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QUALITY PAPER

# Critical failure factors for Quality 4.0: an exploratory qualitative study

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## Abstract

**Purpose** – This study aims to investigate the adoption of Quality 4.0 (Q4.0) and assess the critical failure factors (CFFs) for its implementation and how its failure is measured.
**Design/methodology/approach** – A qualitative study based on in-depth interviews with quality managers and executives was conducted to establish the CFFs for Q4.0.
**Findings** – The significant CFFs highlighted were resistance to change and a lack of understanding of the concept of Q4.0. There was also a complete lack of access to or availability of training around Q4.0.
**Research limitations/implications** – The study enhances the body of literature on Q4.0 and is one of the first research studies to provide insight into the CFFs of Q4.0.
**Practical implications** – Based on the discussions with experts in the area of quality in various large and small organizations, one can understand the types of Q4.0 initiatives and the CFFs of Q4.0. By identifying the CFFs, one can establish the steps for improvements for organizations worldwide if they want to implement Q4.0 in the future on the competitive global stage.
**Originality/value** – The concept of Q4.0 is at the very nascent stage, and thus, the CFFs have not been found in the extant literature. As a result, the article aids businesses in understanding possible problems that might derail their Q4.0 activities.

**Keywords** Quality, Industry 4.0, Quality 4.0, Critical failure factors
**Paper type** Research paper



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## 1. Introduction

Quality 4.0 (Q4.0) is a new term that people in the industry have been using in the recent past while discussing quality management. It is a very new concept, and researchers are still trying to decipher the details of the concept. It is believed to be related to Industry 4.0 (I4.0), but what aspects or components are related, and how does Q4.0 overlaps with I4.0 is a question that many are trying to answer (Antony *et al.*, 2022b). In 2011, when the German Government introduced the concept of I4.0, it quickly became a research area for many researchers (Lu, 2017). The discussions revolved around technical issues, impact on the human capital, talent required to work in an I4.0 environment and application of I4.0 in various sectors including agriculture, healthcare or many others (Zhou *et al.*, 2015). There have been many sectors and industries which have prefaced the term 4.0 to their sector descriptions to demonstrate their advances in sync with I4.0, such as Agriculture 4.0 (Rose and Chilvers, 2018), Healthcare 4.0 (Chanchaichujit *et al.*, 2019), Services 4.0 (Bruhn and Hadwich, 2017) and Logistics 4.0 (Winkelhaus and Grosse, 2020).The concept of quality management and advantages digitalization will bring to it have also been mentioned in relation to I4.0. However, very few have been discussed as Q4.0 (Saihi *et al.*, 2021). Researchers and industry are still in the process of deciphering what Q4.0 means. Some non-peer-reviewed journals, for example, professional organizations such as the American Society of Quality (ASQ), have put forth Q4.0 as the future of quality management. Experts of digitalization equipment and software like to utilize Q4.0 to promote their products to their customers, of which many are manufacturing companies. The generic definition of Q4.0 initially proposed integrating I4.0 features with traditional quality management practices (Enke *et al.*, 2017; Jacob, 2017; Nyendick, 2016). ASQ defines Q4.0 as the fourth generation of quality management, evolving from previous quality revolutions (ASQ).

Many authors believe that Q4.0 is closely aligned with I4.0. The I4.0 technologies can be considered a significant part of the Q4.0 technologies. It is also reported that the deployment of Q4.0 ensures that organizations move forward with efficiency and improved business models (Sony *et al.*, 2020). Moreover, Q4.0 is intended to improve customer satisfaction and the quality of products and services (Antony *et al.*, 2022d). The digitization of many processes in companies has posed an opportunity to achieve goals of operational excellence and performance (Sony *et al.*, 2020). Besides, Q4.0 has reduced quality costs with improved efficiencies, increased revenues, reduced non-conformance, reduced supplier defect rates and further introduction of new products (Antony, 2014).

The literature analysis revealed a significant knowledge gap in the Q4.0 sector. The literature recommends validating the reciprocal link between the dimensions and items of Q4.0 and the sustainable growth of enterprises or society, one of the highlighted research gaps (Nenadál *et al.*, 2022). Sustainable growth can be achieved when an organization knows the critical failure factors (CFFs) and how quality standards are linked to quality initiatives (Bhat *et al.*, 2023; Sreedharan *et al.*, 2018). Despite the benefits of I4.0 technologies for quality improvement, researchers have not yet figured out what will go wrong with the deployment of Q4.0. The literature indicates that CFFs for Q4.0 have not yet been published. In addition, relatively little study has been conducted on the human factors essential for Q4.0 management (Balouei Jamkhaneh *et al.*, 2022). Therefore, there is definitely a need for further exploration of the nascent field of Q4.0 (Sureshchandar, 2023).Additionally, a comprehensive study is needed on the lack of technical, methodological, social and personal capabilities of quality professionals in the I4.0 age (Kannan and Garad, 2020). In addition, there is need for a more extensive study on the fundamentals and problems of Q4.0 (Ranjith Kumar *et al.*, 2022).

Thus, the main objective of this study is to understand Q4.0 from the practitioner's point of view to ensure sustainable growth of the organization and society. Following are the research questions (RQs) to fulfill the research objectives.

*RQ1.* What does the concept of Q4.0 mean regarding its linkage to quality standards?

*RQ2.* What is the training that is provided for implementing Q4.0?

*RQ3.* What are the CFFs in implementing Q4.0?

As the notion of Q4.0 is still in its infancy, this article significantly contributes to the knowledge base. First, it defines Q4.0 from the practitioners' perspective. Second, the study provides the benefits realized by the Q4.0 professionals by implementing the Q4.0 projects. Third, the research illustrates the type of Q4.0 projects initiated by the respondents in the industry. Also, the research contributes to the knowledge base by unearthing CFFs of Q4.0 deployment, which aids the professionals in staying on track with their Q4.0 objectives. Besides, the research will address practitioners' obstacles in upskilling the current workforce and acquiring the abilities necessary to sustain Q4.0 efforts. The project will eventually provide policymakers with a deeper understanding about ways of integrating Q4.0 into quality requirements for knowledge management.

The remaining section of the article is organized as follows. Section 2 includes an overview of the relevant literature, while Section 3 outlines the research methodology used. Results are reported in Section 4, while discussion is provided in Section 5. Finally, Section 6 contains the conclusion and potential for further study.

## 2. Literature review

Q4.0 is a relatively new notion that has gained traction in recent years mainly because of factors like rising levels of competition, dynamic consumer demands and rapid technological advancement (Liu *et al.*, 2023). Q4.0 is an innovative way of managing quality fields that utilizes I4.0 technology, operational excellence (OpEx) strategies and digitalization (Antony *et al.*, 2022c). Q4.0 focuses on identifying and implementing digital solutions that improve an enterprise's capacity to consistently provide high-quality goods and services to consumers (Alzahrani *et al.*, 2021; Sony *et al.*, 2020). Through technology, Q4.0 focuses on reforming and enhancing corporate culture, collaboration, competence and leadership development (Vykydal and Nenadál, 2022). Q4.0 has the potential of providing businesses with an edge in the market by boosting their profitability and upgrading their customers' experiences (Antony *et al.*, 2022c).

The literature review presented in the following parts is in a format that is consistent with the RQs. This section reviews the components of the RQs, such as the linkage between Q4.0 and quality standards, competencies and training needs for Q4.0, CFFs of Q4.0 and measuring CFFs of Q4.0. The study would benefit from this review in order to articulate appropriate interview questions and evaluate the results against the existing body of knowledge.

### *2.1 Q4.0 relationship to quality standards*

Although Q4.0 is not a quality standard, it is very relevant to quality standards. It may aid in establishing and maintaining compliance (Ibidapo, 2022). Q4.0 is synergistic with quality standards because it combines the ideas and practices of quality management systems like ISO 9001 and total quality management (TQM) with those of established I4.0 technologies (Fonseca *et al.*, 2021; Santos *et al.*, 2021a). Q4.0 does not replace existing norms; it provides a methodology for using established quality management practices and resources in the modern, digital setting. It is consistent with current quality standards and may aid businesses in meeting regulatory mandates (Ali and Johl, 2022; Chiarini and Cherrafi, 2023).

There are several ways in which ISO standards and Q4.0 are intertwined. First, Q4.0 expands on the ideas presented in ISO standards like ISO 9001, which provide a basis for contemporary quality management (Chiarini and Cherrafi, 2023). Second, Q4.0 improves quality procedures by combining digital technology with conventional quality management methods. By automating

quality management procedures and delivering real-time data for decision-making, digital technology may also help organizations continue to comply with ISO standards (Glogovac *et al.*, 2022; Ibidapo, 2022). Finally, ISO standards may create a Q4.0-compliant quality management system that fully incorporates digital technology. There is a possibility that, data analytics, machine learning (ML) and other digital technologies may be integrated into a quality management system using the framework provided by ISO 9001 (Chiarini, 2020; Chiarini and Cherrafi, 2023). Since organizations may benefit significantly from implementing digital technologies into their current quality management systems, studies focusing on the convergence of ISO standards and Q4.0 are vital (Zonnenshain and Kenett, 2020).

### *2.2 Competencies and training needs for Q4.0*

For Q4.0 to be successfully implemented, quality management professionals will need the requisite skills and education to meet the demands of I4.0 (Kannan and Garad, 2020; Sony, 2020; Sony *et al.*, 2020) leadership, culture, strategy, people, process and technology are crucial to successfully adopting Q4.0. Q4.0 calls for various skill sets, including technical, methodological, social and interpersonal aspects (Sunarto *et al.*, 2021).The technical competencies comprise knowledge of I4.0 technology, data analytics and cybersecurity (Santos *et al.*, 2021). Methodological competencies include the ability to analyze critically, solve problems and manage projects (Sony *et al.*, 2021). Communication, collaboration and teamwork comprise social competencies. Personal qualities include adaptability, inventiveness and continuous learning (Sunarto *et al.*, 2021). Collaborating with information technology (IT) experts and process managers is another need for implementing Q4.0 (Vykydal and Nenadál, 2022).

Individuals and groups must be acquainted with the many I4.0 technologies and their potential uses in quality management. Some examples of these include cloud computing, robots, the Internet of Things (IoT), artificial intelligence (AI) and ML (Antony *et al.*, 2022b). Q4.0 also requires considerable data analysis and interpretation abilities from individuals and groups. Data visualization, predictive modeling and statistical analysis fall under this category (Antony *et al.*, 2022d; Gembali *et al.*, 2022). In addition, personnel and teams must be well-versed in quality management theories and methods, including Lean, ISO 9001, Six Sigma and TQM. They should also be aware of the norms and expectations of their Industrial sector (Antony *et al.*, 2022b).

In addition, Q4.0 adoption often necessitates substantial modifications to procedures, workflows and organizational structures. Individuals and teams must possess change management abilities to enable these transitions successfully (Chiarini, 2020). In particular, Q4.0 adoption requires excellent communication and cooperation across teams and departments. Individuals must communicate effectively with stakeholders at all organizational levels and work well in a team (Antony *et al.*, 2022b). Finally, to successfully deploy Q4.0 solutions, people and teams must possess technical capabilities. It encompasses computer programming, data analytics and cybersecurity (Antony *et al.*, 2022c; Sony *et al.*, 2020).

In the era of I4.0, training and education may help bridge the gap between the skill sets of today's professionals and those of the future workforce (Kannan and Garad, 2020). Therefore, firms must invest in the essential skills and competencies to adopt Q4.0 (Kannan and Garad, 2020). Training and certification programs must address data analytics, quality management, change management and I4.0 technologies, among other subjects (Santos *et al.*, 2021). Subsequently, companies must offer opportunities for continual training and development to ensure that individuals and teams have the skills necessary to flourish in the fast-evolving ecosystem of Q4.0 (Zulqarnain *et al.*, 2022). Thus, more studies on Q4.0 competencies and training requirements may help firms comprehend the skills and knowledge necessary for success in the I4.0 age. It also allows them to plan and administer

successful training programs that may assist staff in acquiring these abilities, resulting in enhanced productivity, quality and creativity (Fonseca *et al.*, 2021; Thekkoote, 2022).

*2.3 Critical failure factors (CFFs) of Q4.0*

Several CFFs may impede the proper implementation of Q4.0. These include high costs; inadequate cybersecurity; a lack of Q4.0 skills, training and knowledge; unreliable internet connectivity; inadequate leadership support; and employee resistance to change (Antony *et al.*, 2022c). In addition, Zonnenshain and Kenett (2020) observed a dearth of evidence for a successful implementation strategy and the road map to adopting Q4.0. Before deploying Q4.0, enterprises must thus address these CFFs and preparation criteria to ensure their success. This may be accomplished by investing in infrastructure, imparting training and education to staff, establishing a robust data management system and fostering an organizational culture of change and innovation (Antony *et al.*, 2022c; Sony *et al.*, 2020).

Lack of support from top management is one of the vital CFFs of Q4.0 implementation. Without senior leadership support, getting the necessary resources and commitment from other stakeholders might be challenging (Antony *et al.*, 2022b). Inadequate planning and strategy are further impediments. Organizations must have a clear vision, implementation road map and precise strategy for execution (Maganga and Taifa, 2023). According to reports, Q4.0 deployment mostly suffers from inadequate resources. Deployment of Q4.0 requires significant resources, including finance, trained staff and technological infrastructure. Organizations must ensure adequate resources to facilitate implementation (Antony *et al.*, 2022c; Sureshchandar, 2022).

Resistance to change is a fundamental human factor for all major initiatives, including the Q4.0 implementation. Organizations must proactively tackle change resistance and include key stakeholders in the implementation process (Antony *et al.*, 2022b; Sony *et al.*, 2020). A lack of reliable and robust data hampers the Q4.0 roll out. This necessitates effective data management, governance methods and technological infrastructure (Maganga and Taifa, 2023; Ranjith Kumar *et al.*, 2022). Cybersecurity threats may arise as new technologies and systems are integrated into Q4.0. Data breaches and other forms of cybercrime may be avoided if companies have stringent cybersecurity measures. Lack of data analysis, programming and quality management capabilities further slows the Q4.0 roll out. Organizations must ensure they have competent individuals to assist in implementation (Escobar *et al.*, 2021; Ranjith Kumar *et al.*, 2022). Most projects fail because Q4.0 needs to be adequately integrated into existing company procedures. Organizations must use Q4.0 consistently with their overarching business strategy and connect with other critical business operations (Antony *et al.*, 2022b).

Research on the CFFs of Q4.0 is vital since it may assist organizations in identifying the risks and obstacles that may develop during the implementation of Q4.0 projects (Antony *et al.*, 2022c; Chiarini, 2020). In addition, identifying CFFs may assist firms in developing effective risk management strategies to limit the impact of these variables on Q4.0 adoption (Sureshchandar, 2022). Moreover, research on CFFs may assist firms in learning from the mistakes made by other organizations that have adopted Q4.0 programs and avoid repeating the same errors (Antony *et al.*, 2023). Therefore, studying CFFs is essential for the smooth operation of Q4.0 programs.

*2.4 Measuring CFFs of Q4.0*

Q4.0 is concerned with using digital technologies to improve a firm's reliability in providing high-quality goods or services to its customers. Thus, failures of the Q4.0 system should be measured by observing the quality of customer-delivered goods and services (Sony *et al.*,

2020). Another metric for assessing the success or failure of a Q4.0 initiative is the number of customer complaints received (Hendra *et al.*, 2022). Also, Q4.0 aims to enhance product and service quality, decrease costs and improve productivity. Additionally, Q4.0 deployment is expected to improve customer experience and enhance profitability (Antony *et al.*, 2022c, d). Therefore, key performance indicators (KPIs) such as defect reduction, customer satisfaction, manufacturing cycle time, cost reduction, employee engagement, productivity improvement and quality index can be used to measure the effectiveness of Q4.0 deployment. However, the specific KPIs will vary depending on the organization's goals, objectives and industry (Zhao *et al.*, 2022; Zulqarnain *et al.*, 2022).

Eventually, failures of a Q4.0 system may be monitored using a data-driven approach that involves the identification of suitable KPIs, collecting and analyzing pertinent data and implementing any required corrective actions. However, from the literature review, it is found that there was a glaring absence of KPIs for gauging Q4.0's success in practice. Nevertheless, some studies have highlighted the importance of organizational readiness factors (Antony *et al.*, 2023; Sony *et al.*, 2020), motivation factors (Sony *et al.*, 2021; Antony *et al.*, 2022c), critical success factors (Antony *et al.*, 2022c; Dror, 2022) and enablers and technologies that can be leveraged (Maganga and Taifa, 2023). As shown by the previous discussions, further research on metrics and KPIs for Q4.0 is required to enable organizations to monitor and evaluate the efficacy of their quality initiatives in the context of I4.0 (Sony *et al.*, 2020). These data may drive continuous improvement initiatives and help firms remain competitive in an increasingly digital market (Antony *et al.*, 2022c).

## 3. Research methodology

The research was conducted in two stages. The first stage was a comprehensive literature assessment. From the literature assessment, the researchers have comprehended the theory behind CFFs of Q4.0. A qualitative study was carried out in the second stage to study the concept of Q4.0 in depth and its linkage to quality standards, the training that is provided for implementing Q4.0 and finally to probe the CFFs in implementing Q4.0. Qualitative research is designed to explore concepts, gain insights and understand the underlying meanings behind events and behaviors (Baxter and Jack, 2008). Semi-structured interview questions were carried out to elicit detailed responses from the respondents. This type of interview gives the interviewer an organized method to capture the conversation while allowing the interviewee to provide a more detailed response to the questions. Further, it enables the interviewer more thorough understanding of the respondents' experiences, feelings and thoughts about a topic while allowing the interviewer to direct the flow of the conversation (Denzin and Lincoln, 2011; Reja *et al.*, 2003). The interview questions are based on the literature and the research objectives. The interview question was piloted in order to understand its operational suitability for the interview and besides, and it will help in gaining experience in interviewing (Majid *et al.*, 2017). Subsequently, the first draft of the interview questions was sent to 5 experts as a pilot study to ensure the validity (Altheide and Johnson, 1994; Malmqvist *et al.*, 2019). The interview questions were modified based on the review of the expert's suggestions. Judgmental sampling technique was used to identify the experts for the final interviews. Experts with a minimum of ten years' experience in quality management and a minimum of four years' experience in Q4.0 were selected. Another criterion for selection was that experts should be working in senior management positions in the field of quality management. The interviews conducted with the experts were about one hour each, and each expert gave their input on the questions based on their expertise. First, demographic questions were asked to put interviewees at ease. After that, nine nondemographic questions were related to the RQs (Table 1).

| | |
|---|---|
| 1 | What type of Q4.0 training have you attended, if any (e.g., I4.0 technology training as part of a Q4.0 program or other), and what type of topics were covered? |
| 2 | Have you personally completed any Q4.0 projects, and if so, how many Q4.0 projects have you completed (if any), and what was the nature of the project (in your current or previous employment)? |
| 3 | Have all the Q4.0 projects been successful, or are there any projects you can think of that you did not gain many benefits (in your current or previous employment)? |
| 4 | Are you familiar with ISO standards followed by your organization? For example, do you think ISO 9001:2015 is a prerequisite to implementing Q4.0? If yes, why, however? If not, why do you think so? |
| 5 | What percentage of the workforce at your organization has been trained on Q4.0? How many days of training have they completed on average? |
| 6 | For how long has your company been using Q4.0? |
| 7 | What are the critical failure factors of Q4.0 in your organization? |
| 8 | How do you measure your organization's failure related to Q4.0 implementation? |
| 9. | How do you define Q4.0? |

**Table 1.** Interview questions (nondemographic)

**Source(s):** Authors' own work

The grounded theory approach analyzed the responses (Achora and Matua, 2016). To maintain the confidentiality of the experts, code names P1 to P14 (Table 2) are given in the article. Interviewees' industry experience has helped frame in detail their understanding and experience of Q4.0 and what organizations need to consider in the future. The interviews were done iteratively to keep improving the data collection as the project proceeded. In the first stage, five expert interviews were performed. Some subquestions were included during the interview based on the interactions in the next set of interviews to get more insights. The last five interviews were performed depending on the inputs received from the first and second sets of interviews. Over time, this strategy helped gather the maximum information possible in this area. Set 1 included (P1 to P5), Set 2 included (P6 to E 10) and the last and final set of interviews included (P11 to P14). The study used data saturation technique to determine the final sample size. Data saturation is the point in a qualitative study when the researchers no longer find any new information from their sampling and data collection (Guest *et al.*, 2006). It indicates that researchers have collected

| Expert name | Current position | No. of years of experience | Industry |
|---|---|---|---|
| P1 | Director, Product Quality | >20 | Manufacturing |
| P2 | Production Lead | 10 years | Manufacturing |
| P3 | Head of Quality | 30 years | Manufacturing Capital Goods |
| P4 | Business Processing Technology | 10 years | Manufacturing |
| P5 | Research and Development Engineer | 5–10 years | Utility Sector |
| P6 | Consultant | 15 years | Training and Development |
| P7 | Owner of Consultancy | >30 years | Consultancy for Project Management for Quality Improvement |
| P8 | Production Planning Engineer | 4 years | Packaging Firm |
| P9 | Vice President Quality and Consultant | 35 years | Automotive Company |
| P10 | Team Lead for AI and Operations | 12 years | Manufacturing of Defense Equipment |
| P11 | Director | 10 years | Manufacturing |
| P12 | Quality Assurance and Health and Safety | 5 years | Packaging Industry |
| P13 | Leading Quality Excellence Team | 24 years | Automotive Industry |
| P14 | Head of Industrial Engineering and Digitization and Transformation | 10 years | Manufacturing of Defense Equipment |

**Table 2.** Details of experts for the interview

**Source(s):** Authors own work

enough data to identify the themes and patterns that they are researching (Denzin and Lincoln, 2011). To determine data saturation, researchers review the data gathered, look for patterns in the data and compare and contrast information (Guest *et al.*, 2006). When the same information is repeatedly found in the data from different participants, or when the same themes and patterns are observed in the data, data saturation has been reached and data sufficiency is attained. With 14 participants, the data became saturated, and the interviews were discontinued (Saunders *et al.*, 2018). The interviews of the 14 experts were recorded, transcribed verbatim and then coded by the research team. Open coding was the first stage of coding, where the researchers began to develop the main categories. Here, we read through the data and begin to identify patterns, themes and relationships from the material. During this stage, concepts and meaning units from the data were identified and set aside for further in-depth analysis (Strauss and Corbin, 1994). These concepts and meaning units were assigned a code label in a code book for future review and comparison. Axial coding is a process whereby theories from different disciplines, perspectives or data types are incorporated. During axial coding, we considered how the various concepts identified during the open coding stage interact with each other. The third stage was selective coding, which involves integrating the categories and codes developed from the open and axial coding stage (Cascio *et al.*, 2019; Hruschka *et al.*, 2004). Selective coding allows the researcher to combine identify links between the categories and create a story about the overall data set. By connecting the different categories, the researcher can gain insights about the data and understanding of its underlying meaning comprehensively (Goodwin, 2001).

## 4. Results

The outcome of the interview is presented in the following subsections. This section presents the vital outcomes of each interview question among the 14 interviewees.

### *4.1 For how long has your company been using Q4.0?*

All the participants had an active Q4.0 program hence their inclusion in the study. However, some participants were only starting their Q4.0 journey in the last 18 months (about one-third), and two-thirds were deployed over 18 months and less than four years.

### *4.2 How do you interpret or define Q4.0?*

All respondents had an opinion on defining Q4.0 or what Q4.0 means to them personally. Primarily they referred to "the fourth revolution of Quality Management" (**P13**), "the digitalization of quality" (**P12**) and "the Quality section of Industry 4.0" (**P5**). They were unanimous in their views that quality management is "evolving" (**P1-14)** and changing through digitalization which is changing how quality managers do their jobs. Some quotes concerning defining Q4.0 are outlined in Table 3.

### *4.3 What do you see as the benefits of Q4.0?*

The benefits of Q4.0, as seen by the interviewees, are presented in a word cloud in Figure 1. Notably, the key themes were related to "data," "availability" and "capability" of quality data. For example, one interviewee stated, "Q4.0 will bring us better control, to predict the machine failures early and the cause of issues, and the efficiency and costs can be managed earlier and predicted early. In addition, there will be a capability enhancement for the people managing these things. The capability part is very important; the people around us are aware of what is going on" (**P3**). Also, "digitization allows you to convert the data into actionable, that is the critical thing here" (**P13**). Terms such as "early," "improved," "prediction" and "results" were all described as benefits.

"Improving our operations and efficiencies and quality of products by utilizing the latest technologies like the Internet of Things and . . . Artificial Intelligence and Machine Learning. How we are planning and applying these advanced technologies to improve the quality of our products." *P1*
"Q4.0, for me, is a quality management program that consists of different tools aimed at professionals in the quality spectrum to help influence and enable the professionals. It aims at transforming the entire organization towards the digital age now that digitization has come in; it is the difference between Q4.0 and the usual quality management." *P5*
"Q4.0 is the opposite of how companies do things originally with quality . . ..up until now, things were still being captured on spreadsheets and emails, and we have very less automation of quality data and tasks." *P7*
"Q4.0 is an enabler for future changes and will ensure more sustainability and circular economy in companies!" *P9*
"Q4.0 is a subset of I4.0, using smart technologies for quality tasks and reaching Operational Excellence." *P10*
"Q4.0 and calling it Q4.0 is just a lot of people making much money on it. Regardless of Q4.0 - successful digitization projects will improve quality." *P4*
"It is a heterogeneous concept. It is separated into Quality and the 4.0 part." *P13*
"It is a means of quality more focus on organizational excellence and how you focus on quality improvement." *P14*

**Source(s):** Authors' own work

### *4.4 What types of Q4.0 projects are being implemented?*

The interviewees stressed that some Q4.0 projects had come about due to the organization's digitalization strategy, and quality benefits were a positive side effect. Enhanced digitalization translated to enhanced quality. The types of Q4.0 projects being implemented varied from eliminating paperwork and paper documentation and records. For example, several interviewees cited a paperless Quality Management System (QMS) as instrumental in adhering to regulations and helping reduce audit preparation time. In

addition, implementing improved process controls on the production line via technology and software eliminated opportunities for manual errors and defects and improved visual inspection accuracy. Table 4 provides a glimpse of responses related to the type of Q4.0 projects implemented in the interviewees' company.

*4.5 Have all the Q4.0 projects been successful, or are there any projects you can think of that you did not gain many benefits (in your current or previous employment)?*

Most, if not all, of the interviewees were happy with the success of the Q4.0 projects. However, they had a few examples of failures. Most examples were related to support for the project or lack of support from leadership and stakeholders rather than a failure of the actual program change. The lack of qualified personnel to understand the new software or technology mode was also why interviewees felt the Q4.0 program had failed. The reasons why Q4.0 projects failed are outlined in Table 5.

*4.6 What percentage of the workforce at your organization has been trained on Q4.0? How many days of training have they completed on average?*

All interviewees stated that none of their organizations had been trained on Q4.0. They also pointed out that they knew no specific Q4.0 training. In addition, they cited that the area is still very new and emerging and that the training there is specific to I4.0.

*4.7 What type of Q4.0 training have you attended, if any (for example, I4.0 technology training as part of a Q4.0 program or other), and what topics were covered or do you think is needed?*

As highlighted previously, no one had a specific Q4.0 training program. Therefore, any training received or partaken in was related to I4.0 and specific to a digitalization project, system or technology type. The types of Q4.0 training initiated are outlined in Table 6.

"We have digitization of quality projects . . . taken as an adoptive approach -digitizing quality data collection and quality systems tasks. Within the value chain are departments, purchasing, production and operations, then we have quality and the finance component; various parts within those areas are digitization." *P7*

"The biggest focus we have now is to digitize manufacturing plants. The current disconnect would be between the processes and reports what we see from the plants, so we are using software and technology to reduce that disconnect." *P4*

"We had a problem in storing engines, and it costs us a few million, hiring out warehouses in case of warranty replacements, but we got better data to estimate when the engine is going to fail, and we can order the engine from overseas with no lag of when you get it and when you need it. Also, you do not have to store it for so long because if you store unnecessary things, predicting when it is going to fail, so you are also reducing the cost of what you are storing. You can give the customer valuable insights on how they should use data accordingly, and using a digital twin, you can all see and value can be provided along the way." *P6*

"In a steel company, the important point was reducing cycle time when smelting has been done . . . Because the quicker the process, the better it will be for me regarding energy efficiency and capacity utilization. So manual processes were deleted where possible. On adjusting infrastructure, IoT was put in to get the temperature automatically, and there were also digital indicators on the furnace, so the person would understand whether the batch was ok or not. Even on mobile phones, the application is there to measure temperature; we also enabled that so they will come to know when the cycle time is over." *P7*

"If I talk about Q4.0, my organization has a roadmap, though not yet implemented, but we are doing". *P5*

"We are now abandoning the old systems and need to go digital. We initiated different projects in different departments; for instance, in the production line, we installed various devices to calculate various speeds, uptime, downtime and total production time. We educated the shift supervisors on how to use this technology. We gave them apps and designed the apps specifically designed for them; we educated them on how to use the apps -we are automating all of our KPIs." *P9*

**Source(s):** Authors' own work

**Table 4.** Types of Q4.0 projects being initiated – quotes from the interviewees

*4.8 Are you familiar with the ISO standards followed by your organization? For example, do you think ISO 9001:2015 is a prerequisite to implementing Q4.0? If yes, why? If not, why do you think so?*

All of the interviewees' organizations did not ensure an ISO 9001-certified QMS, given that it is the world's most widely embraced QMS standard. The responses were mixed in relation to whether ISO 9001 is a prerequisite for Q4.0 implementation. Many interviewees believe that ISO 9001 is "basic" and has "no relevance." In contrast, others highlighted the importance of the standard as a "structure" and "foundation" for a Q4.0 management system. According to others, the continuous improvement element of the ISO 9001 standard enabled "Q4.0 to fit nicely into our ISO QMS." A selection of quotes about this question is outlined in Table 7.

*4.9 What are the critical failure factors of Q4.0 in your organization?*

Several themes were mentioned in terms of CFFs. Most interviewees mentioned a lack of leadership support, leadership not aligning the Q4.0 projects with strategy and a lack of understanding of the benefits of digitalization in improving quality. Also, respondents highlighted the challenges in finding suitable educational courses and training related to Q4.0. Also, few are concerned about "how digitalization can enhance quality metrics and aid continuous improvement." Further, recruiting and sourcing "suitably qualified personal who understand these modern 'things' because we do not" was indicative of what one interviewee called "the fear of anything with a 4.0 tagged on." Change management, however, or poor change management skills and processes were the predominant CFF highlighted. One interviewee stated, "It is hard enough to get management to pay for these projects for us and to give us resources, but when the project cannot even get off the ground or overcome obstacles—we were wasting our time" (**P10**). Other comments about CFFs are outlined in Table 8.

*4.10 How did you fail to measure Q4.0 implementation in your organization?*

Similarly to the responses as to why projects had failed, the responses to this question related to the measurement of data, not understanding the data and thus "not being able to communicate the implementation impact" (**P8**). One respondent talked about how "we put together a detailed cost-benefit analysis as proof of the project concept and get funding, but then we did not go back and measure the post-implementation impact versus the original analysis …. we were just focused on measuring any downtime, delays, or maintenance upgrades associated with the new technology" (**P3**). Not measuring the time involved in training and learning to use new software and other types of digitalization "was something

| |
|---|
| "We have a project focussed on data acquisition and collecting the data from manufacturing lines and recording and showing us the live efficiencies of our machines. It was only a monitoring device. We could not command the machines through that. Initially, it brought greater visibility, bringing more control, and we can say that we had better engagement of employees. However, 3 or 4 years later, we have seen no improvements or progression; we felt that only this visualization was insufficient. We needed more information about the machines, better control of machines, and information related to breakdowns. That project was not successful in that regard. That is when we felt the need to bring in the other technology, i.e. the digital twin. This will eventually replace the current technology." *P3* |
| "See, I never have leadership not committed to our projects. It is the reverse side; leaders are always committed, so they have started a new thing and a training program and hired a consultant. It is the company and consultant that are not interested. They are so busy; they only want the business results." *P10* |
| "Projects have failed because we did not align with business goals and value delivery." *P1* |
| **Source(s):** Authors own work |

**Table 5.**
Types of Q4.0 projects that failed and why – quotes from the interviewees

| |
|---|
| "The training was not prerequisite classroom training but was more project-based training as the company was learning. If you were completing an IoT project, the training was more project-based. There was no general training on Q4.0 and IoT. Initially, the training was started around the project deployment. Few training methods are available, just maybe some software literature around data sciences and data analytics sectored around our operations and the shared portal. There are not any classroom training or large scale training." *P4* |
| "Whenever you get involved with using very sophisticated equipment, there is always a challenge to see if skilled staff can handle this equipment. The equipment is very sensitive to how you handle them and how you set that equipment. Because somebody has to be trained to set digitalized equipment to run properly, setting up those devices, then taking care of those devices and then doing the right calibrations is important, so training skills need to be specific to the customized needs of the line." *P3* |
| "We have carried out training of operators: we have considered the complexities of the operations and the simulation processes in the training centres in online video formats. The management team is ready to spend, so a library of videos was set up for training. A person is not allowed to work on complex equipment unless and until the person undergoes the right sequence of training on the machines." *P2* |
| "Graduates should come from a university with better understanding and clarity on I4.0 and Q4.0. Practicality is important in student education." *P7* |
| "There is not any Q4.0 training currently." *P9* |
| "It comes down to individual initiative. My company were not prescriptive . . . they did not say to do a Master's in Digital Business and Innovation. However, we found the direction the world is going in, and it is in our interest to learn." *P10* |
| "From my side, I do self-learning. For example, I conducted a full-fledged course on I4.0 (6 days) and engaged all my employees in." *P10* |
| "We have not done any formal external training. We have just used content online and in the public domain and trained our people. So I think the current amount of information we have will suffice, it is not rocket science, and it is common sense." *P12* |
| "People have to have the skills; you should not make datasets without assessing why you need what you need and how you need it. Then you are making cross-matching to determine how you access the data, ensuring it is coming over accurately and correctly. And then you need people who can interpret and assess the information coming on." *P1* |
| "The % of the workforce to be trained, I would say, is very low- say 2 or 4%. The majority of people are hourly work personnel. They are not going to do anything with Q4.0. The minority of the workforce, IT or some quality professionals and engineers would get some part of the training." *P10* |
| "With our pilot apps, we call it our learning fabric, where we train our whole worker base on the new tools. We have a huge development in the industry 4.0 and the digitalization part, but we do not focus explicitly on Q4.0, but we have somewhat on digitalization, and we need to train in it." *P6* |
| **Source(s):** Authors' own work |

**Table 6.**
Types of Q4.0 training being initiated or required – quotes from the interviewees

| |
|---|
| "ISO 9001 gives us a basic structure in place, nothing beyond that. I always say ISO is just a passing mark. Excellence is getting a gold medal, and there is a difference between a passing mark and a gold medal; therefore, I do not see much relevance of ISO on I4.0 or Q4.0!" *P1* |
| "Our organization is ISO 9001 certified for Quality Management Systems. ISO standards provide a solid framework, a concrete foundation if you must say -this is basic for Q4.0. If you do not have the basics, you cannot implement advanced approaches." *P2* |
| "I would say that it is informal linkage – ISO 9001 expects you to have accurate information to analyze it. The active digitization/active Q4.0 programs help you get there. So you need to make sure that those connections are clean. It is also a continual improvement, so I mean that there are several aspects of ISO standards that Q4.0 help you with if you have compliance in a correct manner." *P4* |
| "We need to follow standards -we have standards for welding, we have standards for measuring tolerances and checking them." *P10* |
| **Source(s):** Authors' own work |

**Table 7.**
ISO 9001 as a prerequisite for Q4.0 – quotes from the interviewees

| |
|---|
| "Poor change management strategy, especially regarding communication. From the sustainability point of view, there was no consideration. As a result, it fails after 4–5 years." *P3* |
| "Generally speaking, the issues are: (1) lack of sustainability, (2) a project is not completely implemented, or partial implementation, (3) a commitment from the management side." *P4* |
| "Lack of certifications related to Q4.0 and having some courses for our people, then next would be putting a diverse group of people around our projects who can learn the new technologies." *P13* |
| "It is not only the case of the equipment being very expensive, but it is the case of the mentality. They (the management) do not want to spend money to achieve the product quality." *P8* |
| "In implementing the process change management strategies and frameworks were not applied with due rigour." *P9* |
| "Failure factors are the people mostly. Not the management but the worker base. Management is always on board. Also, the unions can be a problem if you do not get them on board because you do not get support from them then you will have a hard time. You will try to do a technology push, and people do not want the project. They do not want the change." *P14* |
| "I find that when you do new stuff, like innovation, management does not dedicate employees to it. Instead, they say that when the person has free time, they will work on it. However, unfortunately, for the project to work and get going, you sometimes need to put full-time resources into it and get things working. Otherwise, other things always take precedence over it." *P11* |
| "The biggest failure is the IT department. Our whole IT department is not the state of the art. Before we launched the whole digitalization part, we did not do much. So some companies have done digitalization for 20 years. We have done for 2 or 3 years." *P2* |
| "They would fail because people do not understand the connections to pull the data from. Alternatively, the data they thought that it was not, and it has to be recreated and repopulated. You may have people that do not have the subject matter expertise to do the programming. You do not have the resources to do the technical aspect of the work." *P12* |

**Table 8.**
Interview comments about CFFs of Q4.0

**Source(s):** Authors' own work

we did not anticipate and did need to measure so that we could allocate time to it–in hindsight not measuring this affected how people embraced the changes" (**P10**).

*4.11 Have all the Q4.0 projects been successful, or are there any projects you can think of that you did not gain many benefits (in your current or previous employment)?*

Generally, it was felt by all the interviewees that the Q4.0 projects implemented were all in all a success. There were one or two bad experiences which have been discussed previously. However, as one interview put it, "Anything that helps us get data, pull reports, perform root cause analysis to help us improve quality or eliminates human and manual error and error proofs a process and ultimately enhances the customer product or service has benefits—even if the road to implement can be painful" (**P5**).

## 5. Discussion

While each interviewee stated that they were all deploying Q4.0 projects, many had only deployed them in the last 2–3 years. This is unsurprising because Q4.0 is still nascent (Foley *et al.*, 2022; Zulfiqar *et al.*, 2023). In many organizations, the Q4.0 projects that will benefit the effective running of the QMS and improve the customer experience and product and service quality are being run as part of the organizational digitalization program. Thus in many organizations, Q4.0 is seen as a subset of I4.0 (Antony *et al.*, 2021a). The interviewees' experiences within their organizations align with a global study by the Boston Consulting Group that found few organizations had clear direction and a detailed strategy for Q4.0 and had not yet started a Q4.0 implementation program (Küpper *et al.*, 2019). The themes of Q4.0 and digitalization as the future and the next evolution in how quality managers can do their jobs were resounding among the interviewees. However, the evolving challenges were very

much at the forefront of opinions. Q4.0 poses significant challenges to the quality profession by emphasizing the need to adapt to technological innovations, modern data analytics and the entrepreneurship ecosystem that characterizes an era of the fourth industrial revolution. The benefits of Q4.0 have been cited by many authors (Antony *et al.*, 2021c; Antony *et al.*, 2022d) and are aligned with the benefits highlighted in this study. The study participants highlighted how the emergence of technology, such as the IoT and sensors used in manufacturing and equipment, has provided vast amounts of data that can be analyzed and utilized for quality management (Bousdekis *et al.*, 2023). The importance of data availability was highlighted in the examples of projects listed by the participants, namely projects on improving data availability and using data to improve warranty and services.

The respondents highlighted a gap in training for Q4.0 and stated that no real training was available despite deploying digitalization projects. None of the respondents had a training program in their organizations, nor were they of such training available. Now that Q4.0 is enabling quality personnel skillsets to change, the modern Q4.0 professional is a data scientist who can organize and interpret data and databases, uses big data and find trends and patterns via statistical data analysis and creates continuous improvement opportunities (Antony *et al.*, 2022a; Santos *et al.*, 2021).

There were mixed views regarding where Q4.0 fits a traditional QMS, with several unsure about where ISO 9001 fits with Q4.0. While all interviewee organizations had a defined QMS and all had an ISO 9001 certified QMS, some considered ISO 9001 the basic structure of a QMS, and Q4.0 supports the ISO 9001 QMS by enabling projects that improve the management of that QMS. Saihi *et al.* (2021) found in their study that there is a need to include more studies on the integration and inclusion of ISO 9001 requirements and I4.0 features.

The interviewees felt the CFFs of Q4.0 lack leadership support, leadership not aligning the Q4.0 projects with a clear strategy and a lack of understanding of the benefits of digitalization in improving quality. As mentioned, finding training and educational courses in Q4.0 was a struggle. It is also mentioned that finding suitable personnel to use data, analyze it and implement digitalization projects is challenging. According to Escobar *et al.* (2021), a vision for Q4.0 can be created, resources may be allocated, teams formed and projects selected. However, value can only be obtained if the projects are suitable.

Measuring the success of Q4.0 projects or their failures has mixed responses. As with any project implementation, the project managers are concerned with delivering projects on time and within budget. However, the interviewees cited examples of project failure or difficulties measuring success due to a lack of knowledge and personnel qualified to use the new software or understand the technology (Antony *et al.*, 2021b). Interviewees discussed measuring the improvement in customer metrics, KPIs, improved access to data and changes in timeliness to complete tasks: all as methods to measure Q4.0 implementation. Sureshchandar (2023) described 12 axes upon which to measure Q4.0 success or failure; these included the degree of leadership time devoted to Q4.0, the quality culture and time spent focusing on quality, customer centricity measurements through the use of the voice of the customer analysis, as well as levels of compliance to the QMS and data analytic based metrics.

## 6. Implications

This current research contributes to the theory in three aspects. First, the Q 4.0 concept is explored by linking it to other quality standards, and hence, this study provides a valuable insight into how organizations can build effective Q4.0 strategies that align with their existing QMS, by considering the perceived benefits and improvements that Q4.0 will bring to the organization. Further, the study also contributed to the debate as regards ISO 9001 a prerequisite for Q4.0 implementation. Second, it contributed to the body of knowledge on

training and competencies required for Q4.0. Specifically, training can range from traditional classroom-based to project-based and self-learning on Q4.0. Professionals and engineers who are responsible for Q4.0 should receive the majority of the training, while a small percentage of other workers can receive basic training on Q4.0. Training should focus on the complexities of the operations, setting up and calibrating the digitalized equipment, data sciences and analytics and understanding the impact of digitalization on the industry. Third, contribution is specific to understanding the dynamics of CFFs of Q4.0 and how it can contribute in the successful implementation of Q 4.0. Organizations can use Q 4.0 to achieve sustainable competitive advantage our study will help the organizations in identification, classification and analyzing CFFs so that organizations can use Q 4.0 as a distinctive competency, which are valuable, rare and cannot be easily imitated.

## 7. Conclusion and scope for future work

This study identified the CFFs of Q 4.0 using a qualitative study. The study further explores the type of training and competencies organizations should use while implementing Q 4.0. Altogether, this study contributes to a range of topics, including the debate on whether ISO 9001 is a prerequisite for Q4.0, and the CFFs of Q4.0. The analysis demonstrates that Q4.0 deployment across sectors is in its infancy. Moreover, some Q4.0 initiatives have been launched in companies due to their continuous improvement culture and proactive professionals. As Q4.0 adoption is in its infancy, the industry's relationship between QMS and ISO standards is not well-established. Therefore, more studies in this area would aid practitioners in enhancing the strengths and minimizing both weaknesses. An intriguing fact is that organizations do not formally educate their deployment teams to implement Q4.0 initiatives.

Additionally, Q4.0 is not supported by any educational programs or courses. This fact opens a door for academics and professionals to work together to develop a training curriculum for efficient implementation. Finally, it is found that the primary CFFs of Q4.0 implementation include a lack of leadership support, misalignment of Q4.0 projects with the organization's strategy, a lack of knowledge of the Q4.0, a lack of training, a lack of Q4.0 professionals and a lack of change management.

The study is constrained because only 14 respondents were considered, this was because the data saturated, and sample size was considered to be adequate. Since Q4.0 is still developing and respondents have had enough opportunity to engage with Q4.0 initiatives, generalizations may be made. However, the authors want to establish a comprehensive road map for the Q4.0 deployment using a questionnaire-based survey, action research and longitudinal study. In addition, the international group of authors hopes to create a comprehensive training handbook with practitioners and quality consortiums to aid policymakers and companies in establishing efficient Q4.0 training programs.

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