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QUALITY MANAGEMENT PRACTICES IN THE ERA OF INDUSTRY 4.0

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Abstract: Industry 4.0 is a recent trending topic which is widely being discussed in research from different perspectives. Industry 4.0 refers to the fourth industrial "revolution"; some literature defines it as a further industrial "evolution", resulting from the integration of innovative technologies such as the Internet of things, cyber-physical systems, big data, robotics, artificial intelligence, and cloud C computing with industry. This development hascreated new techniques to improve different segments of industry. Such integration has significantly improved production systems, created smarter and highly responsive supply chains, and boosted the product quality due to instant, massive, and real-time quality control systems. Industry 4.0 has a strong impact on different socio-economic fields, thus, several researchers increasingly focus on addressing different impacts on different levels. Accordingly, this paper aims at discussing the impact of Industry 4.0 on quality management systems and practices, such as quality control, quality assurance and total quality management. The paper reviews the best quality practices and proposes a modern framework of an (Industry 4.0-Quality) integrated model, where Industry 4.0 is directly linked with quality practices to produce a new level of quality practices.

Keywords: Industry 4.0, quality assurance, total quality management, quality control, intelligent quality control systems, Quality 4.0

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Introduction

Known as the fourth industrial revolution, Industry 4.0 has become one of the most trending topics in the past few years (MacDougall 2013, p. 6). Industry 4.0 was initiated by the German Government in 2011 as the 2020 high-tech strategy (Zhou, Liu, Zhou 2016, p. 2147). It came as further development following the past three industrial revolutions. The first, which emerged during the 18th century, was based on the mechanical power generated from steam and water. The second revolution, which emerged during the 20th century, was initiated by the use of conveyors to transfer products between machines, enabling mass production to respond to the increasing market demand. At this stage, a single production process was divided

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into smaller stages, each assigned to an individual or a group of workers to capitalize on the experience gained from the repeated work. The third revolution was the result of integrating programmable logic controllers (PLC), invented during the 1970s, which advanced the automation of industrial production and minimized the efforts needed by labor.

Recently, a huge leap occurred in industrial production systems, especially when industrial companies started to integrate and utilize internet and computer systems in their industrial systems, bringing to stage the Internet of things (IoT), big data, and cyber-physical systems which became the foundations of the new fourth industrial revolution, known as "Industry 4.0" (Brettel et al. 2014, p. 43; Qin, Liu, Grosvenor 2016, p. 174; Zezulka et al. 2016, p. 8). Industry 4.0 raised the automation of production to a new advanced level, where machines can cooperate to attain higher efficiency in production systems, increasing productivity and product customization capabilities. The era of Industry 4.0 is characterized by the use of the Internet to connect machines together like in a social network. Cyber-physical systems and artificial intelligence extended the ability of the production system to reallocate and reorganize itself virtually and to respond instantly to any prompt changes requested by stakeholders in the value chain.

In addition to industry itself, Industry 4.0 had many significant consequences for several other socio-economic fields, such as developing new businesses and service models, generation of new types of complex, smart services and products, modern business management systems, collaborative and interactive work environment, which in total led to major changes in the required human skills, as well as in the demographic and social life (Pereira, Romero 2017, p. 1212).

Witkowski (2017, p. 769) examined the impact of utilizing Industry 4.0 techniques, including big-data and the Internet of things, as innovative approaches to supply chain management. He concluded that Industry 4.0 created opportunities to develop logistics and supply chain management, hence, satisfying the needs of customers and improving the time of implementation and provision of services Mrugalska and Wyrwicka (2017, p. 471) examined the impact of Industry 4.0 on lean production techniques. These techniques were successfully challenged in the Industry 4.0 integrated mass production environment. Industry 4.0 has helped to eliminate waste during production by eliminating anything that does not add any value to the product.

Kuo, Ting and Chen (2017, p. 50-52) installed sensors and utilized simulation and artificial intelligence techniques to design and implement an automatic machine prediction model that predicts machine health status and diagnoses any quality defects resulting from machining failures. This resulted in a cost-effective solution for monitoring the production process to improve the quality of products using Industry 4.0 technologies.

Moreover, Albers et al. (2016, p. 265) suggested a three-phase procedure for identifying and running the Industry 4.0 intelligent quality control system, within which a single production process was analyzed to identify quality-related production issues that shall be addressed with an intelligent condition monitoring

quality control system. This procedure is important to help industries move forward in developing their quality control systems in Industry 4.0.

Industry 4.0 became an umbrella for several innovative technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), big data, and cloud computing. As a result of integrating these technologies in the industry, new capabilities and possibilities reinforced the traditional quality techniques and improved the effectiveness and efficiency of production systems. The aim of this paper is to discuss the impact of Industry 4.0 on quality management practices such as "quality assurance", "quality control", and "total quality management". The first chapter will highlight the key features of Industry 4.0 which are relevant to the topic of this research work; it will also present a review of quality management practices and then discuss and conclude the impact of Industry 4.0 on improving quality management practices.

Literature review

Industry 4.0 Features and Technologies

Industry 4.0 came as a result of the advancement in information and communication technologies (ICT), and the integration of this sector with industrial technologies, which led to establishing the so-called: "cyber-physical systems", introducing the "intelligent factory" (Zhou, Liu, Zhou 2016, p. 2148), where machines, products, and people were able to interact and communicate to each other (Husti, Daroczi, Kovacs 2017, p. 66). This advancement boosted digitization and automation in the manufacturing environment and created a digital value chain which eliminated boundaries between digital and physical worlds (Pereira, Romero 2017, p. 1213).

There are several features that characterize Industry 4.0. These are interconnectivity, integration, and big data (Wang, He, Xu 2017, p. 1). *Interconnectivity* refers to the ability of products to communicate with the production system across the value chain. By reading product information, the production system can transfer this information to the cyber-physical system, simulate and iterate scenarios to achieve an optimum production scheme (Wang, He, Xu 2017, p. 1). Machines that are connected to each other can be informed when a part being produced passes from one stage to another, so that the machine is ready to receive the part to continue further production stages. Logistics will also be informed when it is needed during the production process (Blanchet, Rinn 2015, p. 8).

Horizontal integration refers to the collaboration and cooperation between technological and information resources in the value chain, from the supplier to the end-customer, which results in real-time services and products (Zhou, Liu, Zhou 2016, p. 2148). *Vertical integration* refers to the integration between departments and different business units inside the organization, including marketing, research and development, financial, logistics and sale departments etc. (Pereira, Romero 2017, p. 1210). *End-to-end integration* is the total integration of all business units, performing a decentralized system where all participating entities have real-time

access to information and control orders are distributed to the production floor instantly (Brettel et al. 2014, p. 40).

Big-data is the technology which is used to store and analyze the huge amount of data which is generated, gathered and stored from several sources. Big data can deal with huge volume of data and can transform this data into useful and user-friendly information. Big data is used widely now as a decision supporting system, where data, despite its volume, variety, velocity, and value, is deeply analyzed, visualized and presented in a clear format to managers (Witkowski 2017, p. 768).

Industry 4.0 is characterized by three paradigms: *smart machine*, *smart factory* and *augmented operator*. A smart product has the ability to interact with the machining processes, transfer operational data and manufacturing requirements which are stored in a small memory chip fixed to it. A smart machine has decentralized, self-organization capabilities, which allow the machine to locally control itself and collaborate with other machines connected to the same network. An augmented operator monitors, verifies, and interferes when needed to enhance the production strategy (Mrugalska, Wyrwicka 2017, p. 471).

Figure 1 below summarizes the key features and capbilities offered by these paradigms to improve production systems.

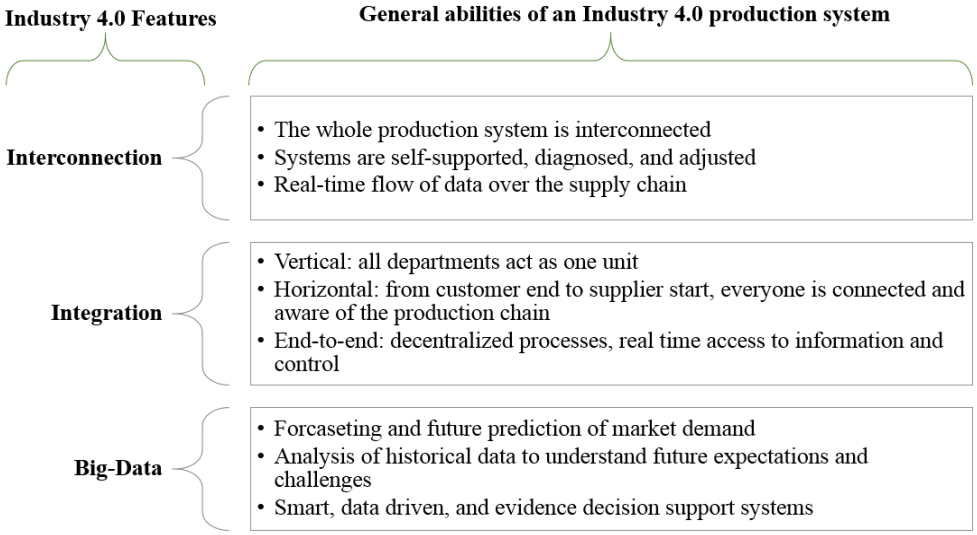

Figure 1. Capabilities offered by Industry 4.0 Key features

Source: Based on own research

Industry 4.0 aims to obtain a flexible and automatic adaption of the value chain, to offer the ability to customize products and maintain mass production at the same time, and to facilitate communication among all production elements; products, machines, humans, and resources. Furthermore, it aims to optimize production and to provide an advanced level of interaction and coordination between different resources (Blanchet, Rinn 2015, p. 12).

Quality Management

Quality has been used as a strategic weapon for businesses to attract and retain customers and to obtain a competitive advantage for the organization. Kanji (1990, p. 11) defined quality as "*conformance to requirements, where requirements are defined as the task to be accomplished in meeting customer needs*". Organizations seek customer satisfaction by providing services and products that fulfil or exceed customer expectations (Foidl, Felderer 2016, p. 127). For manufacturing companies, it is important to increase product competencies, reduce the cost of failures, and improve effectiveness and efficiency (Foidl, Felderer 2016, p. 128). Quality is a continuous approach for organizations and should always be practiced in order to maintain the organization's competitive position. Employees must be motivated to maintain a high-quality level of their work.

There are several approaches to quality management, such as quality control, quality assurance and total quality management (Kanji 1990, p. 5). Total quality management (TQM) has been used as an approach to produce high-quality products that meet or exceed customers' expectations (Yusof, Aspinwall 2000, p. 803). TQM helped countries like Japan take up a global leading position in terms of product quality and business excellence. A few years after the Second World War, Japan became the world star when it comes to the quality of products.

Methodology and Discussion

The aim of this chapter is to discuss the impact of Industry 4.0 on improving quality management practices. A theoretical model is suggested to integrate Industry 4.0 features and paradigms with quality management practices.

Integrating Industry 4.0 with Quality Management

Albers et al. (2016, p. 262) summarized the influence of Industry 4.0 on the industry from the perspective of quality. Studies reported a 50% increase in productivity and 80% of companies using Industry 4.0 indicated its impact on increasing efficiency, whereas 45% believed that Industry 4.0 improved customer satisfaction thanks to the elimination of defected products.

Industry 4.0 offered many possibilities for quality management practices; the technological advancement provided new techniques to ensure the quality of products, new inspection tools, new early failure detection methods, and self--adaptation possibilities, which enabled the production facility to re-design its production lines to respond to customers' requirements, fluctuating demand, or to avoid machine failure or downtime.

Interconnectivity as a key feature of Industry 4.0 enabled the production system to be more flexible, as the entire system is interconnected, and its every part is aware of what is happening to other parts. Moreover, the real-time flow of information from machines, facilities, and labour to and from the factory management made the decision-making process more effective, reliable and prompt.

With horizontal, vertical, and end-to-end businesses integration, departments and business units can act as one unit integrated internally and externally with suppliers and customers. Information from the end-customer to the supplier flows smoothly, customers' orders are transferred instantly along the value chain, notifying the involved parties, customers are able to monitor their product being made in real-time and they can provide further customization when needed. Collaboration among different managerial and operational departments enhanced the coordination and resulted in a dynamic and effective working environment.

Big data which is gathered from ERP systems, sensors, statistics and social media, is processed and modelled in order to provide sufficient and useful visual information that can be used for several quality purposes. For instance, historical data about customers' behaviour could be used to improve production schemes to handle fluctuating demand and balance other production schemes. Moreover, big data can be used to develop artificial intelligence models toenable the machine to make an instant decision at the production floor, it could alert operators to make recommended actions such as predictive maintenance or better production arrangements.

Quality management has never been as smart as when utilizing Industry 4.0 features. *Figure 2* represents the flow of information, data and operational orders from and to the production level. Information is streamed from customers and markets to big data themes, where it is analysed and transferred to production systems as production orders containing instructions, quality specifications, and volumes. The production system will transfer the received orders automatically from the ERP to the CPS to suggest optimum production schemes, where the re-allocation of processes could occur based on new production orders. During the production, sensors transfer data to the big data and ERP systems; this data include row-material requests, maintenance requests, in-process quality reports, and production analysis. Any instant changes occurring during the production (i.e. if production defects were detected or machine failure occurred) will be analysed instantly, and responses are sent automatically to the relevant parties.

From a quality management perspective, sensors and in-process quality control devices will send real-time information to the global big data system and locally at the smart machine level, which will be able to analyse and make proper decisions accordingly to avoid defects, system failure or downtime. Production is optimized by applying lean manufacturing and supply chain management techniques.

The production system can communicate with the ERP and CPS to analyse the production schemes, define production priorities, and align resources. The real-time quality inspection will help to ensure that quality requirements are fulfilled and any causes of defects or production failures are avoided and eliminated.

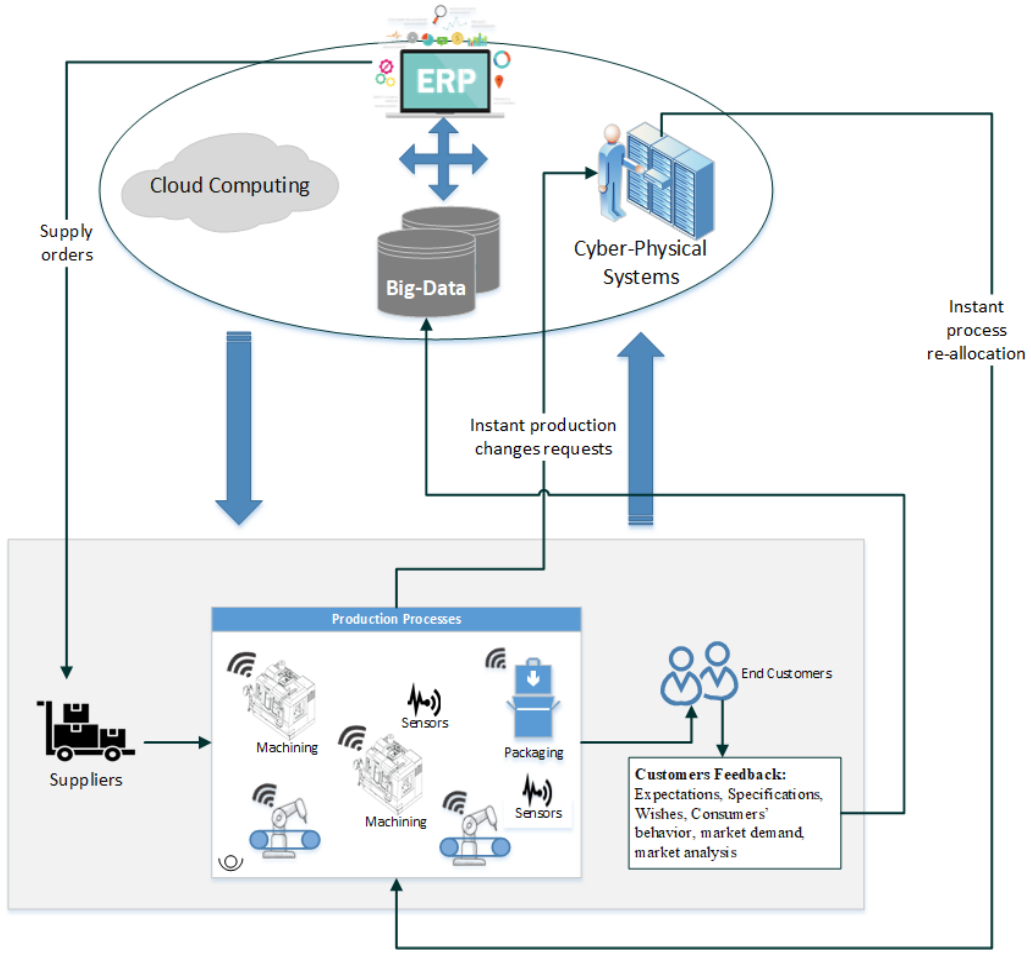

Figure 2. Integration of Industry 4.0 technologies in the value chain

Source: Developed based on own research

The Industry 4.0 quality integrated system will enhance production, ensure that all quality requirements are fulfilled, and total quality management practices from end-customers to suppliers are effectively carried out. Within such system, the cost of quality is minimized, as defective products are early detected, communication with the end-customer is effective and the production system is responsive to market demand.

Conclusions

It is obvious that Industry 4.0 has an important potential to enhance quality management approaches. Quality control and quality assurance are backed by the features and possibilities offered by Industry 4.0. The following are the main

contributions offered by Industry 4.0 to such enhancement, as summarized and discussed in this research paper on the basis of the reviewed literature:

- Developing real-time monitoring and premature failure prediction systems.
- In-process intelligent quality assurance systems which enabled total inspection for products.
- Data analysis and visualization of information which facilitated evidence-based decision making.
- Enhanced integration of the production systems, from suppliers to end-customers, which minimized product lead time, increased responsiveness and improved customer satisfaction.
- Optimized lean production systems and the ability to produce customized products for different customers' demands.
- Optimizing supply chain and logistics management strategies.
- Provided bases for successful implementation of total quality management practices.
- Minimized quality cost thanks to early detection of defects (quality control) and early elimination of their causes (quality assurance).
- Reliable, smart, dynamic planning techniques thanks to rich decision supporting systems and visual information provided by ERP, big-data, and CPS.
- Dramatical change from traditional to smart (product, factory, and augmented operator) production systems, which enhanced productivity and minimized defects.

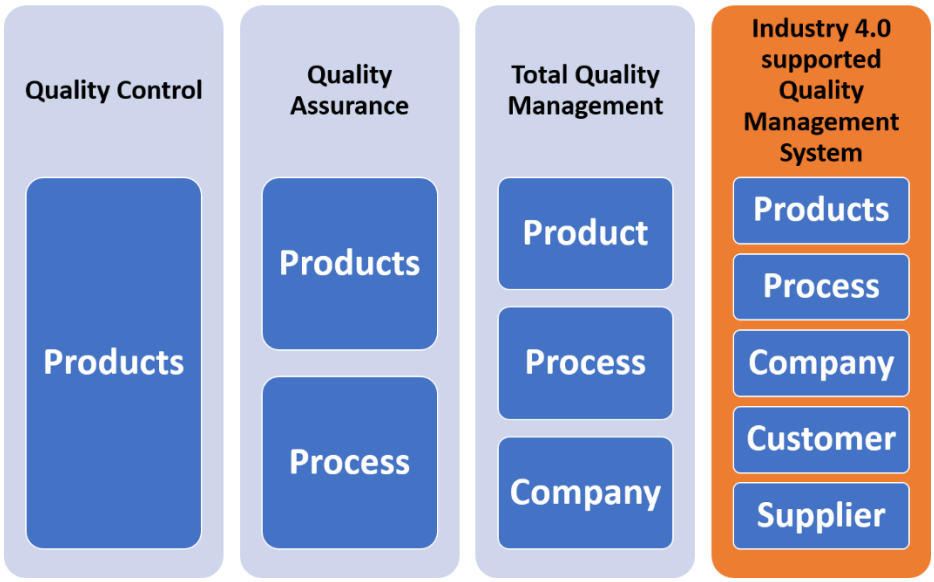

Figure 3. Suggested integrated Industry 4.0 – Quality Management System

Source: Based on own research

All the above-mentioned implications of Industry 4.0 on production systems are supposed to influence quality management strategies and will obtain new methodologies to quality control, quality assurance, and total quality management. *Figure 3* elaborates the new capacities offered by Industry 4.0 to quality management and shows the expanded capabilities earned as a result of integrating the features of Industry 4.0 with quality management practices. However, future research could contribute more to find new implications and examine the impact of Industry 4.0 in quantitative approaches.

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PRAKTYKI ZARZĄDZANIA JAKOŚCIĄ W ERZE PRZEMYSŁU 4.0

Streszczenie: Przemysł 4.0 to najnowszy trend, który jest szeroko dyskutowany w badaniach z różnych perspektyw. Przemysł 4.0 odnosi się do czwartej rewolucji przemysłowej, która w niektórych opracowaniach naukowych bywa określana jako kolejny etap „ewolucji" przemysłowej, wynikający z integracji z przemysłem innowacyjnych technologii, takich jak Internet rzeczy, systemy cyberfizyczne, Big Data, robotyka, sztuczna inteligencja oraz chmura internetowa. Rozwój ten zapoczątkował nowe techniki mające na celu usprawnienie różnych gałęzi przemysłu. Taka integracja znacznie poprawiła systemy produkcyjne, stworzyła inteligentniejsze i bardziej elastyczne łańcuchy dostaw oraz polepszyła jakość produktów dzięki natychmiastowym, masowym i rzeczywistym systemom kontroli jakości. Przemysł 4.0 ma silny wpływ na wiele dziedzin społeczno-gospodarczych, dlatego naukowcy coraz częściej koncentrują się na rozwiązywaniu problemów na różnych poziomach. W związku z tym celem niniejszego artykułu jest omówienie wpływu Przemysłu 4.0 na systemy i praktyki zarządzania jakością, takie jak kontrola jakości, zapewnienie jakości i kompleksowe zarządzanie jakością. W publikacji dokonano przeglądu najlepszych praktyk w zakresie jakości i zaproponowano nowoczesne ramy zintegrowanego modelu (jakość przemysłowa 4.0), w którym Przemysł 4.0 jest bezpośrednio powiązany z praktykami jakościowymi, w celu uzyskania nowego poziomu praktyk jakościowych.

Słowa kluczowe: Przemysł 4.0, zapewnienie jakości, zarządzanie jakością, kontrola jakości, inteligentne systemy kontroli jakości, Jakość 4.0