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Transforming Quality 4.0 towards Resilient Operator 5.0 needs

Monika Hattinger [a] and Kostas Stylidis [b] *

[a] University West, Department of Engineering Science, Division of Production Systems, SE- 461 32, Trollhättan, Sweden
[b] Chalmers University of Technology, Division of Product Development, Department of Industrial and Materials Science, SE-412 96, Göteborg, Sweden

* Corresponding author. Tel.: +0-000-000-0000 ; fax: +0-000-000-0000. *E-mail address:* stylidis@chalmers.se

Abstract

Quality is one of the most important contributors to products’ success in the market and essential input for design and manufacturing. Historically, quality definitions evolved over time but with significant domain-specific differences. One example of these emerging differences is the human-centric, subjective approach to quality. Current Quality 4.0 models, in most cases, are derivatives from the Total Quality Management (TQM) way, solely based on hopes for Data-Driven approaches to solving problems, with the lack of a human-centric operator approach. Industry 4.0 and its associated digital technologies promise to change this notion and make formerly subjective quality dimensions measurable on a scale as input for design and manufacturing. This leads to an opportunity to bridge the current gap and streamline the Quality and Operator in a holistic, data-informed, and digital technology-enabled way. This paper introduces a Quality 4.0 transformation as a vision for the future of Human – Machine symbiosis in the context of Operator 5.0 for intelligent manufacturing systems. We discuss what needs to be added to Quality 4.0 to achieve the requirements set for Operator 5.0 This work suggests how to enrich smart manufacturing systems from a human-centric perspective with Operator 5.0 making own, informed decisions based on data, experience, and tacit knowledge.

Keywords: Operator 5.0; Quality 4.0; Industry 5.0; Smart Manufacturing Systems; Human-Machine Systems; Data-Informed Design.

1. Introduction

The manufacturing industry is transitioning towards a more digital, data-driven future commonly referred to as Industry 4.0 [1]. Under this paradigm, the cyber- and physical-world continue to merge, enabling manufacturing companies to collect and analyze large amounts of user and usage data [2]. This enables advanced manufacturing processes as well as new methodologies for product design. Better understanding of customer preferences and requirements (backed by real data) will change the way products are designed and manufactured [3]. Quality continues to be one of the most important differentiators of manufactured products [4]. It is crucial in consumers’ decision-making processes and a key predictor of companies' success. Companies such as Toyota, Mercedes, and Volvo distinguish themselves on their product and process quality, terming it a key factor of sustained competitive advantage. The challenge for companies today is to design and produce high-quality products based on given boundaries regarding technologies, development time, production systems capabilities, and financial limitations. Hence, product quality must be controlled during all stages of product development.

To control product quality, companies use a range of quality models throughout the product development process, including Design for Quality, Statistical Process Control, Total Quality Management, Six Sigma, and Lean Manufacturing [5]. However, the human-centric approach setting the operator of smart manufacturing system as a decision maker is missing.

In this way, the fourth industrial revolution provides an opportunity for the quality movement to support operators with user-driven data. As a result, Quality 4.0 nowadays refers to using Industry 4.0 technologies, such as the Internet of Things

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(IoT), big data, and artificial intelligence (AI), to improve quality management processes in manufacturing and other industries [6]. However, many of Quality 4.0 definitions are lacking a human-centric approach for systems where the human is the main agent. Often Quality 4.0 is described as a digitalization process of TQM [7], a new DNA of Quality Engineering [8] or a data-driven discipline [9]. The Quality 4.0 movement, which integrates Industry 4.0 technologies into quality management, must be closely linked with a human-centric approach and the Operator 5.0 concept.

Operator 5.0 represents the next stage in the evolution of work and is characterized by a more collaborative, adaptive, and human-centric approach. "Resilient Operator 5.0" is a term that is sometimes used to describe the next generation of industrial operators, who are expected to have the ability to adapt and thrive in the face of uncertainty and change. This would require a combination of technical skills, as well as soft skills such as communication, critical thinking, problem-solving, and emotional intelligence. The focus of Resilient Operator 5.0 is to create a workforce that is able to respond effectively to rapidly changing technological, economic, and societal conditions, and to continually evolve and grow in response to these changes. The goal is to create a more sustainable and resilient industrial landscape, where organizations and individuals can thrive and prosper in the face of ongoing disruption [10].

While the Operator 5.0 concept has many benefits, it also presents a number of challenges that need to be addressed. Industry needs to be proactive in addressing these challenges and have a clear plan in place for implementing Operator 5.0 mindset in a way that benefits both operators and industrial needs. Some of the challenges include (i) Workforce reskilling: Implementing the Operator 5.0 concept requires significant reskilling of the workforce. Workers need to be equipped with a broader range of skills, including problem-solving, critical thinking, and creativity, in addition to technical expertise; (ii) Adoption of new technologies: Operator 5.0 requires the use of new technologies, such as artificial intelligence and robotics, to be integrated into the workforce. Operators are challenged with handling unexpected stops caused by machine failures and the following error recovery process of automated production systems. Typical errors are when a machine tool breaks, and assembly parts are accidentally dropped. Short, long, and unplanned production stops are expensive, unavoidable, and hard to predict in advance which affects operator and maintenance personnel [12]. Altogether it puts high pressure on operators' knowledge and skills in restarting machines and systems caused by errors. Operators require easy-to-use instructions with graphical overviews, hand-held devices to register faults, AR training solutions, etc. Furthermore, they need training in the workplace to reach applicable skills and competence to not only rely on maintenance personnel expertise.

The gap between Quality 4.0 and a resilient Operator 5.0 lies in the integration of human-centric perspectives and technologies within the existing Quality 4.0 framework. Quality 4.0 primarily focuses on leveraging digital technologies, data analytics, and automation to enhance the overall quality management processes. However, the transition to a resilient Operator 5.0 necessitates a more comprehensive approach that prioritizes the human element alongside the technological advancements. To address this gap, it is essential to examine the ways in which Quality 4.0 can be restructured to accommodate the human-centric requirements of resilient Operator 5.0.

This position paper delves deeper into the paradigm of Quality 4.0, posing the critical question: *"Which digital technologies and novel viewpoints must be integrated into the existing Quality 4.0 framework in order to fulfill the human-centric prerequisites established for a resilient Operator 5.0?"* In order to address this query, the paper scrutinizes various technological advancements and emerging trends that can potentially enhance Quality 4.0 and ensure the successful realization of human-focused objectives in the context of an adaptable and resilient Operator 5.0.

2. The evolution of quality models in Industry.

2.1. Quality and the first industrial revolution

The First Industrial Revolution was a period of significant change in which traditional manufacturing methods were transformed by new inventions and technological advancements. The First Industrial Revolution also saw the growth of factories and the rise of the factory system, which transformed the way goods were produced and led to the growth of cities and the development of modern industry. This period of technological change had a profound impact on society, economy, and culture and is considered the first major step towards the modern industrialized world [12]. Initially, quality during the first industrial revolution was not a significant concern. Quality was considered to be an afterthought, and products were often produced with little attention to detail or craftsmanship. However, as the first industrial revolution progressed, there was a growing recognition of the importance of quality in consumer goods. This led to the development of quality control methods, such as the inspection of goods at various stages of production, to ensure that they met certain standards [13].

2.2. Quality and the second industrial revolution

The Second Industrial Revolution led to increased productivity, a larger workforce, and improved standards of living, but also resulted in social and economic changes, such as urbanization, immigration, and the rise of labor unions. During this period, quality became a more important concern for manufacturers and consumers. Companies realized that providing high-quality products was critical to building customer loyalty and maintaining their competitive advantage. The second industrial revolution also saw the development of new quality control methods, such as statistical process control (SPC) to monitor and control production processes, and it is still widely used today [14]. The second industrial revolution marked a significant turning point in the history of quality. Companies began to recognize the importance of quality in maintaining their competitive advantage and building customer loyalty, and new methods were developed to improve quality in production. Today, these methods form the basis of modern quality management systems.

2.3. Quality and the third industrial revolution

The third industrial revolution, also known as the digital revolution, took place from the late 20th century to the present day. This revolution was characterized by the widespread adoption of digital technologies, such as computers, the internet, and mobile devices. Quality during the third industrial revolution has been heavily influenced by digital technologies. With the advent of computers and the internet, companies have been able to collect, analyze, and use vast amounts of data to improve the quality of their products and processes. One of the key trends during the third industrial revolution has been the widespread adoption of Total Quality Management (TQM) and Six Sigma [15]. Another important development during the third industrial revolution has been the rise of lean manufacturing, a method of production that emphasizes the elimination of waste and the continuous improvement of processes. Lean manufacturing has helped companies to reduce production costs and improve the quality of their products [16]. The third industrial revolution had a significant impact on the quality of manufactured products. The widespread adoption of digital technologies has allowed companies to collect and analyze large amounts of data.

2.4. Quality and the fourth industrial revolution.

The fourth industrial revolution, also known as Industry 4.0, is the current era of technological and industrial advancement, characterized by the integration of digital, physical, and biological systems. Key technologies driving Industry 4.0 include the Internet of Things (IoT), artificial intelligence (AI), and robotics [17]. Quality in Industry 4.0 is being impacted by these new technologies in several ways. Firstly, the IoT and AI are enabling companies to collect vast amounts of data about their products and processes, providing a deeper understanding of quality issues and enabling real-time monitoring and control. Secondly, the use of robotics and automation in production processes is improving the consistency and accuracy of production, reducing the risk of human error, and leading to higher-quality products. Another important development in Industry 4.0 is the concept of Quality 4.0, which recognizes the importance of quality in the context of the fourth industrial revolution.

3. Quality 4.0 current state and challenges

The term ‘Quality 4.0’ itself first appeared as the result of integrating Industry 4.0 features with traditional quality management practices [18]. Another approach to defining Quality 4.0 is the notion of the ‘4.0’ as a new fourth evolution phase of quality management assuming three earlier evolution phases for quality

The current state of Quality 4.0 is that it is gaining widespread attention and adoption in many industries as organizations recognize the potential benefits of using advanced technologies to improve their quality management processes. However, the implementation of Quality 4.0 also requires significant investment in technology and training, and organizations must be able to effectively manage and interpret the large amounts of data generated by these technologies. The data-driven approach must be augmented with a data-informed [19].

As we mentioned previously, quality is an inevitable product characteristic and a key predictor of a product’s success in any competitive market [20]. Over time, product quality definitions and knowledge emerged across different domains and industries. As a result, quality evaluation methodologies evolved unevenly and occasionally in isolation. One can outline the major exploratory directions addressing the multi-faceted nature of Quality 4.0 as: i) consumer-centric; ii) technocratic; and iii) design-centric.

Industrial practices within product development contributed to specific quality evaluation knowledge, e.g., in the automotive industry, product quality evaluation is an iterative process as one issue can be resolved while a new one can occur at any point during a design release. The key difference across all existing domains is the fundamental belief whether the quality is measurable (aka. objective) or remains indeterminable (aka. subjective). It results that Quality 4.0 is primarily represented by a data-driven paradigm. These views are based on the established understanding of quality [21] where Quality 4.0 can be defined as the 'degree to which a set of inherent product characteristics fulfills measurable requirements across all quality dimensions on a scale supported by digital technologies' [22].

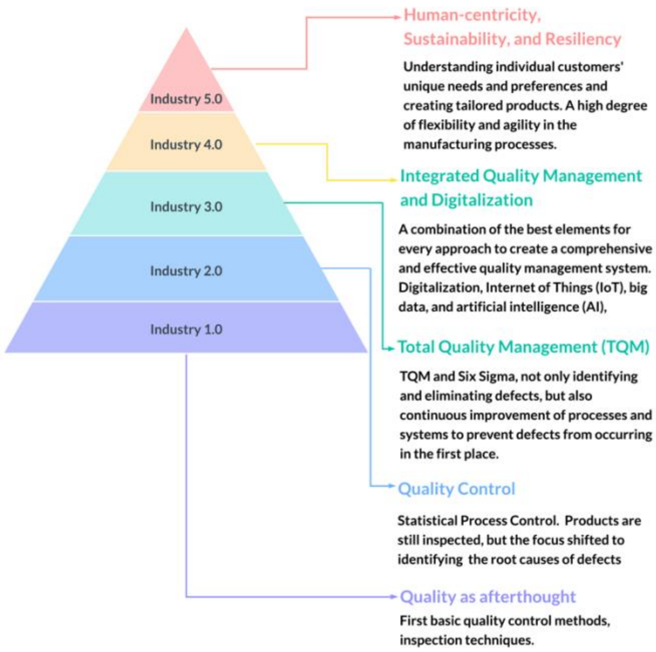

Fig. 1. Evolution of quality models

At this point, we suggest that the use of data-informed approach can help to satisfy the requirements for Operator 5.0. With a data-informed approach, data is used to inform and guide the operator’s decisions, but it is not the sole driver of those decisions. Resilient operators need to use their expertise and intuition to make choices that align with the project's goals while using data to support and validate those decisions.

Quality 4.0 is still in its early stages of development and implementation, but it has already gained significant attention from manufacturers and quality professionals. This is formulated by the need to use digital technologies to create a more resilient process operations planning and implementation with a customer-centric approach to quality management. One of the main challenges is the need for companies to develop new skills and expertise in data analysis and digital technologies, as well as to create new processes and systems to support Quality 4.0. This requires significant investment in training and development for operators.

4. Smart Manufacturing Systems and Operator Guidance

Smart manufacturing systems require operators to reach regular maintenance skills and strategies to move fast when errors are occurring. From that perspective, human-automation interaction offers a broad and fast-developing research area including various design and technical solutions for industrial processes and robotics automation [23-25] which are combined with humans, e.g., human-machine interaction, human-robot collaboration, and human-machine learning [26], [27]. This research describes complex human-automation solutions with human/social interaction on many levels and applications in manufacturing organizations.

One way to sustain a human-centric view of Industry 4.0 automation, in which the human operator works with augmented powers and capabilities, is by using AI technologies and virtual reality (VR) [28]. The proposal is to use robotics and IoT tools to extend the capabilities of the operator to accomplish production tasks to unleash human creativity and complement virtual reality and advanced manufacturing. Also, by creating the operator as a "maker" working alongside the automated production system to enhance the human role. Furthermore, Operator 4.0 will bring social-human benefits to the workplace of increased work quality and higher job satisfaction through work task responsibilities, flexibility, abilities, and skills for shop-floor personnel [29]. This is described by the *human-automation symbiosis as intelligent hybrid agents* through the concept of "Human Cyber-Physical Systems" [30] which are systems engineered to improve human abilities to interact with intelligent cyber-physical systems through intelligent human-machine interfaces combined with human physical-, sensing- and cognitive capabilities. The vision is a super operator termed Operator 4.0 from the human-in-the-loop perspective towards the Resilient Operator 5.0.

5. Data-Informed Quality 4.0 as human-centric approach toward fulfillment of a resilient Operator 5.0

In their previous work, Romero and Stahre [10] defined the concept of Resilient Operator 5.0 – *as "a smart and skilled operator that uses human creativity, ingenuity, and innovation empowered by information and technology as a way of overcoming obstacles in the path to create new, frugal solutions for guaranteeing manufacturing operations sustainable continuity and workforce wellbeing in light of difficult and/or unexpected conditions."* This means that, as an Operator 5.0, one must have a variety of skills, including proficiency in advanced technologies such as AI, automation, and machine learning, as well as strong problem-solving abilities, adaptability, communication skills, and a willingness to learn and embrace new technologies. It is also important to focus strongly on customer experience, operational efficiency, and continuous improvement.

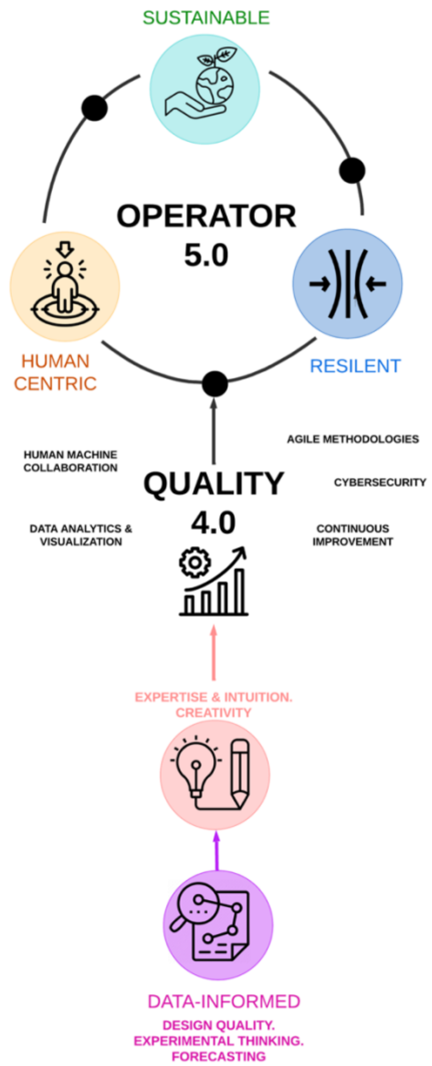

Fig. 2. Data-Informed Quality 4.0 input to Operator 5.0

While a data-driven approach to Quality 4.0 can provide valuable insights and inform decision-making, relying solely on data can have limitations for Operator 5.0.

Here are some reasons why we need to address a problem holistically and include a data-informed approach:

- Data can be incomplete or inaccurate - data is only as good as its quality. Incomplete or inaccurate data can lead to incorrect insights and decision-making, which can have negative consequences.
- Data can't capture everything - data can provide insights into past trends and behaviors, but it can't capture rising trends. For example, data can't capture human emotions or personal experiences, which can be important factors in decision-making.
- Data can't replace human judgment - while data can provide insights and inform decision-making, it can't replace human judgment entirely. Operators bring unique

skills and experiences to the table that can't be replicated by data alone.
- Data can't account for future unknowns - data can provide insights into past trends, but it can't predict the future with certainty. Operators need to be prepared to make decisions in uncertain and unpredictable environments.

A data-informed approach to Quality 4.0 combines the power of data with human judgment and expertise. Operators can use data to inform decision-making, but they also bring their own unique skills and experiences to the table. By using a data-informed approach, Operator 5.0 can make better decisions, optimize processes, and improve the customer experience, while also accounting for the limitations.

To fulfill the needs of Operator 5.0, we suggest adding a few key elements to Quality 4.0. These include:
- Human-machine collaboration - Operator 5.0 will work closely with advanced technologies, such as artificial intelligence and machine learning. Quality 4.0 needs to incorporate a human-machine collaboration approach, where humans and machines work together to optimize processes, improve efficiency, and enhance the customer experience.
- Data analytics and visualization - Operator 5.0 needs to be able to analyze large amounts of data and extract insights that can inform decision-making. Quality 4.0 needs to incorporate advanced data analytics and visualization tools that can help Operators make sense of complex data sets.
- Continuous improvement - Operator 5.0 needs to be focused on continuous improvement and constantly striving to optimize processes and enhance the customer experience. Quality 4.0 needs to incorporate a continuous improvement approach that encourages Operators to identify areas for improvement and make ongoing changes and adjustments.
- Agile methodologies - Operator 5.0 needs to be able to adapt quickly to changing environments and customer needs. Quality 4.0 needs to incorporate agile methodologies that enable Operators to respond quickly to changing circumstances and make decisions in real time.
- Cybersecurity - as Operator 5.0 works with advanced technologies, cybersecurity becomes a critical concern. Quality 4.0 needs to incorporate cybersecurity measures that protect sensitive data and systems from cyber threats.

By incorporating these elements into Quality 4.0, we can create an environment where Operator 5.0 can thrive, using advanced technologies to optimize processes, improve efficiency, and enhance the customer experience while still leveraging human judgment and expertise (see Fig 2).

6. Discussion

Operator 5.0 is an emerging concept that describes the next generation of workers who will be highly skilled in the use of advanced technologies such as artificial intelligence, automation, and machine learning. These workers will use these technologies to optimize processes, improve efficiency, and enhance the customer experience.

Quality 4.0 is a concept that focuses on the integration of digital technologies and quality management systems to optimize manufacturing processes. Sustainability and circularity have become increasingly vital in today's world, as both organizations and individuals endeavor to reduce their environmental impact and enhance resource efficiency. In the context of Operator 5.0, Data-Informed Quality 4.0 can assume a critical role in addressing these issues by leveraging data to establish more eco-friendly and circular processes in manufacturing, all while embracing human-centric perspectives. Operator 5.0 professionals, possessing expertise in data analytics and state-of-the-art technologies, can facilitate well-informed decision-making processes that aim to diminish resource consumption, curtail waste, and refine production processes. This people-focused approach, when paired with Quality 4.0's data-driven analysis, can significantly advance sustainability and circularity objectives. Incorporating human intervention in predictive maintenance, Data-Informed Quality 4.0 can assist in devising strategies that enable organizations to foresee equipment failures and schedule appropriate maintenance activities. Consequently, this optimizes the use of resources and enhances the longevity of equipment. By integrating the human-centric perspectives of Operator 5.0 with the data-driven approach of Quality 4.0, organizations can establish a collaborative and synergistic strategy that propels sustainability and circularity goals in the manufacturing sector. This comprehensive approach fosters a harmonious relationship between human expertise and technological innovation, ultimately paving the way for more sustainable and circular manufacturing practices.

Speaking of human-centric approach in the paradigm of a being resilient we should not forget that Operator 5.0 must represent a new generation of skilled professionals who possess expertise in advanced technologies, data analytics, and human-machine collaboration. Therefore, when it comes to applying a Data-Informed approach to Quality 4.0, the expertise and intuition of Operator 5.0 professionals can contribute significantly to enhancing the overall quality management processes in the manufacturing sector. Operator 5.0 professionals can combine their expertise in data analytics with their intuition and experience to interpret complex data sets, identify patterns, and draw actionable insights. Operator 5.0 professionals can use their intuition and experience to identify areas for improvement in the manufacturing processes. By integrating these insights with data-driven analysis from Quality 4.0 systems, they can effectively drive continuous improvement initiatives that enhance overall process performance and product quality.

In terms of risk management, Operator 5.0 professionals can leverage their expertise and intuition to evaluate potential risks and identify early warning signs that may not be immediately apparent through data analysis alone. This allows for a more comprehensive risk assessment and helps to mitigate potential issues before they escalate.

6.1. Data-driven or Data-informed?

When it comes to using data in this context, many can argue about whether a data-driven or data-informed approach is best. A data-driven approach involves using data as the primary driver for decision-making, whereas a data-informed approach combines data with human judgment and expertise.

Both approaches have their advantages and disadvantages. A data-driven approach can provide valuable insights and inform decision-making, but it can also have limitations such as incomplete or inaccurate data, inability to capture everything, and the need for human judgment. In contrast, a data-informed approach combines the power of data with human judgment and expertise to make better decisions, optimize processes, and improve the customer experience. It can account for the limitations of data and the need for human judgment while still using data to inform decision-making.

To implement an Operator 5.0 concept in practice, it's important to understand the pros and cons of both approaches and use them appropriately. A data-driven approach can be useful in certain situations, such as when dealing with large volumes of data or making decisions based on quantitative metrics, e.g., Digital Twins. However, a data-informed approach may be more appropriate when dealing with uncertain or unpredictable environments or when dealing with sensitive data. Ultimately, the key is to strike a balance between the two approaches, leveraging the strengths of each to make better decisions and achieve better outcomes.

7. Conclusions and Outlook

This paper elaborates on the new perspectives of Quality 4.0 concept to support the implementation of a resilient Operator 5.0 and human-centric requirements in the context of smart manufacturing systems and Industry 5.0. By incorporating these Data-Informed approach to Quality 4.0 and Operator 5.0, industry can create more resilient, efficient, and human-centric manufacturing processes that can adapt to changing requirements and conditions. In the Data-Informed Quality paradigm humans and automation technologies work together in a collaborative and complementary manner. Humans provide creativity, flexibility, and decision-making abilities supported by data, while automation technologies provide efficiency, accuracy, and speed of operations. This will become extremely important in the nearest future for the industries that require complex problem-solving, such as healthcare, manufacturing, and transportation.

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