examples of their organisations. A word cloud was generated, as demonstrated in Figured 2 on the motivations. The key themes or words highlighted as the motivations for Q4.0 are quality improvement,

reduced costs, solving problems with reliable data, sound and efficient decision-making, and reliable and fast data collection. (Figures 1 and 2)

Antony et al. (2021a) described the motivations for Q4.0 as reduced costs of quality arising from improved operational efficiencies, increased profits, reduced defects, improved product compliance, reduced cycle time, increased on-time deliveries, reduced supplier defect rates, and increased successful new product introductions.

Figure 1. Defining Q4.0 – Word Cloud.

Figure 2. Motivations for Q4.0 – Word Cloud.

4.7 *Organisational readiness for Q4.0*

The respondents in this study remarked on the importance of how ready an organisation should be to implement Q4.0 and take advantage of the technologies of Industry 4.0 as a readiness factor. Q4.0 deployment will shift focus from the operationally oriented task of creating and executing a quality strategy to holistically applying quality as a strategy across the entire organisation (Antony and Sony, 2021). An organisation's readiness depends on how well an organisation is ready to implement the technologies of Q4.0 in its respective organisation to meet the organisation's objectives and goals. Q4.0 digitally transforms an organisation through automation and data integration to meet its quality and customer satisfaction goals. Having adequate resources to implement the Q4.0 strategy and project documents was a recurring theme among the respondents. P9 noted 'need dedicated people to deploy – have a project to digitise and measure each phase', while P4 highlighted 'need human resources to deploy', and P11 remarked 'we need a top-down net approach with adequate resources allocated'. The responses are described in Table 6.

4.8 *Measuring Q4.0 effectiveness and success*

To understand if the Q4.0 initiative is effective or successful, there need to be measures of success. Therefore, the interviewees were asked how they would or are measuring the success of Q4.0. A word cloud was created from the responses of which words related to measures of quality, cost, products, business customer, implementation status and metrics related words were listed as shown in Figure 3. The participants cited many measures of success or key performance indicators (KPIs) that can be used for Q4.0, including cost reduction, increased profits, reduced defects, reduced inspection costs, faster cycle time delivery, and improved market share.

The importance of monitoring and measuring the effectiveness and status of Q4.0 implementation projects utilising KPIs was a recurring theme. The intangible measurements or non-obvious measures of success that the respondents highlighted were environmental, green and sustainable benefits, and increased and more efficient compliance to regulations through improved data integrity and electronic records. Data analysis and data measurement was also another theme in terms of comments, for example: 'What is the time taken to have access to data and is this data being utilised properly?' Data gathered for Q4.0 projects or improved data availability is in itself a measure of Q4.0 success. For example, product servicing in the field can be fed back into product design, ensuring the quality and reliability of the design of products and services (Santos et al., 2021; Sony et al., 2021a). An example of some of the measures of success provided by the participants are outlined in Table 7.

Table 6. Organisational Readiness for Q4.0: Responses from research participants.

'The most important part to readiness is that you have to motivate your quality staff to adopt the idea and the thoughts behind Q4.0. It makes it very hard to get them on board, and then your concept will not work. It also means that you have to train them, so it is not a decision.' **P1**
'How do we understand the data before we make a decision or insights? Now how do we remove bias from data?' **P8**
'How do we create a culture of continuous improvement?' **P4**
'There is a lot of effort it takes to resource and implement this initiative.' **P5**
'But in my experience, typically the people who are really good at Q4.0 are not in the organisations today, and you kind of have to recruit them'. **P10**

Figure 3. Measures of Success – Word Cloud.

Table 7. Measures of Success: Responses from Research participants.

'I think the first success you should aim for is getting valid output of an implementation. You can at least evidence that what you did is correct, and then you have to fine-tune and find out. Is it worth the cost? Is this a solution that really is saving money? If not, find out why. Don't stop it but find out either how you can make it more effective or more efficient.' **P2**
'Needs to be measured from the eyes of the customer.' **P3**
'How many problems have we solved? How many problems have we understood? How many latent needs have we identified?' **P4**
'How easy have we made it for the customer to do their business or do their business interests or be sustainable in the organisation and in the industry.' **P5**
'So, how have we made a difference in their (the customer) experience? How do we measure the overall customer experience with us or how have we helped them grow their business?' **P6**

4.9 *The quality curriculum of the future*

Industry 4.0 has transformed the curriculum development of professionals, including quality professionals (Radziwill, 2018). Quality as a discovery phase warrants a quality management system that uses an adaptive intelligent environment and quality tools and methods (Alzahrani et al., 2021). The participants were asked a question on the quality curriculum for the development of Q4.0 to establish what subjects are relevant. The interviewee's cited the importance of data science, data analysis, and a working knowledge of Industry 4.0 technology in order to be able to adapt to the increased world of digitalisation and smart factories (Table 8). Kubler et al. echoed the synergy of big data tools in different phases of continuous improvement programmes.

Quality professionals will need upskilling, reskilling, and training in the new quality curriculum. Escobar et al. (2021) proposed a Q4.0 curriculum based on Green and Black Belt levels for quality professionals. The proposed curriculum combines six areas of knowledge: statistics, quality, manufacturing, programming, learning, and optimisation.

Table 8. Examples of Q4.0 curriculum topics based on qualitative data.

'You know data analytics and AI will be important for the future quality professional as opposed to the classical quality professional that maybe grew up doing an inspection or sampling or something that really was more on paper with checklists and spreadsheets.' **P3**
'AI, Machine learning and Big data, have to be infused into the curriculum.' **P4**
'I also think some exposure to 3D printing and cyber controls.' **P5**
'For example, if you are training an auditor for how to perform an audit in a Q4.0 world. They do not need all the depth of knowledge of how to create an AI, but they certainly need to know how I interrogate if the AI was good to use, or if it has given good results.' **P6**
'I think the foundation is knowledge in data and digital literacy in a way.' **P7**

Jacob (2017) put forward the requirement for structured problem solving, data-driven decision-making, and leveraging cultural change to facilitate improvement, quality analytics, big data management, autonomous processes, quality compliance, and quality culture. However, the future curriculum is evolving and is still a work in progress.

4.10 *Leadership role in Q4.0*

Leadership plays an important role in implementation and readiness for any improvement initiative within the organisation (Albliwi et al., 2014; Laureani and Antony, 2017a; Laureani and Antony, 2017b). Therefore, we asked the research question what roles leadership should play in the successful adoption and deployment of Q4.0. A significant portion of quality leaders do not yet have a clear deployment strategy for Q4.0 and universally cite difficulty in harnessing such technologies (Escobar et al., 2021). The interviewees' responses emphasised the importance of leadership above and beyond many of the other themes of Q4.0 discussed. Industry 4.0 implementation calls for the organisation's digital transformation (Verhoef et al., 2021). The responses are outlined in Table 9.

4.11 *Industry 4.0 tools relevant to Q4.0*

The integration of Q4.0 and Industry 4.0 can spread across the entire supply chain and can help drive quality improvement, control and assurance (Rainnie and Dean, 2020). The respondents cited that predictive analytics, sensors, AI, and machine learning can aid in

Table 9. The Role of Leadership in Q4.0 – comments from interviewees or participants.

'Well, I think with Q4.0 or any other initiative, the rule does not change. So in my view, you know it has to be owned by leadership.' **P1**
'Any change within the organisation, especially the larger ones, has to be owned by the leadership.' **P2**
'I think leadership has to show that they have 100% commitment.' **P3**
'Leadership need to do goal settings accordingly. They need to set the policies accordingly. They need to review accordingly. They need to provide that encouragement when the team fails; they need to continue to believe that one needs to learn from the failures and does not or should not stop doing what they are doing too early.' **P4**
'They need to provide that encouragement when the team fails; they need to continue to believe that one needs to learn from the failures and does not or should not stop doing what they are doing too early.' **P5**
'Leadership are a critical factor here, and they have got to drive and support the change, so it is hard.' **P6**

improving product quality. To answer the research question, what Industry 4.0 technologies can be leveraged for Q4.0 deployment, the participants were asked to discuss what tools from Industry 4.0 technology can be most applicable to Q4.0. The responses are outlined in Table 10.

4.12 *Current Q4.0 application examples*

The participants were asked to give examples of Q4.0 projects they had implemented or worked on in their current organisation. This question was integral to this research work to understand the current state of Q4.0 deployment within organisations. While there are studies on Q4.0, most are on the conceptual stages in the journey rather than implementing it across the business. However, the overarching consensus amongst participants was that the Q4.0 projects they were involved in were considerably advantageous to their organisations and brought numerous benefits.

Many projects were related to using automated inspection with enhanced vision systems. Advantages cited with automated inspection was that the accuracy of the inspection process has increased, there was an elimination of non-value-added human inspection and the costs associated. Automated inspection 'ensures we have the right parts in the right place' and 'we had less handling of products and parts associated with human inspection.' In addition, automated inspection 'freed up our inspectors to work on value-added problem-solving exercises.' A more detailed example of a Q4.0 project was when an organisation had difficulty with sealant inspection in the confined spaces of fuel tanks. Utilising a robotic solution with a specially designed camera ensured access to tight spaces, and an AI algorithm was used to test if the seals were robust. This specific example also eliminated potential safety issues with accessing fuel tanks and inspectors passing out and managing a complex inspection using handheld cameras and mirrors to inspect sealants. Another interesting example was an organisation implementing 3D laser scans of pipes before they left the manufacturing facility. The participant commented, 'Now we

Table 10. Industry 4.0 tools that can aid Q4.0: Responses from interview participants.

'Your data should be stored in central facilities, cloud solutions, or data lakes.' **P3**
'We have our document management system, which was, until two years ago, based on paper and documentation. Now it is paperless.' **P6**
'There are connectivity related tools, and advancement of 5G that we have, which actually can enable the collection of the data even faster and easier.' **P8**
'The first one is AI and machine learning -and the way we integrate that into our existing quality management practices will improve inspection and reduce it.' **P10**
'We can have more integrated product development using digital tools, and enhanced quality.' **P9**
'Predictive analytics is huge. Lots of companies looking at how can I use my data to predict what are attributes of my product, materials and process.' **P4**
'I can monitor from a vision systems perspective. So many companies today are still dependent on manual inspection.' **P2**
'Where I have a distributed network of distribution, remote monitoring of products that we support is critical.' **P1**
'We can use this for real-time process monitoring to control machines or virtual reality.' **P7**
'Problem-solving: investigate and make use of all data and develop prediction technology.' **P3**
'We may have to get the tools we have to integrate them, interface them, create that interface along with the contextualisation in the organisation, and then see how these tools act as an integrated fashion to help the organisation in terms of achieving their business benefits.' **P5**

can pull up the 3D laser scan of the pipe and look at it as it was when it left our factory – before we just had the inspector stamp which was based on manual human inspection.'

Other participants, while not having implemented vision systems or other equipment, commented that they planned to and were purchasing new equipment with better capability to enable the move from manual inspection for growth defects to a camera-based system. Going paperless ensured having 'centralised documentation systems where a document can be uploaded and reviewed.' Workflow tasks can be signed off and registered in a database, and then there is a reduced turnaround time for approvals. One participant cited 'a reduction in document signoffs with the physical paper system that was on average 30 days being reduced to just an average of 3 days on the electronic system.'

Data visualisation of key process data and KPIs was also highlighted as another type of Q4.0 project. Aiding visual data analysis by having electronic dashboards on web interfaces that can be clicked on to drill down into subfields and into further backup data has helped prioritisation of quality issues and tracking of root cause and corrective actions in real-time – all in one place. 'Having an interface aids regular reviews and analysis' and makes the quality management process easier.

The use of technology to replace manual and repetitive interventions in processes was also cited as an area that delivered great returns on investment. Some responses included 'we removed human interventions', 'freed up floor space and had more efficient floor utilisation.'

One software consultant described how he uses AI interfaces with artificial intelligence, machine learning, and built-in sensors in software to track downtime in their customer software and get notifications if there are issues to work on them proactively. The advantages being 'my customer will not suffer, and thus he will give undisturbed, undistracted services in turn continuously to his customers.' Other Q4.0 projects highlighted included the introduction of autonomous mobile robots into single lines to reduce handling, increase floor space and improve quality.

In summary, many of the examples mentioned earlier of Q4.0 helped provide benefits such as improving data in process control, reducing reliance on inspections and testing, and providing real-time data. These projects primarily brought about productivity and quality benefits. The importance of data systems integrated central databases and a complete end to end system that was interconnected was also a theme among the responses.

This study expands knowledge of Q4.0 by investigating the motivations and benefits for Q4.0 from the perspectives of senior quality professionals. As well as these aforementioned factors, a definition of Q4.0 is investigated along with the challenges, CSFs, skills, Q4.0 curriculum, leadership attributes, and Industry 4.0 technology, which can be used in Q4.0 to expand the knowledge of the dimensions of Q4.0. This study can aid academics and industry alike to understand Q4.0 before the onset of deployment. This study also outlines some examples of practical implementation of Q4.0 projects in industry, which further expands the understanding of the benefits and motivations for implementing Q4.0.

5. Managerial & theoretical implications

Q4.0 is still in the nascent stage and there is a dearth of literature as regards to the practice of Q4.0 in modern organisations (Sader, Husti, & Daroczi, 2021). The development of the Q4.0 field will be enriched if there is an understanding of interdependency between the practice and principles of Q4.0. Therefore, this study provides a practical perspective by unearthing real-time organisational benefits and motivations for deploying Q4.0,

understanding the challenges and CSFs required to implement Q4.0 in modern day organisations, and identifying the skills needed by quality professionals in implementing Q4.0.

To comprehend Q4.0 from a practical perspective, we take a knowledge ecology perspective, which warrants an understanding of knowledge ecosystem from its core. Cheng and Leong (2017) suggest that knowledge ecosystems have inputs, throughputs, and outputs, which are operating in an open exchange relationship with their environments. Shrivastava (1983) stated that the key elements of a knowledge ecosystem include aspects related to technology, learning community, and organisational dimensions. From a practical perspective this study finds that for Q4.0 to be a success, it warrants an integration of Industry 4.0 technologies, with existing quality management tools and techniques, along with human elements using a well-defined implementation framework encompassing the CSFs. This study, therefore, adds to the ecological perspective of knowledge management theory in an organisation by suggesting that for Q4.0 to be a success, there is need for synergistic linkage between Industry 4.0 technology, QM tools, techniques and methodologies and human factors. Further, this research confirms the preliminary definition of Q4.0 proposed Antony et al. (2021a) in terms of the integration of Industry 4.0 technologies, quality tools, and human elements to achieve superior quality performance and higher levels operational excellence. This is a very significant theoretical contribution to Q4.0 definition as Antony et al. (2021a) had proposed the preliminary definition and further suggested future research to finalise the dimensions of Q4.0 or what dimensions constitute the definition of Q4.0.

This study offers several managerial implications. First, Q4.0 is an emerging quality paradigm, and this study provides a practical understanding of the motivation and readiness factors for the implementation of Q4.0 in an organisation. Second, quality managers can use this study to understand the benefits, challenges, CSFs, skills required, and Q4.0 curriculum needed from the real-life experience of participants who are senior quality professionals in various multinational corporations. Third, this study stresses the importance of leadership for the success of Q4.0. It further suggests the need for total commitment and support from the leaders. Fourth, there are many technologies of Industry 4.0, and managers must choose the appropriate technology(ies) that will be beneficial for Q4.0 implementation (Frank, Dalenogare, & Ayala, 2019). This study suggests the importance of predictive analytics, sensors, AI, and machine learning as key technologies, which can help in Q4.0 implementation (Sony et al., 2021b). Thus, managers can determine how these technologies can be integrated with their existing quality management tools and methods used in their organisations. Fifth, this study has briefly outlined the type of Q4.0 projects pursued by Q4.0 experts from various participating companies. Many organisations have also digitalised their quality management practices to add new value to their customers. This is a strategic exercise involving multi departmental teams to identify activities that can be digitalised to create new value proposition for the customers. Managers can also determine how this improved value proposition for customers can be captured by modifying the business models.

6. Conclusion, limitations & future research

Future studies should include samples from developing countries to capture wider viewpoints of the motivations and barriers of Q4.0. There is also a need for a study to be carried out to compare the various themes studied in this paper (e.g. challenges, benefits, organisational readiness factors) between manufacturing and service companies as well as developed and developing nations. Also, there is an urgent need for a

study to explore the relationship between Q4.0 and business performance (i.e. operational, financial, social).

Q4.0 is a new concept to organisations, and many organisations are only beginning to understand it. Q4.0 and a digital transformation strategy are integral to the strategic direction of an organisation. Organisations must integrate Q4.0 initiatives into their strategic plans and ensure their leadership understands, embraces, and are committed to Q4.0.

Organisations must also focus on building a workforce with the new skills required to perform data analytics, handle big data, and have more technology-centered supplier chain, production, and other functional area tasks. This study builds on previous quantitative and qualitative studies to research and understand Q4.0 and how it is being implemented in organisations. A limitation of the study was that it was qualitative and, therefore, subjective in terms of the viewpoints captured. However, building on previous research, this study provides a more concrete understanding of Q4.0. A longitudinal case study within an organisation would be valuable to understand this journey to Q4.0 from its initiation and infancy to project execution. As such, the authors plan to carry out such case studies in different industrial settings (e.g. manufacturing vs. service, large vs. medium size) where they hope to assess Q4.0 readiness and application to gain more insight into Q4.0 topics.

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