# Technology and quality management: A review of concepts and opportunities in the digital transformation

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# Technology and Quality Management: a review of concepts and opportunities in the Digital Transformation

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**Purpose -** The Digital Transformation brings change to organizations, their processes, and their production systems. Nevertheless, most efforts observed in its context tend to be technology-driven, and it is often argued that Quality Management is inadequately integrated into the discussion.

**Design/methodology/approach** – Surveying the literature, this work reviews, list, and organizes the different technological concepts and integration opportunities that have been explored in the scope of Quality Management in the Digital Transformation.

**Findings –** Findings include the expanded capacity of quality tools and methods for managerial purposes; the reinforced importance of Data Quality; the increased automation and augment resources for Quality control; and the increased process optimization and integration of systems and between organizational areas.

**Originality/value -** It is demonstrated that although scattered in the literature, there are already a number of works exploring the impacts of technology in the management of Quality in the scope of the Digital Transformation. Three main areas for integration arise: (a) Digital Quality Management (application of industry 4.0 technologies to Quality Management itself, its tools, methods, and systems), (b) the management of the Quality of digital products and services, and (c) the management of the Quality of digital product development and production processes.

**Keywords**: Quality Management, Digital Transformation, Industry 4.0

**Paper type:** Literature review

## INTRODUCTION

Industry 4.0 and the Digital Transformation have been studied predominantly from a technological point of view (Liao et al., 2017; Schroeder, et al. 2019; Vial, 2019). As a result, advancements are mostly observed at a technical and technological level (Kan, 2002; Firesmith, 2005).

Technology is often argued not be the most important driver of the Digital Transformation (Kane et al., 2015), being only part of the complex puzzle that must be solved for organizations to remain competitive in an increasingly digital world (Vial, 2019). It is in this perspective that we argue for the importance of discussing the implications for Quality brought by Digital technologies. It has been claimed that, in the scope of the Digital Transformation, there has been limited innovation in the field of Quality (Lee, Kao, and Yang, 2014; Shubin and Zhi, 2018). The truth, however, is that there has been an active discussion in this scientific and professional field – one that has often revolved around the branding of "Quality 4.0" (Schönreiter, 2016; Jacob, 2017; Krubasik, et al., 2019). It has taken two forms: one, led by Quality experts, has been focused on how to advance the field in the face of the new technological and organizational opportunities brought by the Digital Transformation. The other, led mainly by technologists, has been driven by effort to guarantee technical performance of new technologies and systems. These different approaches have a deep impact on the general perceptions of Quality Management moving forward. In this sense, it is important to gain an overview of each one, and understand how to better integrate them.

The approach promoted by Quality experts and researchers has focused on concepts, strategies, methods, and tools of Quality in this transition. Examples include the issue of Quality Assurance in manufacturing processes (Illés, Tamás, Dobos, and Skapinyecz, 2017) or the revision of performance improvement initiatives under the concept of Organizational Excellence (Carvalho, Sampaio, Rebentisch and Saraiva, 2019). Some authors have looked at the opportunities and challenges for Quality in different organizational areas, including strategic alignment (McAdam, Miller, and McSorley, 2019), supply chain integration (Zhang, Guo, Huo, Zhao, and Huang, 2019) or the combined monitoring process and product information (Xiao, Jiang, and Luo, 2019). Others have focused on the fit between existing Quality tools and methods and the new industrial paradigm (Bossert, 2018; Vandenbrande, 2019).

In parallel, several works have been presented from a more technology-oriented point of view. Works sharing this perspective highlight the potential that the use of new industrial technologies has for the improvement of quality and performance in an organization (Stojanovic, Dinic, Stojanovic, and Stojadinovic, 2016; Oliff and Liu, 2017; Radziwill, 2018).

These two perspectives have been poorly integrated, impairing the understanding of the role and impact that the technological development has for Quality Management in the Digital Transformation. It has been argued that it is hard to find studies on the role of related technologies and their impact on Quality Management (Gunasekaran, Subramanian, and Ngai, 2019). Furthermore, the literature shows that most organizations do not yet have a specified a Quality-based strategies or models to address this transition (Bauer, Bas, Durakbasa, Kräuter, and Ugur–Tuncer, 2019; Völker, Friesenhahn, and Seefeld, 2019).

Consequently, a generalist approach is increasingly observed in Quality issues in the Digital Transformation, and topics that have been discussed in Quality-specific forums do not transition to practical deployment (Bossert, 2018). Likewise, efforts and budgets to fund Quality Management Systems are being diverged for new production technologies (Johnson, 2019). While critiques to generalist perspectives on Quality Management are not new in the field, this increased focus on technology brings the problem back into the spotlight. In a transition that is mostly technology-driven, the lack of such perspective means that technologists rather than quality-experts are making the decisions on Quality Management.

It must be admitted that this technology-driven advancement of Quality does have its benefits, and that it creates expectations also within the Quality community. Závadská and Závadský (2018) surveyed Industry 4.0 expectations next to Quality managers, and identified prospects of significant growth in the use of technology to improve Quality control and management. Furthermore, these technologies have been proved to help improve the performance of an organization (Stojanovic, Dinic, Stojanovic, and Stojadinovic, 2016; Oliff and Liu, 2017), and can themselves be branded as "Quality 4.0 Tools" (Radziwill, 2018). However, they are not guided by a Quality-driven perspective, and offer limited creativity in terms of Quality itself (Lee, Kao, and Yang, 2014; Shubin and Zhi, 2018).

This becomes critical also as we look at the today's increasingly digital and data-driven products. Products are moving from a single 'physical' reality to one that includes also a 'digital' dimension, where the online and offline states are interrelated, interdependent, and complementary (De Beer, 2016). In the face of such reality, manufacturing processes are increasingly becoming more digitalized (Parkhurst, Morris, Tahy, & Mossberger, 2015). As a result, and it is important to understand what quality issues might affect the growing range of digital products and their (also increasingly digital) production processes.

## RESEARCH OBJECTIVES AND METHODOLOGY

Research on the impact of Digital Transformation technologies on Quality is still somewhat limited and, above all, poorly connected. In order to counter this reality, this paper reviews, lists, and integrates different concepts and examples existing in the literature. It is made with a double aim of (1) understanding the contributions of new technologies to Quality Management, and (2) understanding how to manage the Quality of products and processes deeply changed by Digital Transformation technologies. The outcome of this review is not meant to be an in-depth exploration of the individual relations between different technologies and their impact on Quality, or vice-versa. Instead, its goal is to identify some of the different technologies that offer a potential for integration with Quality, based on already demonstrated and published applications.

In order to conclude this review, works from both academic and professional authors were considered. The initial screening for sources targeted scientific works with high impact and citation rates, using databases such as Scopus and Web of Science. While these guaranteed sources of quality and relevance to the field, they also left outside the scope of this research a series of works – which, either for their origin, means of publication, or newness were not featured in these databases, but could provide different perspectives and valuable inputs to the review of the literature. Accordingly, in a second phase particular efforts were made to include recent works with new research trends and yet limited impact, and non-scholar perspectives. One of the databases/search engines added – the one with the most impact in the search for literature – was Google Scholar.

Ultimately, sources of this review included books, journal articles and proceedings within the research fields of quality engineering and management, operations management, industrial engineering and engineering management, computer science, information sciences, and organizational sciences (business and management). The selection was made with basis on the critical analysis of their quality and fit against the identified gaps, or promotion of relevant perspectives.

## LITERATURE REVIEW

Literature on the Digital Transformation often shows a generalist approach to Quality Management, with limited integration and innovation in the field (Lee, Kao, and Yang, 2014; Shubin and Zhi, 2018; Bossert, 2018). In this review, we tried to cover the existing works that may help counter this view. In order to do so, this work lists not only the reported benefits of the relationship between technology and Quality Management, but offers also an integrated perspective on how this relationship can be further explored to improve the performance of organizations. It aims to emphasize the practical applicability of new technologies in pursuit of better Quality.

Analyzing the literature, it was found that three main areas arise. They are (a) Digital Quality Management (i.e. application of industry 4.0 to Quality Management itself, its tools, methods, and systems, as well as the impact on people), (b) the management of the Quality of digital products and services, and (c) the management of the Quality of digital product development and production processes. These were used to structure the literature review.

### Digital Quality Management

Digital Quality Management is understood here as the application of digital technologies to Quality Management, with impact in its tools, methods, and systems – both at a technical and human levels. Related works are centered in circumstances that these Quality Management face in an increasingly connected and data-driven industrial setting. With increasingly integrated and connected systems, the assessment and control of isolated processes becomes outmoded. Vandenbrande (2019) argues on the need for a new perspective for Statistical Process Control (SPC)**,** arguing that technology itself is replacing process control. In this sense, the author suggests that SPC can have renewed impact if used as a managerial tool, shifting its attention from the control of isolated processes to a perspective of system and organizational management.

A similar perspective is found in regards to Six Sigma methodologies. Bossert (2018) argues that the use of six sigma methods has to be directed to the creation of data strategies for our organizations with respect to Quality, process improvement and analysis. However, there is yet a poor integration of Six Sigma with **Big Data**, and to improve this reality, it is imperative that fundamental gaps are understood and addressed (Antony, Sony, Dempsey, Brennan, Farrington, and Cudney, 2019). Six Sigma must support the use of Big Data, connect with new technologies, and be expanded with the use of predictive analytics and multivariate analysis (Bossert, 2018). On example of such integration is provided by Graafmans, Türetken, Poppelaars, and Fahland (2020). The authors explore the usage of **Process Mining** techniques in Six Sigma-based process improvement initiatives, showing the benefits that using process mining offers for collecting data on their business processes through their event logs. As a result, a standard operating procedure is proposed to increase the efficiency and effectiveness of process improving efforts in their organizations. Process Mining allows the collection of data from different processes, based on their event logs (van der Aalst, Weijters, and Maruster, 2004). Its application results in the improved description of processes, products and organizational systems (Kirchmer, M., Laengle, S., and Masias, 2013), and may be used for improving quality, auditing, compliance adherence and risk management (van Aalst, van Hee, van Werf, and Verdonk, 2010; Caron, Vanthienen, and Baesens, 2013). Furthermore, it allows to automatically discover process models from raw event data, do conformance checking, and perform bottleneck analysis (van der Aalst, 2016). Accordingly, process mining brings digitalization and **Data Science** into Quality Management Systems. It reinforces the process-centric vision of an organization, providing important inputs to the integrated Management Systems and allowing to better promote process improvement and ensure compliance and standardization. In the same lines, the way data is collected and treated is critical for the creation of such value.

The use of these data-driven technologies thus needs to be combined with quality tools and methods, expanding their capacity as managerial instruments in the digital era.

As for the human side of Quality Management, Gunasekaran, Subramanian, and Ngai (2019) propose a research pathway for exploring its alignment with technology. Different scenarios are presented in accordance to different levels of engagement. Deeper individual engagement and newer technology is referred as micro level engagement, and focuses on specific issues such as security, risks, compliance management, alignment of Quality Management Systems, and the use of new technologies. Macro level engagement is more about continuous improvement issues addressed by both human aspects and technological revolution (Gunasekaran, Subramanian, and Ngai, 2019). However, the authors still identify a clear research gap in understanding how human aspects affect the integration between Quality Management and technology aspects. This aligns with an overall trend in Industry. Rauch Linder, and Dallasega (2020) used an anthropocentric perspective to look at the business environment before and during the transition towards Industry 4.0. The authors highlight the central role that a human-centered approach has in both paradigms, but identify different perspectives before and during this transition. Before, the environment was shaped by a change from technology-oriented production design towards a human-centered design. However, the authors claim that during the transition there has been a technology-driven transformation of physical and cognitive systems – leaving the human side often forgotten.

**Quality of digital products and services**

The Digital Transformation accelerated the advent of digital products, and with them, bought new perspectives for the management of Quality. One example relates the use of **Internet of Things (IoT)** in these products. IoT devices are linked in a network, and capable of interacting both with each other and with a centralized system (Lee and Kyoochun, 2015). As such, not only they provide new features for end users, but they also create an opportunity for constant monitoring, fault detection, and diagnosis of these products (Yen, Zhang, Bastani, and Zhang, 2017). IoT systems support higher levels of Quality Assurance by integrating and validating the different parts and components of a system - its devices and sensors, gateways, and apps (Tuncer, Davutoğlu, Durakbasa, 2019). Additionally, after sale, they provide organizations with improved access to real time data, and expanded use information sharing Karkouch, Mousannif, Al Moatassime, and Noel, 2016).

With new products and services being able to collect, generate, or make use of **Big Data**, integration is facilitated. Nevertheless, when making use of large volumes of data, it is important to understand that the quality of the information collected is critical. Gathering large volumes of data does not create value – that happens only when the collected data leads to organizational gains (G. Watson, 2014). Similarly, it does not ensure the correct use of such data. That occurs only when the collected data is treated and used in such a way that it creates feasible strategies with clear organizational gains (H. Watson, 2014).

Data Quality thus becomes a critical component of Quality Management in the Digital Transformation. With new products increasing connected and interacting with large volumes of data, integration is facilitated by the creation of information loops, which allow new functionalities based on the collaboration between systems (Colombo, Karnouskos, Kaynak, Shi, and Yin, 2017). They promote an integration between the digital with the "real" dimensions of a product. However, it is important to understand that the ideas of digitization, connectivity and analytics go beyond the simple use of platforms and technological tools (Leischnig, Ivens, Wölfl, and Hein, 2019), and should focus in adapting to them to enhance productivity and value generation for the customers (Skapinyecz, Illés, and Bányai, 2018; Lele, 2019). In the scope of data-driven and digital products, the use of **Machine Leaning** (ML) and Artificial Intelligence (AI) also brings promising potential. ML and AI may be used to combine quality control and reliability analysis in order to support predictive maintenance (He, Gu, Chen, and Han, 2017) and to reduce the number of customer complaints (Lou and Huang, 2003). Nevertheless, important questions are still being raised concerning safety in Machine Learning (Amodei et al., 2016; Varshney and Alemzadeh, 2017), a topic that will have strong impact in the Quality of these products, processes and systems. The same is true for bias towards certain groups or populations (Holstein et al., 2019; Mehrabi, et al., 2019).

Furthermore, ML can be used for the improvement of Quality along the design and development phases of new products, as well as for its production processes (see next section). Acooridngly, ML is set to become part of the design tools and to help improve product quality, but also production efficiency (Long, Lin, Cai, and Nong, 2020).

With improved connectivity, access to greater volumes of data, and the use of machine learning and artificial intelligence, maintenance and after-sales assistance go live, allowing level of "supercare" – one with a greater focus on continuously improving the service provided to the customer, that predicts and prevents errors before they occur, and that reduces the frustration of breakdowns and complaints. However, and with the closer integration of the digital with the "real" dimensions of a product, Data Quality and security become critical components for the management of Quality.

## Quality of digital product development and production processes

The Digital Transformation and the increased use of Smart Manufacturing technologies offers a good fit for further integration between Systems Engineering and Quality. Systems Engineering and Management deals with the development of highly complex products and projects (Oehmen, Thuesen, Parraguez, and Geraldi, 2015), promoting the integration between different organizational areas (de Weck, 2018).  Such integration is seen as critical for the mapping and assessment of this new industrial paradigm as a whole (Brusa, 2018; Wortmann, Combemale, Barais, 2017).

Amongst possible applications is the use of **Digital Twins**. Digital Twins allow the digital representation and modeling of smart systems. They help organizations create an experimental, virtual reality that can be used not only for engineering challenges but to address different aspects of the organization (Schluse, Priggemeyer, Atorf, and Rossmann, 2018). Digital Twins offer a simulation-based, interdisciplinary systems approach, enabling the consistent use of simulations to assess varying scenarios throughout the lifecycle (Schluse et al., 2018). Integrated with smart manufacturing technologies, Digital Twins lay the foundation or innovative products and Quality traceability (Tao, Qi, Wang, and Nee, 2019).

Taking advantage of the growing integration possibilities offered by **Cyber-physical systems (CPS)** also offers opportunities. By creating interconnected systems, these CPS allow different technologies to be structured and managed in a collaborative way. Through their use, information is closely monitored and synchronized between the physical factory floor and the cyber computational space, allowing for enhanced equipment efficiency, reliability and quality (Lee, Bagheri, Kao, 2014). Similarly, **Closed-loop Manufacturing (CLM)** also allows quality related data, gathered during manufacturing in the production machine, to be shared in a closed loop with different systems along the product lifecycle (Danjou, Le Duigou, and Eynard, 2017). This allows immediate information sharing with product development activities, leading, for example, to the update of CAD drawings and simulations, reducing process variability and the risk of non-conformities from (Saif and Yusof, 2019).

The quality of processes may also be improved through the use of increased automation – such as **Robotic Process Automation (RPA)**. RPA allows the elimination of operational risk and brings companies the opportunity to better manage their resources, attaining savings in time and cost (Jovanović, Đurić, and Šibalija, 2018). RPA will deliver higher quality by standardizing operations and processes, and reduces human errors by diminishing or eliminating the possibility of a process being done the wrong way or by an operator without proper knowledge (Mendling, et al., 2018; Jovanović, Đurić, and Šibalija, 2018).

Another area that gains interest from a systems perspective is that people increasingly collaborate with robots and intelligent assistant systems (Gorecky, Schmitt, Loskyll, and Zühlke, 2014; Kadir, Broberg, Souza da Conceição, 2018). Technologies supporting such systems include **collaborative robots (COBOTs)**, **Augmented Reality (AR)**, and **Smart Human Interfaces (SHI)**, and a number of smart technologies such as screens, 3D glasses, or exoskeletons. Such systems, rather than replacing humans, collaborate and augment human capabilities. As such, they too allow companies to achieve standardization, attain superior performance, and avoid human errors (Djuric, Urbanic, and Rickli, 2016; Frank, Dalenogare and Ayala, 2019; Chiarini and Manesh, 2020).

In the same scope, the relationship between **Additive Manufacturing** (AM) and Quality Management deserves attention for the process advancements it brings. By promoting an alliance between information and digital technologies and advanced production technologies, Additive Manufacturing creates truly new manufacturing realities. AM goes beyond the features and usability of products, and includes benefits such as faster design, development, and prototyping (Hamzeh, Zhong, Xu, Kajati, and Zolotova, 2018; Tortorella and Fettermann, 2018; Frank, Dalenogare, and Ayala, 2019), superior level of customization, and a closer relationship with customers (Schmidt et al., 2015). AM offers an opportunity for both superior Quality and reduced process costs, as it reduces the investment in tooling, cuts the time between design and production and - by allowing the final design to be approved by the customer - reduces the costs of resigned or rework (Preuveneers & Ilie-Zudor, 2017). This reality leads to a future empowerment and amplified voice of the customer, creating a personalized and individualized experience of collaboration and co-creation (Zairi, 2020).

In short, the Digital Transformation offers increased automation and augmented resources for Quality control. The same gods for optimization and integration between processes, systems, and organizational areas. Furthermore, it helps bring the customer into the design and development process, enhancing the customers experience and improving the potential for satisfaction.

## CONCLUSIONS

This review departs from the understanding that there is limited research and alignment between the technological aspects of the Digital Transformation and Quality Management. In the face of this reality, this article surveys the literature for different practical examples of how Quality Management may both impact and be impacted by the use of new technologies. In doing so, it creates a better understanding of the relationship between Quality Management and the technologies supporting the Digital Transformation.

First, it is demonstrated that although scattered in the literature, there are already a number of works exploring the impacts of technology in the management of Quality in the scope of the Digital Transformation. Furthermore, this work resulted in the sorting and integration of the reviewed works into three areas:

(a) Digital Quality Management, considering the application of digital technologies to Quality Management itself, its tools, methods, and systems, and its human side;

(b) Implications for the management of Quality in digital products and services, often data-driven and marked by increased connectivity;

(c) Implications for the management of the Quality in increasingly digital product design, development, and production processes.

Table 1 summarizes these findings.

*Figure 1 - Summary of the literature review on the implications of technology for Quality within the Digital Transformation (DT)*

| Area | Description | Technology integration | Findings |
|---|---|---|---|
| Digital Quality Management | Quality tools, methods, and systems; human side in Quality Management | • Big data<br>• Process Mining<br>• Data Science | (1) New data-driven technologies may be used together with quality tools and methods, expanding their capacity as managerial instruments.<br>(2) Studies on impact of technology in the human side of Quality Management (QM) are limited, curbing its understanding. |
| Quality in digital products and services | The management of Quality in digital products and services | • Internet of Things<br>• Big Data<br>• Machine Learning | (3) Maintenance and after sales services go live, allowing level of "supercare".<br>(4) With the integration of the digital with the "real" aspects of a product, Data Quality and security become critical components of QM in the DT. |
| Quality of digital product development and production processes | The management of the Quality in increasingly digital processes | • Digital Twins<br>• Closed-loop Manufacturing<br>• Robotic Process Automation<br>• Collaborative Robots<br>• Augmented Reality<br>• Smart Human Interfaces<br>• Additive Manufacturing | (5) DT offers increased automation and augmented resources for quality control.<br>(6) DT allows for increased optimization and integration between processes, systems, and organizational areas. Furthermore, it helps bring the customer into the development process. |

In this review, it is demonstrated that there are clear benefits brought by these technologies for the management of Quality in an organization. Expanded integration and connection are amongst such benefits. Several new technologies support and promote integration and connectivity across an organization, allowing different functional units and systems to better work together. This improves information sharing, quality assurance, and efficiency, while reducing risks and uncertainty, and driving down costs. Nevertheless, it is clear that an anthropocentric perspective and a combined Quality strategy are the main limitations of this relationship.

## Limitations and future work

There are some limitations to this work that must be reported, especially as they may also configure future research opportunities. This review focused on technologies that offer the most potential for integration with Quality Management, based on already demonstrated and discussed applications. It looks essentially at new technologies for process and systems integration, data management, and integration with existing Quality tools, techniques, and systems.

What it does not consider is the relationship between Quality and Risk Management under this disruptive scenario, especially for (1) Quality processes that primarily deal with uncertainty and probabilistic phenomena, and (2) the further integration of processes and tasks along the lifecycle of a product. Risk Management can serve as a bridge of efficiency in the development of digital products and digital production capabilities. This relationship may significantly improve the quality during the early production runs by better leveraging testing and sensor data for understanding production-related quality risks: feeding-back information from production to development areas (to avoid production risks during design), as well as feeding-forward information from R&D to production (to better prepare for unavoidable production challenges). Risk Management is especially relevant for radically new products, as there is significantly more uncertainty, and Quality Management extends to earlier phases of the development and business case.

Another limitation relates to the depth to which each technology or its resulting opportunities for Quality Management have been presented in this review. The objective of this work is to identify, list, and organize some of the different technological opportunities for Quality Management in the Digital Transformation. Due to size limitations and narrative constraints, we could only highlight a few aspects of what each technology brings to Quality Management. Accordingly, a more profound review and better understanding of the relationship between each technological opportunity and Quality Management offers a clear opportunity for future research.

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