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Quality 4.0 – How to Handle Quality in the Industry 4.0 Revolution

Master's thesis in Quality and Operations Management

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CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020
www.chalmers.se
Report No. E2019:128

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SUMMARY
The global industry is facing a fourth industrial revolution, called Industry 4.0. It refers to connectivity and integration of systems to gather and analyze data and digitalize the operations of the organization. Quality 4.0 is a concept related to this fourth industrial revolution in terms of the digitalization of quality work in the context of Industry 4.0. This thesis explores how Quality 4.0 is part of the evolution of quality work and proposes a definition based on literature. A case study research was done together with several Swedish and international organizations, focusing on understanding how the organization should transition into Quality 4.0. A definition of Q4.0 is presented and a general roadmap for transition to Q4.0 is proposed, which comprehends six sequential phases and is applicable to different organizations that plan to transition into Quality 4.0.

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Keywords: Industry 4.0 Quality 4.0 strategy, Lean, digitalization, Big data.

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Acknowledgment

This report is the result of our thesis work performed at the Engine Systems division at GKN. First, we want to thank our supervisor from Chalmers, Monika Jurkeviciute, for your guidance and continuous support. Your encouragement and interest in our continuous learning and personal development were truly important for this work. We would like to give special thanks to GKN for allowing us to work together, especially our company supervisor Irene Skystedt and our sponsors Anna Bäck and Taina Olsson. Your feedback and support were important and truly appreciated. A special thanks to all the people we met during the interviews for being open to sharing ideas and to our examiner Dan Andersson for guidance and feedback.

1. Introduction

This chapter provides the background to the master's thesis, a brief description of the company as well as the aim of the study and its delimitations.

1.1. Background

In recent years, a fourth industrial revolution has taken place, built upon wireless connectivity that allows the integration of different devices into a system for gathering and analyzing data more efficiently, using Cyber-Physical Systems (Watson, 2019). This allowed organizations to start the digitalization of operations (LSN Research, 2017). In 2011, the German Federal Government was among the first to officially address digitalization and announced its High-Tech Strategy 2020 Action Plan. Which resulted in the establishment of "Plattform Industrie 4.0", where many leading German companies have their digitalization and automation initiatives (Geissbauer, Vedsø and Schrauf, 2016).

Quality 4.0 is a concept related to Industry 4.0. It refers to the digitalization of quality and how digital tools can impact technology, processes and people (LSN Research, 2017). The changes that come with digitalization must be considered as organizational issues where quality work will be related to find new data sources that can be analyzed to deliver insights to people, suppliers and customers for doing their work better.

Although there has been research done on the topic of Industry 4.0 during the last few years (Alcácer and Cruz-Machado, 2019; Geissbauer, Vedsø and Schrauf, 2016; Ibarra, Ganzarain and Igartua, 2018; Leineweber et al., 2018), little has been investigated about Quality 4.0 and how to transition an organization into working under this paradigm. Industry 4.0 focuses on the implementation of technologies, but not necessarily on how these create value for different stakeholders, the changes within the organization and how quality work will be done. Organizations could benefit from transitioning to Quality 4.0 by being more effective in managing costs and allocating resources. Managing costs and allocating resources would be done more effectively.

Organizations have required a more in-depth research in the area of Quality 4.0 over recent years. It is considered as relevant by many organizations yet there is little understanding on how to transition into Quality 4.0. Organizations are then interested in a roadmap to know where to start and what steps to take for this transition.

The research in this thesis has been conducted with the participation of Swedish organizations and in collaboration with GKN Aerospace, which has been growing as an organization by performing a series of acquisitions all around the world. The Engine Systems division has been working with Industry 4.0 projects during the past years and due to recent organizational restructuration, this topic has been considered very important for the future of the company. Internal company programs aim to include a new concept of process excellence and high quality,

but how quality work will be affected in an Industry 4.0 context is a topic not fully investigated, both internally and in research. It is then interesting and relevant to study Quality 4.0, especially how would a company transition into it.

1.2. Aim

Organizations are asking for in depth knowledge about how to transition into Quality 4.0. This study in collaboration with GKN aims to first understand what the awareness of Quality 4.0 in organizations is, to provide ground for defining a series of steps for transition to Quality 4.0. To address this, the authors have proposed the two following research questions:

RQ1: What is the awareness of Q4.0 in organizations?

This question will provide information of how the concept of Quality 4.0 is understood in the organization and will also provide ground for the next research question.

RQ2: What steps should an organization take to transition to Quality 4.0?

This question will provide a roadmap for organizations to transition to Quality 4.0, defining which steps to take for moving towards it.

1.3. Delimitations

The in-depth information obtained in this study was limited to the Aerospace Engine Systems division at the GKN Aerospace Sweden site in Trollhättan. Other companies provided data, but in-depth studies have not been conducted at other companies outside of GKN Aerospace Sweden.

The data was obtained from a limited number of occupations within the interviewed organizations such as quality engineering, information technology, production development and Industry 4.0. Interviewing a broader range of occupations such as financial, human resources and sales might have enriched our understanding and affected the roadmap for transition to Q4.0.

Due to time and scope limitations, no specific plan for implementation of the roadmap for transition to Q4.0 within any organization was developed.

2. Literature review

This chapter includes the literature review that provided the theoretical basis for the project. First, the concepts Industry 4.0, Quality and Quality 4.0 are discussed, definitions are presented and the relationship between the concepts is explored. Second, the state of Industry 4.0 and Quality 4.0 in Sweden is discussed. Then, models and frameworks related to Quality 4.0 are presented and analyzed.

2.1. Industry 4.0

Three industrial revolutions linked to historical events have taken place: The commercial steam engine and mechanical loom (mechanization) in the late 18th century, mass production (electricity) at the end of the 19th century and the start of the 20th century, and the computer (Information Technology) after World War II (Geissbauer, Vedsø and Schrauf, 2016; Kagermann, Wahlster and Helbig, 2013). In recent years it has been argued that the world has entered into a new industrial revolution which is defined by the advances in connectivity, mobility and analytics that have helped the digitalization of operations, companies and societies (LSN Research, 2017). The fourth industrial revolution has been built on wireless internet connectivity that allows the integration of different devices into a system to gather and analyze data in a more efficient way using Cyber-Physical Systems (CPS) (Watson, 2019). The term Industrie 4.0 or Industry 4.0 (I4.0) refers to the fourth industrial revolution that seeks to improve the industry by incorporating emerging technical advancement and dealing with some global challenges, like improving people's standards of living and setting up a better work environment for employees (Wang et al., 2016). For this study, the term "Industry 4.0" (I4.0) will be used onwards.

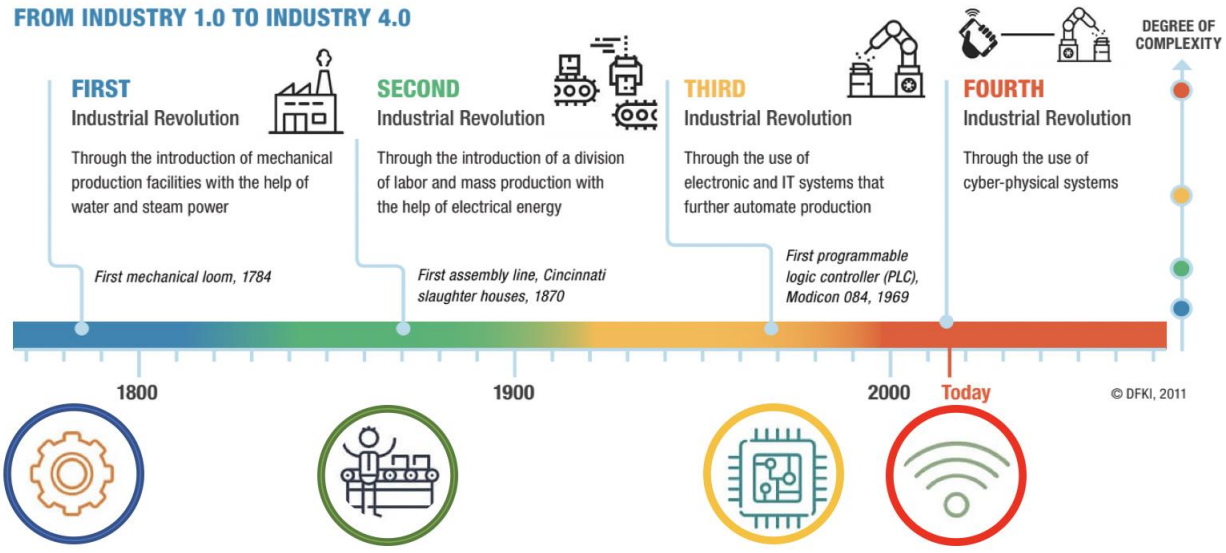

Figure 1. The four industrial revolutions (Adapted from LSN Research, 2017; Amil, 2019)

Alcácer and Cruz-Machado (2019) argue that the fourth industrial revolution has been announced even before it took place. Being aware of a potential new industrial revolution presents a possibility to shape the manufacturing future in

co-working environments with the participation of academic researchers and industrial practitioners. This is particularly important since the link between academy and industry could be strengthened and both theoretical and empirical concepts might be mixed more efficiently.

Amongst authors who argue that organizations are now facing challenges in this fourth industrial revolution, it is difficult to find a proper definition of the concept. Kagermann, Wahlster and Helbig (2013) defined *three* main features for I4.0: Horizontal Integration through value networks, end-to-end digital integration of engineering across the entire value chain with vertical integration and networked manufacturing systems. While Hermann, Pentek and Otto (2015) consider *four* main components for I4.0:

- Cyber-Physical Systems (CPS): Physical processes affect computations and vice versa
- Internet of Things (IoT): Things and objects are allowed to interact with each other and cooperate
- Internet of Services (IoS): Offering of services and support features via the Internet
- Smart Factory: A factory that assists people and machines in the execution of their tasks. Padhi and Illa (2019) define this concept as a manufacturing facility able to analyze and make sense of big data generated on the shop floor, also being automated, autonomous and data driven.

Geissbauer, Vedsø and Schrauf (2016) argue that *three* aspects of digitalization make the core of an I4.0 approach: Full digitalization of a company's operation, redesign of products and services and closer interaction with customers. To make this work in an organization, a strategy must be developed and then changes in organizational practices and structures must take place to adapt different aspects regarding Information Technology (IT) architecture, data management, regulatory compliance and overall company culture. I4.0 requires then that companies have a formal strategy regarding digitalization and that it is harmonized through the whole organization. Still, many organizations manage digital transformation projects as common IT projects, showing a lack of understanding about the drivers for the transition to I4.0, the true motives for the companies to do so and the importance of organizational change in the context of digital transformation (Issa et al., 2018).

Leineweber et al. (2018) argue that to facilitate the transition to I4.0, companies must first define the present and future states by addressing three dimensions: Technology, organizations and personnel, as well as the dependencies between them. A study by Geissbauer, Vedsø and Schrauf (2016) shows that analytics and organizational analytic capabilities, which are important for I4.0, require that people acquire the expertise to manage and analyze data in a more effective way. This analysis provides insights to change designs, improve production schedules, reduce waste and balance trade-offs.

Regarding business models, three approaches have been identified to respond to features and challenges of I4.0 (Ibarra, Ganzarain and Igartua, 2018):

- Service-oriented: Change from product to service mindset and expanding the role of a company in the supply chain by extending the product with services that add value.
- Network-oriented: The horizontal and vertical integration provides new ways to offer value through systems that go beyond the individual value chains.
- User-driven: Manufacturing gets aligned with customer creation processes and provides opportunities for customization.

In 2011, the German Federal Government announced its High-Tech Strategy 2020 Action Plan, where I4.0 was one of the adopted strategic initiatives (Kagermann, Wahlster and Helbig, 2013, p. 77) and resulted in the establishment of "Plattform Industrie 4.0", where many of the leading German companies have own initiatives today (Geissbauer, Vedsø and Schrauf, 2016). Similar strategies were also proposed in the USA, as "Industrial Internet" (The Industrial Internet Consortium, 2014) and in China as "Internet +" (Wang et al., 2016) to face the challenges from this fourth industrial revolution. Just a few years after, the ZVEI (German Electrical Industry) and other German industrial partners developed the reference architecture for I4.0 (RAMI 4.0) as a guideline for I4.0-compliant production equipment (ZVEI, 2015). All the local initiatives started in different countries consider the importance of digitalization of the operations in an organization to be competitive.

2.1.1. Industry 4.0 In Sweden

In 2016, the Swedish Ministry of Enterprise and Innovation published a strategy for new industrialization for Sweden called Smart Industry. It comprehends four focus areas (Swedish Ministry of Enterprise and Innovation, 2016):

- Industry 4.0, to exploit the potential of digitalization.
- Sustainable production, to improve sustainable and resource-efficient production.
- Industrial skills boost, to ensure the supply of skills to the industrial sector.
- Testbed Sweden, to create attractive innovation environments.

A study performed by Antonsson (2017) concluded that in general, Swedish organizations have a low I4.0 maturity level which is related to a lack of strategy for I4.0 implementation.

2.1.2. Industry 4.0 and Sustainability

I4.0 plays a role for reaching the 17 sustainable development goals, shown in Figure 2. These goals were set by the United Nations (2015) and went into effect starting the 1st of January 2016, with a timeframe up to 2030. These goals consider challenges such as world poverty, environmental damages, prosperity

and peace. Zaman (2018) argue that some of the goals are strongly connected to I4.0 such as:

- Goal 8, sustained economic growth and productive employment: Low cost labor is no longer an advantage for developing countries to be attractive for organizations to move operations there. However, I4.0 technologies can be accessed by all countries today and this is an alternative to drive economic growth.
- Goal 12, sustainable consumption and production: I4.0 aims to reduce waste by producing just in time, minimizing material waste in design by using data to manufacture products within given parameters, leading to fewer rejections and less usage of natural resources. This leads to a more sustainable production.
- Goal 17, foster global partnerships for sustainable development: I4.0 provides tools to design strategies for countries to grow sustainably while also creating opportunities for innovation. Global issues like pollution, climate change and migration could be addressed by expanding cooperation between countries and increasing access to science, technology and innovation. I4.0 is believed to foster cooperation and the sharing of technologies for mutual benefits.

Kleindorfer, Singhal and Van Wassenhove (2005) argue that sustainability is a key element in every supply chain, where companies have previously only focused on profitability in monetary terms. However, in today's economy, organizations have to focus on several aspects related to the triple bottom line (3BL). This means that companies put emphasis on People, Planet and Profit and they must act in the best of its capabilities in each of these aspects to be successful. Sustainability has been embedded into I4.0 completing the mindset of a circular economy, instead of the more traditional economy. A circular economy can be described as a closed-loop supply chain with a stronger focus on the "end of life" of the product beyond its consumption. I4.0 can provide strategies for recycling, reusing, restoring or manufacturing in modules that can be easily changed, which reduces the waste of materials (Madhusudan, 2019)

Figure 2. The 17 sustainable development goals (UN, 2015)

Bonilla et.al (2018) analyzed the sustainability impact and challenges of I4.0 from four scenarios: Deployment, operation, integration and long-run. The study identified predominant positive expected impacts derived from I4.0 but concluded that these impacts must be supported by the integration of I4.0 with the sustainable development goals in an eco-innovation platform. Other studies performed in German manufacturing industries concluded that environmental and social opportunities are positive drivers of I4.0, mainly related to waste and energy reduction and improvements in the workplace (Mülle, Kiel and Voigt, 2018).

2.1.3. Industry 4.0 and Lean Six Sigma

It could be argued that there is a close relationship between I4.0 and Lean Six Sigma. Lean management provides the tools for process improvement by generating value to the stakeholders and reducing waste, while Six Sigma gives tools and knowledge for problem-solving and for handling the obstacles within the organization to reduce variation. Mayr et al. (2018) developed a conceptual conjunction of I4.0 features and lean management methods as Just-in-time, Kanban, value stream mapping, visual management and total productive maintenance. The authors of that study concluded that both I4.0 and Lean Six Sigma complement each other on a conceptual level. Lean processes can be a starting point to efficiently and economically implement I4.0 features and, by using I4.0 features, processes can be stabilized and refined.

I4.0 can help an organization in gathering data from its whole supply chain or its complete life cycle of the products. A prime concern, however, is to transform large amounts of data into useful information that can help to streamline operations, a process usually referred to as managing Big Data. Lean Six Sigma provides tools to clean, filter and analyze the data transforming it into business intelligence that can be part of successful strategies. The knowledge generated by Lean Six Sigma projects makes it easier for the organization to ensure that new technologies are incorporated into robust processes in a meaningful way (Six Sigma Daily, 2018). However, larger amounts of data bring greater complexity for operations, thus proper tools must be used for data analysis.

2.2. Quality and Total Quality Management

There are many different definitions of quality and many organizations develop their definitions depending on their strategy and stakeholders. Garvin (1984) identified five approaches to quality:

- Transcendent: Quality is identified when experienced.
- Product-based: Extent to which a product possesses defined characteristics.
- User-based: To which degree a product fulfills the needs and expectations.
- Manufacturing-based: Fulfillment of tolerances and requirements.
- Value-based: The relation between cost and price.

In the context of an organization and for this work, a user-based or customer-oriented definition from Bergman and Klefsjö (2010) will be used:

> *The Quality of a product (or service) is its ability to satisfy, or preferably exceed, the needs and expectations of the customers.*

Total Quality Management (TQM) was developed from integrating total quality theories and management theories, by considering customer focus, continuous improvement and teamwork in three dimensions of principles, practices and techniques (Dean and Bowen, 1994). TQM can even be considered a substitute for a proper strategy. It is a philosophy to organize the quality improvement by considering the needs and expectations of internal and external customers, covering all parts of the organization, examining the costs of quality, being proactive and developing systems to support improvement (Slack and Lewis, 2017). Bergman and Klefsjö (2010) define TQM from a holistic perspective as:

> *A constant endeavor to fulfill, and preferably exceed, customer needs and expectations at the lowest costs, by continuous improvement work, to which all involved are committed, focusing on the processes in the organization.*

Quality control is a part of TQM that is focused on fulfilling quality requirements of the organization with inspection and using techniques like statistical sampling and statistical process control (Bergman and Klefsjö, 2010; Sader, Husti and Daróczi, 2019; ISO, 2015). It aims to correct unwanted or unexpected changes and bring stability and consistency for a product (Radziwill, 2018). Quality assurance is also part of TQM and is focused on providing confidence and ensure that quality requirements for manufacturing products are fulfilled (Bergman and Klefsjö, 2010; Sader, Husti and Daróczi, 2019; ISO, 2015). Designing processes to build in quality in the product and developing monitoring systems to measure performance contribute to preventing events that can affect quality negatively.

Bergman and Klefsjö (2010) also name six cornerstones related to TQM needed to develop a culture built upon continuous and consistent management commitment:

- Committed leadership
- Focus on customers
- Base decisions on facts
- Focus on processes
- Improve continuously
- Let everybody be committed

The ISO 9001:2015 standard (ISO, 2015) provides guidelines for the adoption of a quality management system related to TQM. It proposes seven Quality Management principles that should work under a process approach:

- Customer focus
- Leadership
- Engagement of people
- Process approach
- Improvement
- Evidence-based decision making
- Relationship management

Regarding the evolution of quality, it can be argued that three phases take place within an organization, as shown in Table 1.

Table 1. Evolution of quality (adapted from Sader, Husti and Daróczi, 2019; Radziwill, 2018)

Phase	Quality Control (QC)	Quality Assurance (QA)	Total Quality Management (TQM)
Scope	Product	QC, processes	QA, organization, people
Meaning of quality	Inspection	Design	Empowerment
Features	Product specifications, statistical process control and variation. Correction	Built-in process quality. Process performance and metrics. Prevention	Organizational goals linked to metrics. Quality as a strategic imperative. Continuous improvement

For the past years, TQM became very close to concepts such as a sense of safety, aesthetics, well-being, engagement and participation. It is also related to organizational innovation, which is a valuable strategy for world-class performance by value creation, new thinking and operational improvement (Lee, 2015; Watson, 2017).

2.3. Quality 4.0

The concepts that make up the term Quality 4.0 (Q4.0) were forecasted by Watson (1998) more than 20 years ago, due to the growing availability of telecommunications technology, the Internet, personal computing, networks and thought machines that would make quality functions and analysis somehow automated. 20 years later, quality has gotten a larger role than its traditional meaning, in an ever-changing context where quality professionals must adapt to the environment of high technology and innovation (Elshennawy, 2004). Quality professionals should then shift focus to anticipating change and integrating new concepts into business models.

Q4.0 is an integral part of I4.0 and could be defined as the digitalization of TQM and its impact on quality technology, processes and people (LSN Research, 2017). It could also be defined as the application of fourth industrial revolution

technologies, such as digitalization and artificial intelligence, to quality (Bowers and Pickerel, 2019). Due to shifts from a customer-centric perspective to co-creating with customers and other stakeholders, Lee (2015) argues that TQM becomes an important part of organizational innovation where disruptive and radical innovations open the way to big changes to the concept of quality. In the context of I4.0, quality should be considered as the discovery of data sources, root causes and insights about products and organizations by augmenting, and improving upon, human intelligence (Radziwill, 2018).

The changes that comes with digitalization, automation, big data and cybersecurity are not important only from an IT perspective but must be considered as organizational issues. Quality professionals should then have the skills to determine how and why data should be used since it is the process that must dictate the use of information and not the other way around (ASQ, 2018). Radziwill (2018) argue that the fourth industrial revolution provided seven tools and technologies that can be used to improve quality:

- Data science and statistics: Drive value through predictions, finding patterns and generate viable models and solutions. Identify causal and noncausal relationships through data aggregation, data classification, real-time pipelines and dynamic modeling that generates knowledge related to problem-solving.
- Enabling technologies: Always related to the latest developments in connectivity like sensors, mobile devices, networks, Internet of Things (IoT), Industrial Internet of Things (IIoT), integrated systems, Virtual Reality and cloud computing. Also related to how to manage documentation.
- Big data: Related to the infrastructure for managing and analyzing large data sets that arrive very fast, in different formats, with high variation in data quality, from different stakeholders, could be easily modified and when there may be restrictions for its use.
- Blockchain: Permanent monitoring for allowing transactions to happen only if quality objectives are met. Contributes to ensuring data quality, trust and to develop a quality culture.
- Artificial Intelligence (AI): For making complex decisions like computer vision, chatbots and robotics.
- Machine Learning (ML): It helps when heuristics are used for decision making and also for forecasting, filtering of information and recommendation systems. Helps a company to do jobs better by finding levers within the processes that can ensure consistency and alignment across the whole organization. The uncovering of relationships helps build a safety and quality culture.
- Neural Networks and Deep Learning: Used for forecasting and complex pattern recognition. It incorporates layers with special functions.

How these tools relate to each other is also important to consider, depending on the expected value to be generated if intelligence and automation are introduced into a process, as illustrated in Figure 3.

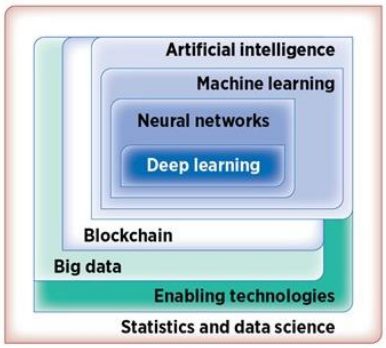

Figure 3. The seven Q4.0 tools (from Radziwill, 2018)

Lyle (2017) considers that the full- or semi-automated quality data collection gives organizations the ability to increase the efficiency of quality oversight. Automated analysis in real-time can provide a fast reaction when trends, values out of specifications and variances are identified and handled properly with tools for statistical process control. This can also represent savings in time and paper costs. Furthermore, the visibility obtained by the centralization of data opens a possibility that all stakeholders are aware of the activities from beginning to end and can contribute to improving the whole supply chain by increasing output and decreasing costs. In this context, Radziwill (2018) gives a simplified definition of Q4.0 related to the information as the connectedness (connection to the data), intelligence (understand and respond to the data) and automation (bring the data when needed and with less effort) for improving performance, supported on the value propositions presented in Table 2.

Table 2. Value propositions for Q4.0 (From Radziwill, 2018)

Value for Q4.0
Augment, or improve upon human intelligence
Increase speed and enhance the quality of decision-making
Anticipate changes, reveal biases and adapt to new circumstances
Learn how to learn. Cultivate self-awareness and other-awareness
Reveal opportunities for continuous improvement
Improve transparency, traceability and auditability

Radziwill et al. (2008) argue that the value propositions must be coherent with increasing quality and satisfaction while decreasing costs for that to happen. The goals of a TQM system under the context of digitalization remain the same and provide a solid ground to build Q4.0. However, Fundin et al. (2018) argue that research is still needed about how TQM can enhance organizational learning and innovation. Systems design, process adjustment, adaptive learning, systems integration and human performance contribute to the rise of data scientists that manage big data for predictive analytics (Watson, 2019) that are valuable for quality professionals. However, as in the case of I4.0, the transition to Q4.0 is still a big challenge for many companies due to lack of knowledge about its context,

impact (Jacob, 2019) and how to adapt their Enterprise Quality Management Systems (EQMS).

I4.0 brings many opportunities and challenges for the organizations and the role of the quality professional is to seek digital diversity by focusing on anticipating changes, the integration of technology into the human sphere, integrating new concepts into business models and creating customer experiences that help people in the pursuit of a successful life and achieving a quality of life (Watson et al., 2018). Radziwill (2018) argue that quality professionals are already suited with the necessary skills to lead digital transformation in organizations, such as systems thinking, decision making based on data, leadership for organizational learning, continuous improvement processes and the ability to understand the consequences of decisions taken regarding society, environment and ethics. It could be argued then that it is quality, not IT, the most competent area to be in charge of digitalization within a company. Lim (2019) argues that with Q4.0 quality professionals will be more capable to answer questions about product robustness, process excellence, customer satisfaction, risks in new product development, traceability and transparency.

Furthermore, Radziwill (2018) highlights three preconditions for moving to Quality 4.0: Alignment between strategy and objectives, data governance and management, and cybersecurity as a strategic imperative. To reach this state, management systems must first strengthen data management and scalability as foundations of the system itself and then integrate processes and systems to improve alignment and agility. Albers et. al. (2016) started work on an intelligent quality control system, analyzing the current state of the system, defining its targets and requirements and the project stakeholders. The study concluded that a comprehensive understanding of both technical and organizational situations is necessary beforehand to set boundaries, identify constraints and interfaces between value-adding partners to develop a proper quality control system.

In the case of Sweden, no official strategies for Q4.0 exist in per 2019. Since Q4.0 is related to I4.0, this could be linked to the findings of Antonsson (2017) regarding the lack of strategies for I4.0 from the companies in his study. Besides, the concept has its origins in the USA, it is quite novel and its application has not been studied in detail.

Sörqvist (2019) argues that the purpose of Q4.0 is to integrate customer-driven business development with technology-driven business development. To reach this objective, integration of different models, programs and tools like Six Sigma and Lean must be achieved. The author also suggests that this integration of different concepts is more common in the USA than Sweden and that investment in training soft skills like problem-solving, leading improvement teams, development of a quality culture, data analysis and the use of statistical methods is the first step towards the digitalization of quality.

The Swedish Institute for Quality (SIQ) has developed a concept called Quality 5.0 (SIQ, 2019). It is related to the fifth wave of quality “societal satisfaction”, where the first four waves are identified as “do it yourself” in the 17th century,

"specialization and professional knowledge" in the 18th century, "mass production, low customization" in the 19-20th century and "total quality management, customer satisfaction" since the middle of the 19th century. This concept proposes three aspects to increase the competitiveness of Swedish products: a new adaptive leadership model, digitalization from a customer perspective and sustainable development.

2.4. Models related to Quality 4.0

Four existing models related to quality in the context of I4.0 were identified from the literature.

The first model is from a manufacturing context, where Padhi and Illa (2019) propose four aspects of TQM that make a difference between a traditional factory and a smart factory, shown in Table 3. This model gives an approach to quality in smart manufacturing and tries to illustrate the predictive analytics that may take place for detecting trends in a process. However, it is only limited to manufacturing and only mentions basic aspects related to the differences between smart factories and traditional factories. Besides, the aspects of TQM proposed do not cover the traditional elements of quality work that provide ground to Q4.0.

Table 3. Smart vs traditional factory (adapted from Padhi and Illa, 2019)

	Aspect of Total Quality Management			
Type of factory	Seamlessly integrated system architecture	Automated data processing	Increased level of autonomy	Predictive analytics
Smart	This is the standard	Automated to a large extent, depending on user needs	Quality-related processes autonomous to a large extent	Preempt defects, values outside specifications or without control and take corrective measures
Traditional	Quality-related data may be in separate systems, not fully integrated with each other. Information flow may be difficult	Data collection and data entry may be manual.	Operator intervention may be required to perform an action plan	Analysis and actions are reactive and based on action plans

A second model to grasp the current state of a company and identify how to move into the future state of Q4.0 was developed by LNS Research (LNS Research, 2017). It builds upon traditional quality methods and considers the impact of digitalization on quality technology, processes and people, as shown in Figure 4. This framework could be used to assess where a company is in every axe and to know how to prioritize investments. After assessing the level on all the axes, a company identifies the different technologies that could help to improve performance and develop quality objectives aligned with a digitalization strategy. Some companies that are interested in moving to Q4.0 could find themselves on a low level in this framework but this situation might be solved by

investing in a TQM system as a first step. This framework proposes a way to assess the current state of an organization, but it does not provide guidance on how to transition into Q4.0. Besides, it considers that a digitalization or I4.0 strategy is already in place at the organization.

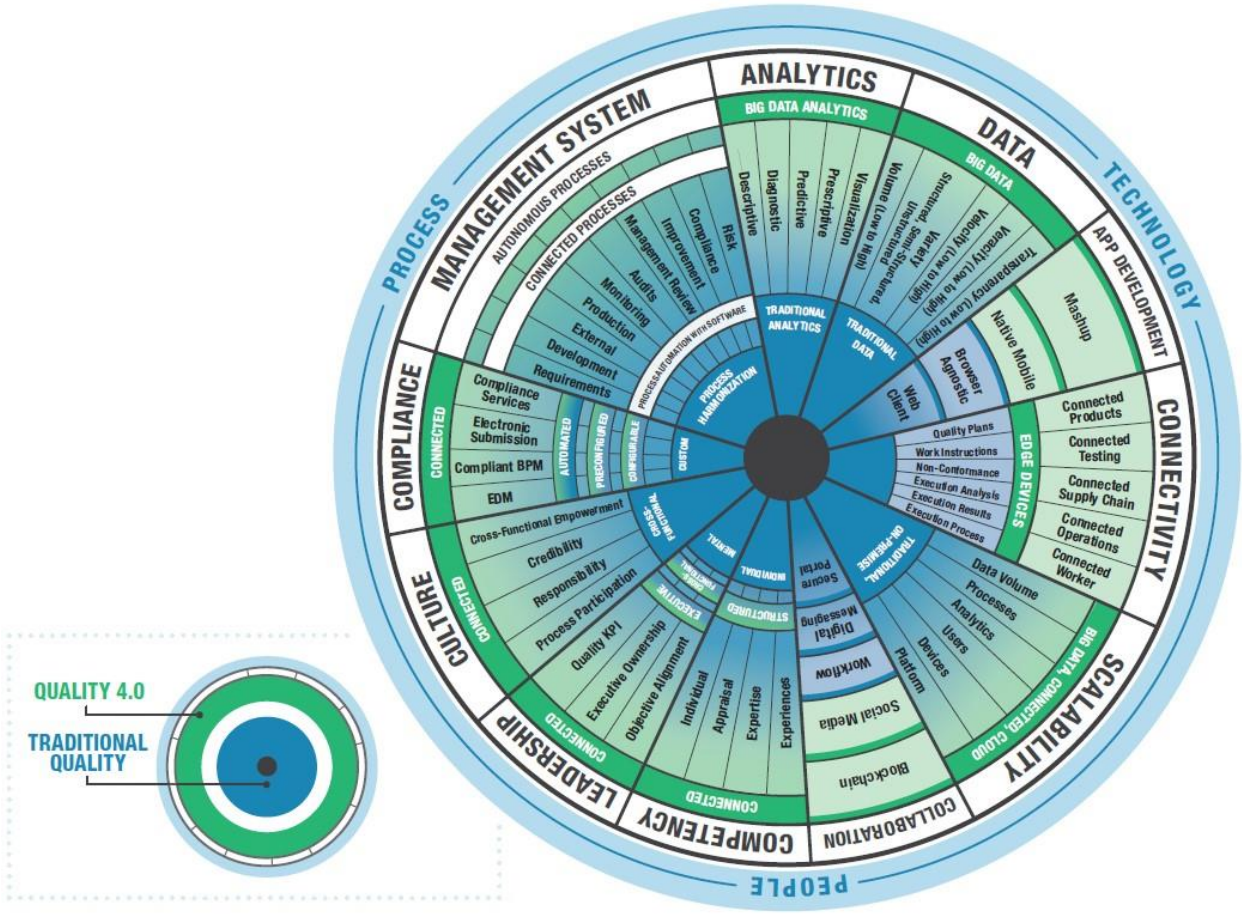

Figure 4. 11 axes of Quality 4.0 (from LNS Research, 2017)

Sader, Husti and Daróczi (2019) developed a third model considering I4.0 as an enabler for implementation of TQM practices, using the seven Quality Management principles from the ISO 9001:2015 standard (ISO, 2015) and adding quality assurance and quality control. Furthermore, they analyzed these principles in the context of I4.0 features and tools as illustrated in table 4. However, it is important to highlight that only I4.0 features are not sufficient for TQM since knowledge, skills and organizational barriers exist for the application of new technologies. This model does not consider cyber-security and data protection which are also a difficulty for implementing many features and neither the lack of proper change management that considers present and future states for all stakeholders.

Table 4. TQM and I4.0 practices (adapted from Sader, Husti and Daróczi, 2019)

TQM principle	I4.0 opportunities
Customer focus	Improved responsiveness, customization, smart forecasting
Leadership	Smart resource allocation, improved coordination, effective evaluation
Engagement of people	Improved communication and collaboration, facilitating innovation and sharing of ideas
Process approach	Transparency, self-learning and early prediction of errors, less downtime with early maintenance prediction
Improvement	Dynamic interaction with market needs, instant reconfiguration of manufacturing processes, motivating for change environment
Evidence-based decision making	Rich information and analytics, early failure prediction, early decision making
Relationship management	Early identification and communication, segmentation of stakeholders, stronger collaboration with partners
Quality Assurance	Pre-production quality assurance, early failure detection and prediction
Quality Control	Intelligent quality control system, real time quality inspection

The fourth model related to Q4.0 is proposed by Lim (2019) who argues that Q4.0 is a combination of IT and Operations Technology (OT), together with human intervention at the center of the model as an important part of digital transformation, as shown in Figure 5. This integration contributes to real-time quality management and increased use of big data for analysis that could represent advances towards predictive quality. However, even if this model proposes how to integrate different aspects related to I4.0 under a Q4.0 perspective, it is still generic and lacks a definition of its components and in which order to proceed.

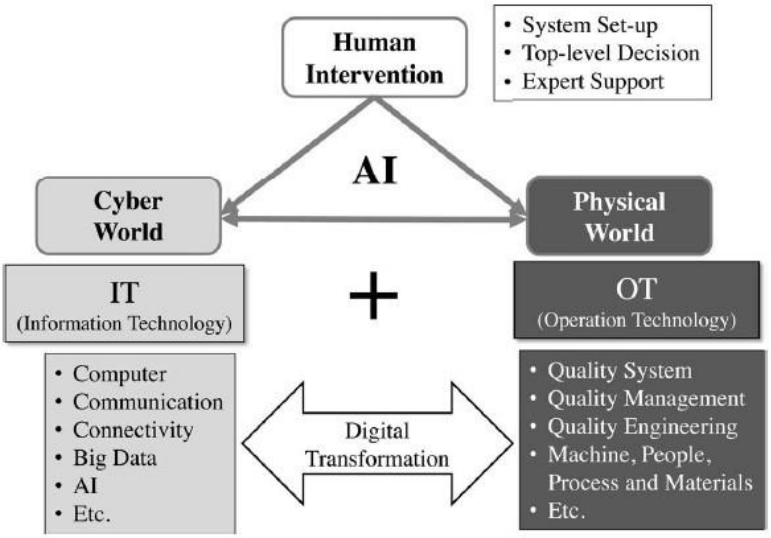

Figure 5. Quality 4.0 (from Lim, 2019)

2.6. Key takeaways

The first takeaway from the literature review relates to the definition of the fourth industrial revolution and I4.0. Since the concept I4.0 is quite open to interpretation, for this work the definition given by Hermann, Pentek and Otto (2015) will be used:

> *I4.0 is a collective term for technologies and concepts of value chain organization. Within the modular structured Smart Factories of I4.0, CPS monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. Over the IoT, CPS communicate and cooperate with each other and humans in real-time. Via the IoS, both internal and cross-organizational services are offered and utilized by participants of the value chain.*

The second takeaway is the lack of definition of Q4.0. As is the case with I4.0, the concept of Q4.0 is quite novel and open to interpretation. However, Radziwill (2018) and Jacob (2017) have identified some misconceptions of Q4.0 such as:

- Q4.0 is the same as IIoT and is all about technology
- Q4.0 is only about creativity, teamwork and innovation
- Q4.0 is the implementation of an Enterprise Quality Management Software (EQMS)
- Q4.0 is the smart factory
- Q4.0 is separate from traditional quality
- Q4.0 is the responsibility of only IT

The third takeaway is the lack of clear steps or a roadmap which organizations can use to transition to Q4.0. Existing models related to Q4.0 consider that an I4.0 strategy is already in place and address issues from a manufacturing perspective but not from an organizational perspective.

The final takeaway is related to the concept of Quality. Within the context of I4.0 it has changed and is currently integrated with other concepts such as innovation and co-creation. The authors of this thesis propose Q4.0 as the next phase in this evolution, as illustrated in Table 5.

Table 5. Evolution of quality to Q4.0 (developed by the authors based on the literature)

Phase	Quality Control (QC)	Quality Assurance (QA)	Total Quality Management (TQM)	Quality 4.0 (Q4.0)
Scope	Product	QC, processes	QA, organization, people	TQM, systems, stakeholders
Meaning of quality	Inspection	Design	Empowerment	Innovation
Features	Product specifications, statistical process control and variation. Correction	Built-in process quality. Process performance and metrics. Prevention	Organizational goals linked to metrics. Quality as a strategic imperative. Continuous improvement	Suppliers, customers and society are integrated. Focus on data and how digital tools provide new and timely insights

Q4.0 is grounded in TQM, but it goes beyond and includes all the stakeholders and also the systems needed for the data flow. Quality in the context of I4.0 is more related to value creation, organizational learning, organizational innovation, sustainability and discovery of data that brings new insights (Lee, 2015; Radziwill, 2018; Fundin et al., 2018). The integration of suppliers, customers and society as co-creators of products and services provides new opportunities for organizations to source data that provides valuable insights more effectively.

It is clear that the term I4.0 involves many other concepts, some of them are presented in Figure 6.

Figure 6. Terms related to I4.0

3. Methodology

This chapter explains how the study has been conducted in terms of research strategy, design and methods.

3.1. Research Process

The general research process used for this study is depicted in Figure 7.

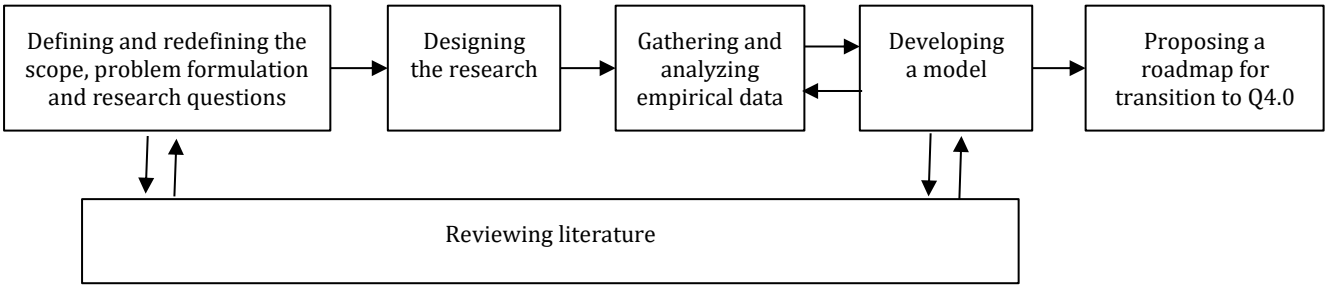

Figure 7. Research process

The scope, problem formulation and research questions were defined in the first place, with help from the theory and developed together with the company representatives. After this, the research was designed to define the research methods and to structure a way to gather the empirical data. Then, data analysis was used to develop a model, with input from theory. Finally, a roadmap for transition to Q4.0 was proposed. The project was developed in 32 weeks and the activities performed are shown in Figure 8.

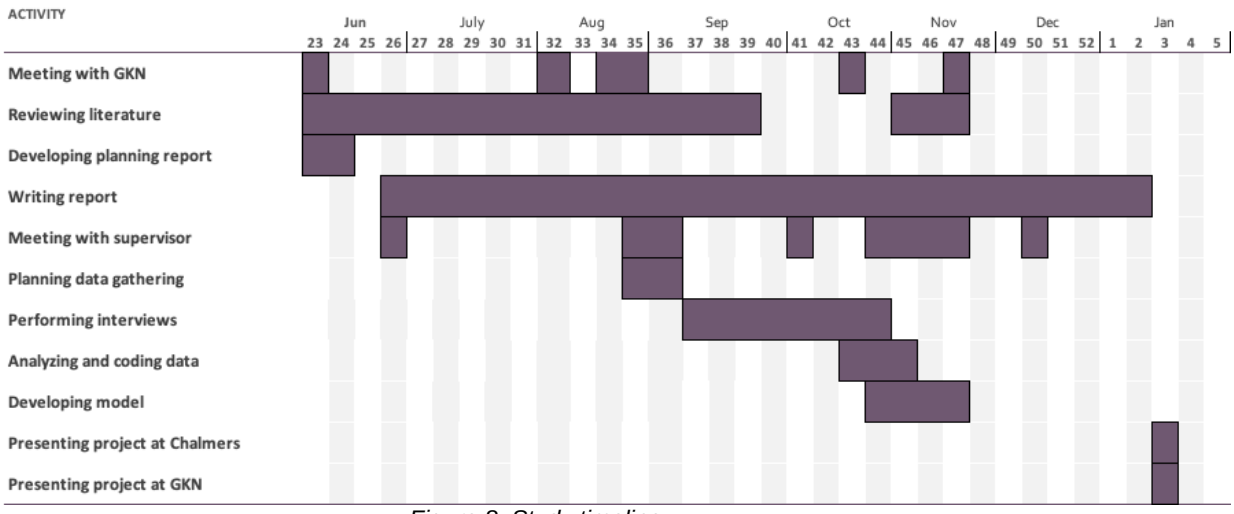

Figure 8. Study timeline

3.2. Research design

This study has been realized under a qualitative research strategy with a case study design and an abductive approach, to answer the research questions.

The starting point was a practical need from organizations regarding how to work with quality in the context of I4.0, that led to scientific inquiry. Since there is no published research about the perception of Q4.0 in the organizations and neither theory about how the organization should transition to Q4.0, a qualitative research design was chosen Astalin (2013) argues that a qualitative research design covers a wide variety of methods and is highly flexible compared to other techniques. It can help to decide on how to collect descriptive data, how to include people's own words and how the data should be analyzed (Taylor, Bogdan and DeVault, 2016).

Yin (2015) defines a case study as an empirical inquiry that investigates, in-depth and within its real-world context, a phenomenon or case. It relies on multiple sources of evidence, where data converges and benefits from the prior development of theoretical propositions to guide data collection and analysis. This study was conducted as a case study and was implemented using a qualitative research strategy. A case study design should be chosen if the research questions seek to explain some present circumstances and require an in-depth description of a phenomenon, which was the case with the organizations included in this study (Yin, 2015).

The abductive approach was a suitable strategy for this thesis because it refers to the researcher's understanding and description of the world from the perspective of the participants in the study. The theoretical account is then grounded in the worldview of those researched (Bryman, 2012). Dubois and Gadde (2002) argue that by this approach there is a simultaneous evolution of a theoretical framework, an empirical fieldwork and case analysis. For this work, the abductive approach helped in formulating the problem and developing the research questions, based on the practical needs of the organizations that led to scientific inquiry.

Interviews were used to gather empirical data for the development of a roadmap for transition to Q4.0 that was finally enriched with theory.

3.3. Participants in the study

This study started with a mutual work agreement of the authors with the Engine Systems Division at GKN Aerospace. Physical space for the study was assigned by GKN Aerospace Sweden, which is part of the Engine Systems Division, at the facility in Trollhättan, Sweden. The Engine Systems division has a revenue of $1500 MUSD, with 13 sites in 6 countries, employing about 4000 people. The facility in Trollhättan was founded in 1930 as Nohab Flygmotorfabriker and became Svenska Flygmotor Aktiebolaget in 1941 when AB Volvo acquired the majority of the stock. It was once again renamed Volvo Aero Corporation in 1994 until GKN acquired the company in 2012. Today, this facility has around 2200

employees and focuses on the manufacturing of components for civil aircraft, engine products and space and military engines (GKN, 2018).

GKN has been growing as an organization by completing a series of acquisitions all around the world. The company has been working with I4.0 and digitalization during the past years and due to recent organizational restructuration, this topic has been considered very important for the future of the company. Recent internal initiatives aim to include a new concept of process excellence and high quality, but how quality work will be affected with digitalization has been a topic for investigation. Q4.0 is then an interesting and highly relevant concept to be studied.

Other Swedish companies that had already started different I4.0 projects also contributed to this study. Their experiences and knowledge within I4.0 led to a broader understanding of best practices for transitioning to Q4.0. University professors and researchers working on the themes related to quality and digitalization were also interviewed to gather data about research trends on I4.0. The different organizations that participated in this study are shown in Table 6.

To gather relevant data from an organization, it is important to interview the right persons. The experience and participation of the interviewees in the development of I4.0 projects, as well the variety of respondents from different industries and positions within a company and their availability, gave way to valuable statements for chapter 4 that are relevant for this study.

3.4. Research method

Bryman and Bell (2015) define the research method as a technique used to collect data. For this work, semi-structured interviews were considered as a suitable method for gathering data. Waller, Farquharson and Dempsey (2016) argue that this kind of interview is guided by what the interviewee has to say instead for the interview questions, so it is to be considered more as a guided conversation. Semi-structured interviews provide access to data that is directly relevant to the purpose of the study, while simultaneously creating an opportunity for a deeper understanding of the context. Bryman (2012) argues that an interview guide can be designed but questions might not follow in that particular order. Additional questions might be asked as the interviewer receives more data from the interviewee, but all original questions on the guide should be asked.

Non-probability purposive and volunteer sampling techniques were used (Saunders, Lewis and Thornhill, 2016) for selecting interviewees that could provide relevant data about practices for the implementation of I4.0 and its perceived effect on quality and Q4.0. The interviewees' selection was based on their position within the company, availability, willingness to share information and relevance of their position within the company regarding experience and participation in digitalization, Quality, Q4.0 and I4.0 initiatives, which was considered

The interviewees were selected considering their expertise in quality, I4.0 and digitalization. For this work, 12 people at GKN were interviewed. 6 people from other Swedish companies that are currently working with I4.0 projects were also interviewed. Finally, 6 university professors and researchers working on themes related to quality and digitalization were interviewed. These interviewees from other companies and researchers were selected by snowballing, being referred by other interviewees. The interviews are presented in Table 6.

Table 6. Interviews

Interview	Company	Position	Type of business	Duration	Date
1	SIQ	Research	Consultancy	90 min	10-09-2019
2	GKN	Strategy	Manufacturing	60 min	11-09-2019
3	GKN	Innovation	Manufacturing	90 min	11-09-2019
4	Parker	Production Development	Manufacturing	90 min	11-09-2019
5	Parker	Quality and Environment	Manufacturing	90 min	11-09-2019
6	Chalmers University of Technology	Research	Research	60 min	16-09-2019
7	Volvo CE	Quality and Safety	Manufacturing	90 min	18-09-2019
8	Alfa Laval	Smart Manufacturing	Manufacturing	90 min	18-09-2019
9	GKN	Zero Defects Initiative	Manufacturing	60 min	19-09-2019
10	GKN	Data Science	Manufacturing	60 min	19-09-2019
11	University West	Research	Research	60 min	25-09-2019
12	GKN	Quality	Manufacturing	90 min	24-09-2019
13	GKN	Quality	Manufacturing	90 min	24-09-2019
14	GKN	Quality	Manufacturing	90 min	24-09-2019
15	ABC	Digital Strategy	Service	90 min	27-09-2019
16	GKN	Trainee	Manufacturing	60 min	30-09-2019
17	GKN	Infomation Technology	Manufacturing	90 min	08-10-2019
18	GKN	Industry 4.0	Manufacturing	90 min	11-10-2019
19	Sustainable Innovation	Research	Consultancy	90 min	11-10-2019
20	GKN	Systems architecture	Manufacturing	90 min	17-10-2019
21	GKN	Systems architecture	Manufacturing	90 min	17-10-2019
22	Chalmers University of Technology	Research	Research	60 min	18-10-2019
23	LSN	Research	Consultancy	45 min	23-10-2019
24	SKF	Quality	Manufacturing	60 min	29-10-2019

The questions for the semi-structured interview guide were:

1. *Are you familiar with the terms I4.0 and Q4.0? How have you acquired this information?*
2. *Have you been involved in projects related to digitalization and I4.0?*
3. *Why does your organization want to implement I4.0?*
4. *What would a company think about when starting with I4.0 regarding quality? Who should be involved? What is important to move forward?*
5. *How did the company start with I 4.0 and Q4.0? Where is the company in this transition?*
6. *Are there any special investments required in terms of infrastructure, skills and competences?*
7. *Would you know when a company knows that I4.0/Q4.0 is fully implemented?*
8. *What would the company gain from implementing Q4.0?*

The interview questions were tested in two rounds with the participation of the thesis supervisor and the company representatives. The interaction between both interviewers during the interview was discussed and prepared before the interview. When requested, the questions were sent in advance to the interviewees by email. The physical space for the interviews was decided with the interviewee and booked in advance.
All interviews were completed within eight weeks to facilitate answers being compared within a reasonable timespan. The interviews were performed by two interviewers and conducted in person, by audio link or by telephone. The interviews were digitally recorded when allowed by the interviewee and were between 45 and 90 minutes in length. One of the interviewers was in charge of leading the interview while the other took notes. Both interviewers were able to ask questions when considered relevant during the interview.

The understanding of Q4.0 in the organizations was gathered by asking the interviewees if they knew about this concept. Follow-up questions were asked when the interviewees were aware of the term Q4.0 to get an in-depth understanding of the concept. Every interview was transcribed within 24 hours and complemented with relevant annotations from the interviewers.

3.5. Data analysis

Answers to the question 1 in the interview guide were aggregated from all respondents. Common denominators of understanding the concept of Q4.0 were identified, which allowed to define the understanding of Q4.0 as perceived by the organizations. The definition was verified in light of the existing literature.

For the development of a roadmap for transition to Q4.0, process coding was used to imply actions through time that can become strategically implemented. SaldaÑa (2016) argues that in qualitative research a code can be a phrase or word that symbolically assigns an attribute for a portion of language based on the data. Codifying is the process of applying a code to qualitative data in order to divide, group, (re)organize and link data and posterior development of an explanation. Each researcher individually analyzed and coded the empirical data from the interviews. Then, the common codes were agreed by consensus and provided a basis for the development of the elements for a roadmap for transition to Q4.0. As part of the abductive approach for this work, theory helped to provide a name for the codes which gave way for developing the names for the phases and steps for the roadmap.

3.6. Ethical aspects

From an ethical perspective, Bryman and Bell (2015) argue that four areas should be kept in mind when involving people in studies: Harm to participants, lack of informed consent, invasion of privacy, and deception. It was truly important that the gathered data from the interviews could not be traced back to the interviewees if they decided to remain anonymous.

The participants were informed about the research goals, the methods, and the purpose of the study. Thereafter, they chose whether they wanted to participate or not. If they agreed to participate in the interview, then they were asked whether they wanted to remain anonymous or not and how the data gathered would be stored and handled. The participants were also informed that they were free to stop the interview at any time if they wished to and secrecy issues were again discussed after the interview. These measures were taken to provide an environment in which participants could be more truthful in their answers, and in return helped to achieve more valid results (Landström and Palmås, 2019) .

The participants were protected from sensitive information being leaked or other possible scenarios that may threaten the participant's integrity by storing the data in a local computer, with access only from the two interviewers and without sharing it with third parts.

3.7. Research quality

Elements of research quality considered for this work were credibility, transferability, dependability and confirmability which are the elements of trustworthiness (Halldorsson and Aastrup, 2003).

3.7.1. Credibility

Halldorsson and Aastrup (2003) argue that credibility is parallel to internal validity and refers to which degree the participant's constructions of reality are matched to the researcher's representation of these. The researcher proposes a picture of the reality and the participants play a role in correcting it. Bryman and Bell (2015) argue that internal validity aims to understand if conclusions regarding relationships of two or more variables truly have the connection concluded or if there are other variables affecting the output.

All the interviewees were experts in their field and played an active role in verifying the validity of the conclusions proposed by the researchers. Since people from other companies and researchers were also interviewed, it could be argued that different perspectives were compared and thus triangulation of sources was made. The results of the study were discussed with members of two organizations that work with quality and one researcher working on I4.0, which provided feedback to make changes to the roadmap.

3.7.2. Transferability

This element is the extent to which the research can make general claims about the world and is related to the concept of external validity (Halldorsson and Aastrup, 2003). Bryman and Bell (2015) argue that external validity aims to understand if findings are general and applicable to a wider range or specific to a particular research study. To generalize it is important to consider the context of the research and how changes in space and time can affect it.

For this study, the research setting was described and the data collection explained in detail. This research tried to gather the best practices for the organization to transition to Q4.0. Since these best practices were grouped, defined and described it can be argued that the applicability of the roadmap in different contexts is determined by the reader when analyzing its similarities in a specific situation. The roadmap could then be applied to different types of industries. It was intended for the roadmap developed to be as general as possible and to accomplish this, data was gathered from people working at different positions in different organizations and within a short timeframe.

3.7.3. Dependability

Halldorsson and Aastrup (2003) argue that dependability is related to reliability. Bryman and Bell (2015) argue that reliability addresses if the results of a study are repeatable and concerns whether data is stable or not over time. Any change done to the methodology can have an effect over it.

All the interviewees had roles connected to the research topic and were aware of concepts such as digitalization, quality and I4.0. The selection of these persons had an important role in the dependability of this study. All interviewees were approached with the same base questions as part of the semi-structured interview. Therefore, if these persons would be interviewed again within a short timeframe from this thesis, the result of the interviews would likely be similar. However, this study was made at a certain point in time and new developments might happen at the interviewed organizations. Moreover, the subject is still under research and novel concepts can emerge and be discussed when doing new interviews.

3.7.4. Confirmability

Confirmability is parallel to objectivity (Halldorsson and Aastrup, 2003). This aspect or the quality research examines if the findings of the research do represent the results of the inquiry and not the researcher's biases, meaning that the findings can be confirmed through the data itself.

The process of data gathering and analysis was defined and explained. Interview questions were developed to gather data relevant to the research and coding was used to develop a base for the phases and steps of a roadmap for transition to Q4.0. The proposed roadmap was presented to the company representatives and a researcher within the field of I4.0, who asserted the results of the study.

4. Findings

This chapter will present the findings from the interviews with the experts presented in table 6 and the development of a roadmap for transition to Q4.0 based on the empirical data.

4.1. Awareness of Q4.0 by the organizations

All the interviewees had at least a basic understanding of the term I4.0 before the interviews. Some pointed out a connection between I4.0 and digitalization projects that had already been completed or set in motion in different areas of the organization. Meanwhile, Q4.0 is a term that only three interviewees from GKN were familiar with and had a basic knowledge about, but all the interviewees still managed to link Q4.0 as part of I4.0.

Interestingly, the interviewees argued that I4.0 and Q4.0 are just names that should transcend and go beyond being labels. I4.0 is considered by some interviewees as a label for a trend that could be over within a short period of time. They also agreed that the importance of digitalization will still increase and since it is connected to industry development, it cannot be stopped. All the interviewees agreed that it is important to not follow the I4.0 trend blindly, but to understand the financial value of digitalization itself and how it can be used for organizational improvements.

However, the interviewees considered that many organizations are still waiting for a clear definition of both I4.0 and Q4.0 to lead organizational transformation and this may be a reason why not too many companies have moved forward with I4.0 projects. Organizations expect these definitions to come from universities or from other companies that are willing to invest in I4.0 and lead this transformation.

4.2. A roadmap for transition to Q4.0

Five phases were identified from the empirical data. Steps for the roadmap were developed based on the coding.

4.2.1. Assessing the readiness level

Before pursuing Q4.0, all interviewees put emphasis on the fact that the organization should evaluate itself and understand the implications of the development of I4.0 projects. Building a base to start the transition to Q4.0 is the subject of this phase.

Assess the I4.0 maturity level

It is important to not jump directly into the implementation of digital solutions as part of the development of I4.0 projects. All interviewees argued that organizations must have a baseline for starting the implementation and this can be done by assessing the level of digital maturity.

Interviewees argued in general that to support the development of I4.0 projects, it is important to measure the I4.0 maturity level of processes, infrastructure and competences in the organization, among others. By measuring, it is then possible to detect the needs of the organization and create an action plan. To fill the gaps, it might be necessary to support systems, acquire technology or increase knowledge by developing competences. Interviewees were also aware of the need for external competences before I4.0 initiatives are implemented. Competences such as data analysis, continuous improvement, process thinking and customer perspective are important for transitioning to Q4.0. It is important to define the needs for competence development in the organization to increase the maturity level. For the interviewees, digital maturity was closely related to organizational culture.

Assess the stability of processes and data flows

The stability of processes and flows within the organization is vital when working on a strategy, both long- and short-term according to half the interviewees. There seems to be a consensus among interviewees that an organization should address issues with deliveries, quality and internal reorganization before developing a strategy of digitalization, automation or I4.0, which must be connected to the organization's goals. The interviewees also argued that processes should then be understood, stable and documented before organizations should even consider doing big changes, which is the case with I4.0 and Q4.0.

Lean thinking, Six Sigma and traditional TQM features reflected in the ISO 9001:2015 standard was mentioned as a good basis before starting with I4.0 projects. I4.0 and the use of digital tools were also said to help stabilize and develop robust processes allowing built-in quality for the product and the possibility to apply changes more easily. Standardization of processes was mentioned by the interviewees as important before starting I4.0 projects at multi-site companies. However, companies with sites in different countries argued that different cultures and different levels of digitalization bring challenges for standardization. Sometimes, companies must keep some processes functioning in one site only to be compatible with other sites that still work with more manual operations.

All interviewees argued that organizations with different facilities could have different I4.0 maturity levels and then it is important to consider this before standardizing processes and implementing digital tools across the whole organization.

Monitor regulations and standards

Half of the interviewees argued that companies should have a constant monitoring of the local, regional and international regulations and standards that could affect the operations of the organization. The interviewees emphasized that with digitalization and automation, regulations are expected to change and adapt to the use of digital tools and even the use of new techniques could be adapted to new regulations. General Data Protection Regulation (GDPR) is one example of a regulation that aims to protect the integrity of users of systems and platforms. Another example is that new regulations for the use of robotics in a production line will be important to guarantee that the humans that interact with machines are protected and have a proper work environment.

4.2.2. Setting up

Once the needs and gaps within an organization are identified for the development of I4.0 projects, interviews argued the next phase comprehends what should be done for making the transition towards Q4.0.

Align strategy to I4.0

Interviews argued in general that members of the organization should agree upon the expected benefits of I4.0 for the company. However, only half of the interviewees considered having adequate strategies for I4.0 in their organizations. This shortcoming creates uncertainty on the direction that the organization may take in the context of I4.0 and how investments should be handled. Most interviewees agreed that an understood vision with short-term goals is important for developing a strategy for I4.0.

All interviewees argued that reasons for implementing I4.0 are different for every organization due to their activity and business lines and it can go from achieving benefits in terms of better quality, improved flexibility, increased productivity and system integration to lowering costs, increased competitiveness and increased profit margins. Organizations could also become more flexible to compete and could have a first-mover advantage. For this to happen, interviewees argued that the organization should align its strategy to I4.0 and every member must be aware of what I4.0 techniques can provide, to do a better job and improve continuously.

Sustainability was mentioned by all interviewees as an important topic to think about in the context of I4.0. The circular economy-thinking should be embedded within I4.0, bringing new possibilities to plan strategy from the integration of People, Planet and Profit within the operations of the organization.

Develop business cases and secure management support

When the organization starts to consider the transition to Q4.0, it must assess the possibilities of new techniques and how these could help to improve operations within the company. Still, interviewees in general considered difficult for the upper management levels of the company to see how these initiatives can

generate benefits. How these solutions help people to solve a problem and create value for the whole organization should be a prime concern for developing a business case. Management awareness and participation in I4.0 projects are important to secure that there is a consistent level of understanding throughout the organization, that all its members see the implications and value of digitalization and that resources can be allocated.

Building business cases for I4.0 projects is a good practice according to the all interviewees. These are key for receiving adequate funding and allocate resources, involving financial benefits for the organization that can be shown to management. Considering the cost of implementation, expected profit and timeframes allow companies to better develop I4.0 strategies and allocate resources. The interviewees agreed in general upon the fact that people from different units within the organization must be involved in I4.0 projects and that cross-functionality is an important concept for successful project implementation. By using business cases, management should assign responsibilities to different projects. Virtually all the areas in a company work with some digital tools today, so digitalization should not be the responsibility of only one function in an organization.

When developing business cases, small dedicated teams could more effectively handle I4.0 projects and achieve fast results. Pilot projects with defined responsibilities, short-term goals and specific hypothesis testing, could allow this specialized team to focus on fast gains and to minimize the impact of projects in other areas of the organization. Most of the interviewees agree upon the iterative nature of I4.0 initiatives, so starting with simpler tools to test routines first and then make those more effective could be a good way to start. The interviewees argued in general that starting I4.0 projects with big demands and scope requires large amounts of resources and time, which may negatively impact or lead to neglect in other areas of the organization. Also, implementing the same solution at different sites of the same organization and at the same time, could be very complex.

All interviewees argued that small teams are related to an agile approach to handle risks better and have a customer focus through the whole implementation, which creates fast gains to show success. In parallel, it is important to group the current I4.0 projects developed through different areas of the organization, avoiding working in silos. The interviewees argued that by making these changes to the work environment, knowledge sharing has improved.

The importance to gather all I4.0 projects that are being developed at different locations and levels throughout the organization, to learn from each other and avoiding working on the same solutions at the same time was highlighted by the interviewees in general. I4.0 is then seen as a concept that identifies, groups and connects the different digitalization projects within the organization which is of particular interest since many organizations already use techniques that have been around for decades such as use of sensors, robotics and connectivity between machines.

Some of the interviewees that have worked with I4.0 initiatives for the past years agree that the organization must make a decision about ending pilot projects and start to implement solutions. This is particularly related to the conservative nature of some organizations where in many cases potential changes need to be challenged, documented and tested through several rigorous and expensive tests before potential implementation. This extensive process could limit the ability to test new ideas and new ways of working as they come up. From the interviews, it became clear that a success factor in previous I4.0 initiatives was that people took it upon themselves to question the established way of working, followed by suggesting new ways to solve their tasks with current technology to improve efficiency and quality of their work. It is also suggested that having an innovative environment to share ideas and facilitate knowledge transfer is important when developing I4.0 projects. Interviewees emphasized the fact that change usually does not come from a top-down approach but rather a bottom-up approach.

The development of business cases could be difficult if the internal competencies are not yet developed. Commonly, consultancy firms are hired to perform certain functions within the company to fill the gaps. Consultants could also be appointed for training members of the organization in digitalization, automation and I4.0.

Anticipate changes

Trying to anticipate changes when implementing new technologies was mentioned as highly relevant by all the interviewees. How to deal with uncertainty and anxiety should be managed accordingly to have organizational ambidexterity. This is of special importance since all the interviewees argued that no one knows for certain the consequences of digitalization on sustainability, employment and quality.

All Interviewees from organizations with I4.0-related strategies consider themselves halfway in the journey at some sites. Most companies have different facilities in different countries, with different cultures and different levels of technology utilization, where the levels of standardization and digitalization vary. The interviewees agreed in general that these differences must be addressed beforehand. This is considered important to see common benefits for all sites.

The nature of the organization is important to be considered when making changes within. Some organizations are more traditional than others and this conservative nature could hinder innovation and limit growth.

Four interviewees consider trade unions and social organizations as important stakeholders to include when managing change, because of their competences in regulations and standards. Many competences might not be relevant and people affected would need to accept change, learn new things and adapt. Showing benefits from previous projects can help employees to see the benefits of I4.0 for themselves lowering anxiety and encouraging curiosity.

Manage knowledge

I4.0 projects bring a new level of knowledge that should be integrated into the organization. Companies have been starting I4.0 projects with the help of consultancy firms for support in some areas such as systems support, digitalization, automation and programming, but the knowledge is not transferred into the organization. Organizations should have routines and processes that manage to capture and keep the knowledge within the organization after the consultants leave.

In the majority of the organizations, it was also common that enthusiastic people developed and implemented smart solutions for a specific problem. However, those were not documented nor explained. In some cases, people were unknowingly solving the same problem at different times or even those solutions were very difficult to integrate with other systems and processes. This brought some problems related to standardization, time waste, resource waste and non-value adding operations. It is then important for an organization to document and reuse the knowledge acquired through the development of I4.0 projects, to learn from past experiences and be more effective when implementing new techniques. Knowledge transfer and knowledge management in these cases should be addressed to guarantee that the organization creates knowledge and learn.

4.2.3. Involving stakeholders and systems

All interviewees argued that products can gather vast amounts of data due to built-in sensors and wireless connections, where customers could provide that data for their suppliers to be used for quality work. It is then important to work closely with suppliers and customers to understand their needs and expectations and to integrate these from the start when developing I4.0 projects. Internal customers will be important for identifying needs within the organization and propose new ways to do more effective work.

The organizations must have an understanding of the market in which they operate and be aware of their competitors, suppliers and customers. Governmental subsidies and fast-changing regulations might be useful in promoting digitalization. It is crucial that in an I4.0 context, organizations start thinking about networks and the needs, expectations and I4.0 maturity levels of the stakeholders.

Address changing roles and competences

The interviewees in general argued that digital transformation is an ongoing iterative process somehow embedded in human evolution. I4.0 and digital transformation increase automation which could lead to machines being less supervised. It is a concern for the organization to consider the role of the members of the organization in the context of I4.0, by example how the operators should act when automated processes fail. All the interviewees agreed upon the importance of integrating both the human being and the environment with the implementation of new techniques in I4.0 projects.

The role of different members of the organization will have to change as machines and processes become increasingly connected, automated and complex. One example for a future scenario is that an operator should have a higher level of understanding about how the machine works and develop creative ways to use the new techniques. A risk with this could be that there is an increased amount of technology and fewer humans, making that organizations lose the high level of competences and know-how of the operators. Since competence development is an important part of any quality improvement, the organization should design a development plan that emphasizes increasing the ability of humans to adapt and to self-organize work to generate value in an I4.0 environment. All of the interviewees agree with the need for creative and innovative people that think outside the box, trying to test new solutions for doing a better job.

Customer perspective and process improvement are the most relevant competences for quality professionals in the context of I4.0. For Q4.0, the quality department is expected to participate by setting demands and targets for digital solutions and coach the other members of the organization during the implementation of new technologies with fundamentals of process thinking, standardization, systems thinking and continuous improvement.

Involve suppliers

All interviewees argued that suppliers will handle new specifications, requirements and demands that come from new and improved digitalized processes of their customers. However, they might not have the knowledge or capabilities in place to handle such change. If that is the case, organizations must work together with their suppliers when implementing new solutions and consider also their needs and expectations for digital development. This is particularly important when there is only one supplier of a specific material or service and the organization must work with it, independently of its willingness to change and adapt.

Co-creation was mentioned by the interviewees as a good possibility to have a deeper understanding of how technologies could be used for continuous improvement. When both suppliers and customers work together to create value, resources are used in a more efficient way.

Involve customers

Considering and agreeing upon the needs and expectations of the customers, both internal and external, should be the first step for making changes to the process and products, as with any quality initiative. Interviewees agree that customers are in some cases the key drivers for developing I4.0 projects, demanding to their suppliers to adapt and provide new digital solutions to increase efficiency and productivity. If the organization is not able to do this, the whole business relationship could be endangered. Furthermore, organizations need to evaluate if it is worth that new techniques are implemented for a process since high technology investments for some products might not be profitable.

Digital and effective solutions should be implemented for lowering costs and achieving higher quality for the customer, but at the same time companies seek to increase profit margins and invest in research and development. One interviewee argued that when changing processes and products through increased digitalization, a company might need to deliver products from both the old and new production systems, which actually could lead to increased costs for a short period. There is also a risk for the organization to be forced to change systems to be aligned with its customers or vice versa.

Improve the interoperability of systems

I4.0 is in many cases directly related to changes in manufacturing, but the organization could miss the benefits that digitalization could generate between departments, as well as its contribution to cross-functionality. Relationship between areas like research and development, logistics and sales and how changes in one process will affect others, bring new possibilities for implementing digital tools. Interviewees argued that these relationships and systems view is important to define how different data systems must interact with each other to gather all necessary information that contributes to solving a problem.

Systems integration was related to the digitalization of quality, where Interviewees agree upon the potential of working towards predictive quality. However, work needs to be done about understanding what data is needed, for whom and how the data will be shared, before developing a system with trend analysis and warnings, for example. Interviewees from companies that have experience with I4.0 argue that predictive maintenance and the possibility for customers to gather data might increase customer satisfaction levels and contribute to precise deliveries.

4.2.4. Creating value

All the interviewees agreed that the organization must not invest in I4.0 just for the sake of it, for being a trend or because competitors do it. It is relevant to consider the value that can be created for the stakeholders. This is also in line with reducing costs and minimizing waste, increasing efficiency and productivity by focusing on what is truly important for the organization.

The organization needs to consider which processes, flows, activities or routines should be improved to create value. Knowing which stakeholders the company wants to deliver value to and which digital tools need to be used are vital for developing the I4.0 strategy.

4.2.5. Managing data

For all the interviewees, the main challenge for digitalization is to manage and understand the data gathered. New knowledge and competencies are required to provide an understanding of the possibilities that data brings for Q4.0. Data security and data management are mentioned by all the interviewees as very important since too much data could be accumulated for analysis and, in many

cases, data is underutilized. Organizations will have to prioritize which data to analyze and store because large costs can be connected to data storage and securing data quality. In the future, companies will put more emphasis on the master data and since machines and people will base fast decisions on data, the quality of data is important to consider when developing I4.0 projects.

To manage data, new competencies are needed today such as systems integration, connectivity, automation and cybersecurity. Other relevant technical competences for managing data mentioned by the interviewees, were connectivity, machinery, data storage, database administration, programming and data science. Infrastructure for storing, analyzing, protecting and managing data was a prime concern for all the interviewees when implementing I4.0 technologies. Interviewees agreed that access to different digital techniques is easier today, but how to use these in practical cases to deliver useful data to somebody is more important.

The connection and interconnection of machines are quite demanding and ideally data gathered could be analyzed with the same code and same infrastructure, but the reality is different. Interviewees argue that structure for data analysis and clarity about the benefits of using data must be in place. A lot of data can be gathered from modern machines. However, since data quality is not always optimal, it has to be cleaned and filtered before it can be analyzed and eventually present clear information for different stakeholders. For all the interviewees, it is important to analyze data to deliver the right insights for people to do their work better.

Increased digitalization and the use of new techniques could represent new risks related to cybersecurity. Interviewees agreed upon the fact that cybersecurity has not been addressed properly by many organizations although it becomes truly important when the data that is gathered represents a competitive advantage and might be confidential. Cybersecurity could be unclear for some members of the organization according to the interviewees, where people might think that data is only secured with physical barriers. Awareness of the risks of gathering, storing and sharing data must be included in the competence develop

4.2.6. Phases and steps for a roadmap

Table 7 resumes the phases and steps developed (as seen in 3.5) from the empirical data and explained in this chapter.

Table 7. Phases and steps from the empirical data

Phase	Steps
Assessing the readiness level	Assess the I4.0 maturity level Assess the stability of processes and data flows Monitor regulations and standards
Setting up	Align strategy to I4.0 Develop business cases and secure management support Anticipate changes Manage knowledge
Involving other stakeholders and systems	Address changing roles and competences Involve suppliers Involve customers Improve the interoperability of systems
Creating value	No steps for this phase
Managing data	No steps for this phase

5 phases and 11 steps were derived from the empirical data. These reflect the findings from the empirical data, provided by the experts that were interviewed for this study.

5. Results

This chapter will present a definition of Q4.0 and a roadmap for transition to Q4.0 and discussing its strengths and limitations.

5.1. Quality 4.0 definition

The lack of a definition of the concept of Q4.0 was related to the lack of awareness of this concept by the organizations, presented in chapter 4. To give ground to the roadmap developed in this study, the authors propose the following definition for Q4.0:

> *Quality 4.0 refers to the digitalization of Total Quality Management and its impact on quality technology, processes and people. It builds upon traditional quality tools and considers also connectedness, intelligence and automation for improving performance and making timely data-driven decisions in an end to end scenario, involving all the stakeholders and providing visibility and transparency.*

Q4.0 could be considered as the next phase in the evolution of quality, as presented in Table 5. In the context of I4.0, quality is related to organizational innovation and the discovery of data that brings new insights, creates value, contributes to organizational learning and sustainability (Lee, 2015; Radziwill, 2018; Fundin et al., 2018). One possible benefit of Q.4.0 is predictive quality, where the organization would know from the start exactly how the outcome of the product or service will be

5.2. A roadmap for transition to Q4.0

The phases and steps for the roadmap are resumed in Table 8.

Table 8. Phases and steps for the roadmap

Phase	Steps	Source of the findings
Assessing the readiness level	Assess the I4.0 maturity level Assess the stability of processes and data flows Monitor regulations and standards	Empirical data and theory Empirical data and theory Empirical data
Setting up	Align strategy to I4.0 Develop business cases and secure management support Anticipate changes Manage knowledge	Empirical data and theory Empirical data and theory Empirical data and theory Empirical data and theory
Involving other stakeholders and systems	Address changing roles and competences Involve suppliers Involve customers Improve the interoperability of systems	Empirical data and theory Empirical data and theory Empirical data and theory Empirical data
Finding new ways to deliver insights	No steps for this phase	Theory
Creating value	No steps for this phase	Empirical data and theory
Managing data	No steps for this phase	Empirical data and theory

As part of the abductive approach taken for this work, the theory presented in chapter 2 and the empirical findings presented in chapter 4 were integrated together. This resulted in an extra phase for the roadmap named "*finding new ways to deliver insights",* giving place to 6 phases and 11 steps for the roadmap. Sources of the findings are also presented in Table 8, being empirical data and/or theory. A graphical representation of a roadmap for transition to Q4.0 is shown in Figure 9.

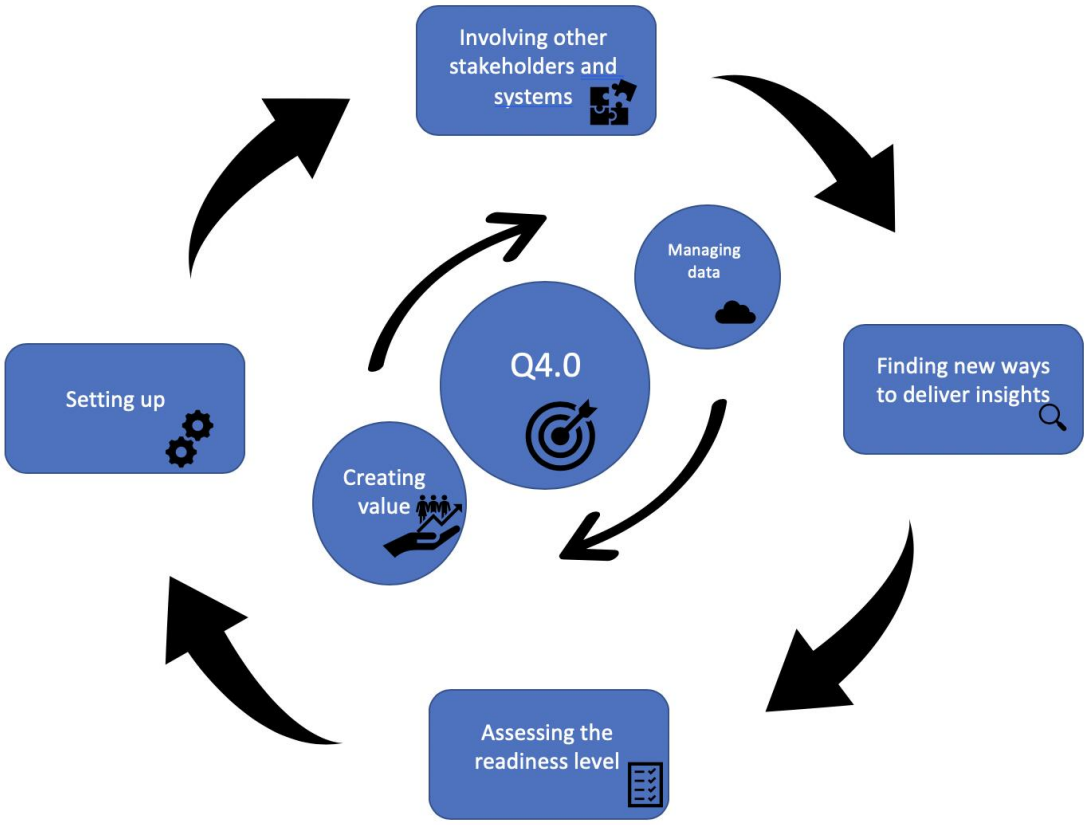

Figure 9. A roadmap for transition to Q4.0

Organizations should start their transition to Q4.0 with the first phase of the roadmap which is assessing the readiness level and consists of three steps: Assess the I4.0 maturity level, assess the stability of processes and data flows, monitor regulations and standards. The second phase is setting up and it comprehends four steps: Align strategy to I4.0, develop business cases and secure management support, anticipate changes, manage knowledge. The third phase of the roadmap is involving other stakeholders and systems and consists of four steps: Address changing roles and competences, involve suppliers, involve customers, improve the interoperability of systems. The fourth phase is finding new ways to deliver insights which closes the cycle, in line with continuous improvement and TQM tools such as the PDCA cycle.

The last two phases are creating value and managing data. These continuously overlap with the previous four phases and should be considered when the organization is working in every phase. All phases and steps will be explained in this chapter.

5.2.1. Assessing readiness

The first phase in the roadmap is to assess the readiness of the organization for its transition to Q4.0. The organization must first measure its I4.0 maturity level and then assess the stability of processes and flows. At the same time, it is

important for the organization to monitor new regulations and standards regarding data, automation and digitalization, among others.

Without assessing the readiness for transitioning to Q4.0, the organization risks to miss which aspects need to be improved before the development of I4.0 projects and how to prioritize and what to focus on. This phase was emphasized by all the interviewed organizations and consists of three steps, where two of them were related to the theory that can be applicable in the context of Q4.0.

Measure the I4.0 maturity level

By assessing the I4.0 maturity level, it is recommended for organizations to evaluate the ability of processes to consistently contribute to the achievement of the organizational objectives, which was the case in a practical setting. A study in Sweden (Antonsson, (2017) showed that the maturity level of I4.0 in organizations needs to be improved.

Organizations must assess their I4.0 maturity level before starting with digital transformation in order to understand weaknesses, strengths and gaps and identify opportunities for continuous improvement. Different I4.0 maturity models are available (Schumacher, Erol, and Sihn, 2016; Leineweber et al., 2018) but it is important that the organization uses a model it feels comfortable with and understands the full implications of its use. One practical example is when internal competences are not sufficient and then it is necessary to include consultants for training and for filling temporary functions in the organization.

Assess the stability of processes and data flows

Classic tools and programs related to quality such as TQM, Lean Six Sigma and Statistical Process Control are and will still be important when developing projects in the organization and to standardize material and data flows. Standardized processes, data flows and routines make the organization better suited to adapting new technologies, especially in the case of multi-site companies as processes and routines will be similar at all company sites.

Stability of processes and data flows is emphasized in Value Stream Mapping, tools that has recently been integrated into I4.0 to define both current and future states in digital environments, considering the flow of materials and information (Haschemi and Roessler, 2017). The Smart Value Stream Mapping proposed could be a good tool to assess how the processes and flows are in every operation.

Monitor regulations and standards

New legislation and standards related to protection of integrity and use of digital tools are currently developed and new ones will be in the future. Organizations must monitor and increase awareness about which new regulations at local, regional and international levels could affect the operations of the company. This

is of prime concern for companies that have different manufacturing sites in different countries or that sell their products in different geographical regions. Since regulations about the use of digital tools and automation are and will be developed depending on new technological advancements, there is no current theory about how to monitor these. This step was not included in the models related to Q4.0 presented in chapter 2.

5.2.2. Setting up

The second phase in the roadmap is to set up the organization for transitioning into Q4.0. The organization must align its strategy to I4.0 and develop business cases for every I4.0 project, contributing to securing management support. It is important to anticipate changes that might happen when implementing these projects in terms of routines and roles within the organization (Kotter and Schlesinger, 1979). A way to manage knowledge across the whole organization must be in place to secure continuous learning (Kotter, 1996).

The steps for this phase were derived from the empirical data and complemented with theory since it was shown that these were useful in a practical setting. This phase consists of four steps.

Align strategy to I4.0

Members of the organization must understand the meaning and implications of I4.0 and Q4.0 to their work (Aiken and Keller, 2009). They should be involved early when creating and developing a strategy to create engagement, get insights and gather points of view that help shape the direction of the organization. This can also contribute to lowering the anxiety. Geissbauer, Vedsø and Schrauf (2016) argue that strategy must be aligned in order to create change, which is the case when developing I4.0 projects.

Develop business cases and secure management support

Business cases are useful to show management the potential benefits for the organization, the value creation and awareness of the expected changes. Empirical data showed that an important part of a business case is to minimize the impact of a project for the whole organization. When developing I4.0 projects, setting up a small dedicated core group with short-term goals and short time frames is a good practice, to handle high variation and building knowledge clusters (Reiter et al., 2007).

Top management needs to guarantee that I4.0 means more than a short-term trend within the organization. I4.0 projects must contribute to improving data flows and this is a challenge for some traditional businesses where management is still related to organizational units and not about their interactions. I4.0 and Q4.0 will be imperative for a company to be competitive in the future so it will be a matter of survival for many organizations. Even if this kind of projects is relatively new, development of business cases proposed by Gambles (2017) can be used for I4.0 projects.

Anticipate changes

Changes in routines, processes and operations will take place when developing I4.0 projects, affecting people as well. It is then important for the organization to invest in competence development and allow people to detect the possibilities to be more effective in their work, thinking how digital tools provide new possibilities for doing that (Kotter and Schlesinger, 1979).

Manage knowledge

To manage knowledge is to secure that the knowledge acquired with the development of new projects, with the participation of internal and external actors, stays within the organization and is useful as input for new projects. Creating, acquiring and transferring knowledge are features of a learning organization, where continuous improvement is part of the company culture (Bergman and Klefsjö, 2010). This theory is applicable to the context of Q4.0, since any project development generates knowledge that should allow the organization to learn from past experiences. In the organizations, knowledge and data sharing can be used to avoid developing the same solutions or I4.0 projects more than once, avoiding unnecessary waste of time and resources.

5.2.3. Involving other stakeholders and systems

The third phase in the roadmap is to involve systems and stakeholders when transitioning into Q4.0. The organization must be aware of the needs and expectations from customers, suppliers and internal customers (Bergman and Klefsjö, 2010) and how those could be fulfilled with the help of I4.0 projects. Also, the interoperability of the systems inside and outside of the organization should be improved to facilitate data flows. By involving their stakeholders, organizations will find new data sources that are the basis for value generation.

The participation of stakeholders is considered important for any quality improvements within the organization, which will be the same case in the context of Q4.0. This phase consists of four steps.

Address changing roles and competences

People within the organization have needs and expectations and since their role will change with digitalization, the organization is responsible to develop their competences and ability to adapt and innovate. Internal customers must also have an adequate training, support and tools to be able to operate the new organization with adapted roles, which has been the subject of recent studies (WMF, 2019).

The role of quality professionals in the context of digitalization will change and adapt (Elg et al., 2018). Fundamentals of quality work will still be important such as systems thinking and continuous improvement, but the use of digital tools

requires to develop new competences for quality professionals. Cross functionality will be more common in future organizations.

Involve suppliers

Suppliers will have a more active role as co-creators and help organizations to develop innovative solutions. For this, it is important to have a close relationship with suppliers, where they are actively involved in the testing of new techniques and tools for changing certain processes and routines. It is also important for organizations to assess the risks of having one supplier in terms of feasibility, financial stability and licensing (Toivo, 2008), (Vainalis, 2012).

Involve customers

Q4.0 and I4.0 projects reveal changes to traditional organizational boundaries where customers take a more active role when developing their own products. The customer will no longer expect products, but also services, platforms and other support features (Birch-Jensen, 2018). More data will be available to detect the needs and expectations of the customers with the help of technologies such as sensors and AI. It will contribute to improve the flexibility of the operations and bring different levels of customization.

Improv the interoperability of systems

It is highly important to effectively manage data for quality work. Systems must be able to speak with each other and facilitate decisions based on facts. Having shared systems that interact with each other across different operations and sites and also between customers and suppliers contribute to standardizing and provides a way for better, timely analysis of data.

5.2.4. Finding new ways to deliver insights

The fourth phase in the roadmap is derived from theory and is related to innovation. The contents of this phase were not specifically mentioned during the interviews. The connection between quality and innovation has been proposed in recent studies (Lee, 2015; Watson, 2017; Watson et al., 2018; Fundin et al., 2018; Watson, 2019) and the opportunities for organizations to address this relationship are emerging.

Trott (2012) defines innovation as managing the activities related to the process of idea generation, development of technology, manufacturing and marketing of a new or improved product or process. In the context of Q4.0, innovation is related to finding new ways to deliver insights for continuous improvement of process and products. Lee (2015) argues that quality is no longer concerned to produce and sell according to specifications, but to organizational innovation as a strategic imperative. The participation of stakeholders will provide new modes of co-creation that create value for all involved. Innovation is then closely related to Q4.0, providing technologies that can contribute to continuous improvement. Digital tools presented in Figure 4, like Machine Learning, Big Data and Artificial

Intelligence can be used to analyze data in a more effective way, providing information in real-time that can be used to improve processes and build in quality for products across all locations.

5.2.5. Creating value

When new technologies are going to be implemented in different operations as part of I4.0 projects, the organization must consider if there is some value generated for stakeholders.

Creating value overlaps with all the other phases where value is created in each on of them . Theory that supports this phase can be related to Bergman and Klefsjö (2010) who argue that both TQM and Lean, focus on creating value for the customer and in increasing effectiveness and efficiency. However, they also argue that the boundaries between an organization and its customers and suppliers are less clear today. By involving both customers and suppliers as co-producers, value creating networks will be common in the future. It is then important for the organization to be aware of which processes, flows, activities and routines should be improved to create value for the stakeholders.

Radziwill (2018) argues that a value-based approach in new business models will bring benefits for transparency, security and trust. Value propositions presented in Table 2 are also included in this step to illustrate the value creation in a Q4.0 context, as shown in Table 9.

Table 9. Value creation for Q4.0 (Adapted from Radziwill, 2018; Lee, 2019; Sader, Husti and Daróczi, 2019)

Value propositions for Q4.0	Q4.0 innovations
Augment, or improve upon human intelligence	Real-time work instructions. Early identification and communication. Segmentation of stakeholders. Stronger collaboration with partners. Improved communication and collaboration, facilitating innovation and sharing of ideas
Increase speed and enhance the quality of decision-making	Cyber-aided quality training. Quality tracking and forecasting. Improved responsiveness. Customization. Smart forecasting
Anticipate changes, reveal biases and adapt to new circumstances	Real-time machine management. Machine management by Big Data. Rich information and analytics. Early decision making. Pre-production quality assurance. Early failure detection and prediction
Learn how to learn. Cultivate self-awareness and other-awareness	Supplier chain quality management. Dynamic interaction with market needs. Instant reconfiguration of manufacturing processes. Motivating for change environment
Reveal opportunities for continuous improvement	New product development quality. Lean quality management. Smart resource allocation. Improved coordination and effective evaluation
Improve transparency, traceability and auditability	Real-time quality audit. Self-learning and early prediction of errors. Less downtime with early maintenance prediction. Intelligent quality control system. Real time quality inspection

5.2.6. Managing data

Managing data is to have the adequate infrastructure for administering data and dataflows, bringing the right insights to people in a timely fashion, for doing their work better.

This is a support feature for the roadmap, since the empirical data showed that data administration and data flows overlap with all the other phases. Flows of processes and materials are still important for a system view of any operation, but data flows become more important for Q4.0 by creating value inside the organization, related to how to allow the right people to receive opportune insights to be more effective at their work. The empirical data can be enriched by three features related to data flows proposed by Radziwill (2018), which are also important for creating value for stakeholders:

- Connectedness: Connection to the data. To define which data do people need to be connected to, if some levels of the organization need to be better connected and if machines need to be connected between them.
- Intelligence: Understand and respond to the data. Consider the insights that could be provided at the right time and the data analysis behind it, done by the right people. Data must be understood to respond.
- Automation: Bring the data when needed and with less effort. Consider if insights could be delivered automatically and if the data analysis can be done using digital tools.

The use of digital tools and increased work done in digital environments will increase the need of addressing cybersecurity, to have safety and security measures in place. All members of the organization must be trained about the potential risks of producing, sharing and storing data to minimize the risks of tampering and violating confidentiality. Protecting the data is also an important part of keeping a competitive advantage.

5.3. Strengths and limitations of the roadmap

The roadmap for transition to Q4.0 proposed is composed of iterative steps and can be adapted by companies that have a quality system in place, based on TQM theory or the ISO 9001:2015 standard. For the same reason, it could arguably be used in both manufacturing and service organizations.

Another strength of the roadmap is the process view, providing a sequence of activities for an organization that wants to transition to Q4.0. It is focused on how data management and value creation contribute to organizational development and strategy in the context of I4.0.

The roadmap does not propose a particular set of digital tools for quality work since it is general. Every organization should decide which tools are more appropriate to use for managing data for Q4.0. Finally, the roadmap needs to be tested in a practical setting. This was not possible due to time limitations.

6. Conclusions

This chapter aims to sum up the finding and its outcome in relevance to the research questions.

The methodology used for this study provided answers for the two research questions.

RQ1: What is the awareness of Q4.0 in the organizations?

The general awareness from the organizations that contributed to this work was that Q4.0 is a concept related to I4.0. It is about how digitalization will change the quality work at an organizational level. It can be argued that the concept of Q4.0 is not clear for Swedish organizations.

This work proposed a definition of Q4.0 in the context of using technological developments and innovative digital tools to improve continuously in different areas of the organization such as company culture, competence development, customer satisfaction, knowledge management, data management and integration. This definition can contribute to a better understanding of the term Q4.0.

RQ2: What steps should an organization take to transition to Quality 4.0?

This thesis provides a roadmap for transition to Q4.0 with a structure for organizations to transition into Q4.0 regardless of business line. It is grounded on known quality theories and principles such as TQM, Lean Six Sigma and ISO 9001:2015. The roadmap should be relevant for companies aiming to include I4.0 in their strategy while considering how the changes within the organization will affect quality work in the future.

Another outcome of this research was that roles within the organization will change in the context of I4.0. The need for acquiring new competences and the digitalization of operations will require particularly that the quality area of the organization is able to adapt to changes and drive innovation.

Our conclusion is that the, awareness of quality 4.0 and its impact are low and further research should be done in order to fully understand the long-term consequences for humans. Industry 4.0 projects must be aligned with the strategy and goals of the organization. Deciding when to end pilot projects and dare to invest in order to fulfill their strategy and thereby getting closer to industry 4.0 is important for organizations. Investments in competence development of staff throughout the organization must be done in order to learn how to face the implications of industry 4.0.

7. Suggestions for future work

This study provided a roadmap for transition to Q4.0 that has not been validated in a company setting, due to time concerns. Applying the roadmap in service or manufacturing organizations would give valuable insights into its strengths and weaknesses for further development.

The concept Q4.0 was originally developed in the USA but no clear definition was found during this study. This study proposes a definition for Q4.0. To enrich this definition, but it is relevant to investigate the perception of this concept in other countries.

This study put some emphasis on change management and the consequences of change and how that will affect the organization. Since I4.0 involve a high level of changes to the processes and to the company culture, it could be a good idea to expand change management aspect further.

An assessment of the competences required for the different levels of the organization when transitioning to Q4.0 should be done when implementing the I4.0 strategy. It is then recommended to do research in defining what kind of knowledge will be needed for the current functions in the organization and the role of the operators in digital development. The role of quality professionals will change in the context of Q4.0. Some discussion about this subject is mentioned in this study but it is relevant to investigate further in this field.

This study provided some ground for handling digitalization from a quality perspective while only approached some concepts related to sustainability and leadership. It is relevant for Swedish organizations to investigate how these two concepts can be integrated with Q4.0 in the future, as is the case with the concept of Quality 5.0.

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