SUGGESTED INDICATORS TO MEASURE THE IMPACT OF INDUSTRY 4.0 ON TOTAL QUALITY MANAGEMENT

Sami S. A. Sader.[1], Professor István Husti.[2], Miklós Daróczi.[2]
Ph.D. Student, Doctoral School of Engineering, Szent István University, [1]
Institute of Engineering Management, Faculty of Mechanical Engineering, Szent István University [2]
Páter K. u. 1., Gödöllő, H-2103, Hungary

Sami.S.A.Sader@phd.uni-szie.hu, husti.istvan@gek.szie.hu, daroczi.miklos@gek.szie.hu

Abstract: *The development of "Smart Factories", featured by the arrival of "Internet of Things", "Cyber-Physical Systems", "Cloud Computing", "Big Data" etc., became widely deployed at the industrialized economies. Several researches highlighted the impact of utilizing such technologies (so-called Industry 4.0) on the industry; i.e. enhancement of products' quality, manufacturing processes, and customers' satisfaction. However, very few researchers focused on determining the impact of Industry 4.0 on enhancing the practice of Total Quality Management (TQM). This paper identified the set of qualitative and quantitative measures that can be used to determine the impact of implementing Industry 4.0 technologies at any industrial firm from a TQM perspective. The paper explored the TQM principles, identified qualitative and quantitative measures to be assessed, and suggested the means of data gathering sources and analysis techniques, hence, it would be possible in further research to determine the quantitative impact of Industry 4.0 on TQM*

Keywords: Total Quality Management, Quality Assurance, Industry 4.0, Big-data

1. Introduction

The tremendous development in every technological field reached an outstanding position in the recent decade, communication and networking technologies are quietly advanced, evolution of broadband and wi-fi connections, Internet of Things, Big Data, artificial intelligence and Cloud Computing, paced up an intelligent era symbolled by "Cyber-Physical Systems", which accordingly paved the way for further revolutions in several fields, hence, the industrial fields.

Industry 4.0, interpreted by several literatures as the "fourth industrial revolution", appeared firstly in 2011, and publicly announced in 2013 during the Hanover fair in Germany as the next industrial vision (Qin, Liu, & Grosvenor, 2016; Scheer, 2013; Zezulka, Marcon, Vesely, & Sajdl, 2016). Industry 4.0 came because of the increasing demand for innovative solutions in production and logistics, producers are focusing on creating greater value for customers, who are becoming more aware and demanding more advanced, reliable, personalized and high-quality products (Witkowski, 2017). Industrial businesses are seeking more competitive position through acquiring flexible production lines, zero inventory, efficient resources allocation, high responsiveness to market demand, lower logistics and labor costs, and to acquire more competitive advantages above other competitors (Rennung, Luminosu, & Draghici, 2016; Wang, He, & Xu, 2017).

The impact of utilizing technological solutions on the quality of industrial production was mentioned in several researches. Modern technologies assisted several quality approaches such as quality control and quality assurance techniques. Real-time quality monitoring and failure prediction models were developed by the help of new sensing technologies and big data analysis (Jiang, Jia, Wang, & Zheng, 2014).

The aim of this paper is to identify a set of qualitative and quantitative measures that can be used to determine the impact of implementing Industry 4.0 technologies at any industrial or business firm from a TQM perspective. The first section of this paper explores Industry 4.0 competences, and its impact on industrial advancement. The second section reviews the TQM principles, identify qualitative and quantitative measures to be used as assessment measures for good TQM practices. Accordingly, the discussion section will suggest the meeting point between Industry 4.0 and TQM, hence, determine the quantitative and qualitative indicators to assess the impact of Industry 4.0 on TQM.

2. Industry 4.0

The evolution of industrialized economies passed through three previous industrial revolutions; ***mechanization***, ***electrification*** and ***information*** (Zhou, Liu, & Zhou, 2016). ***Mechanization*** represent the first industrial revolution, initiated in the 18th century and symbolled by the utilization of mechanical production using water and steam power. The emergence of ***electricity*** at the beginnings of 20th century revolutionized the industry for a second time; electricity enabled industrial automation using electrical conveyors and assembly lines, this facilitated mass production in order to respond to the accelerating population growth after second world war. The third industrial revolution was symbolized by the further usage of mechanical ***automation***, using programming (programmable logic controllers) and mechanical robotic arms. (Blanchet & Rinn, 2015; Keller, Rosenberg, Brettel, & Friederichsen, 2014; Qin et al., 2016; Zezulka et al., 2016; Zhou et al., 2016)

The fourth industrial revolution (***Industry 4.0***) came as further ***evolution*** for the three previous revolutions, it came as a result of the advancement occurred in information and communication technologies (ICT), and the integration of this sector with industrial technologies, establishing the so called: "Cyber-Physical Systems", introducing the "Intelligent Factory" (Zhou et al., 2016), where machines, products, human became able to interact to each other and act autonomously.

There is no single definition for Industry 4.0, several definitions were introduced by several scholars. In his literature review (Lu, 2017) highlighted three definitions for Industry 4.0. ***Firstly***, Consortium II Fact Sheet, defined Industry 4.0 as "the integration of physical machinery systems with networked sensors and software used to predict, control and plan for better business and societal outcomes." ***Others*** defined Industry 4.0 as "a new level of value chain organization and management across the lifecycle of products.". A ***third*** opinion defined Industry 4.0 as "a collective term for technologies and concepts of value chain organization." Industry 4.0 is characterized by the integration occurred based on the Cyber-Physical Systems, Wi-Fi connectivity, Smart robots and machines, big-data, and smart factory to build an intelligent manufacturing system, emphasizing consistent digitization and linking of all productive units in an economy (Blanchet & Rinn, 2015). A core aspect of Industry 4.0 is the continuous connection between human, machines, and products during the production process (Albers et al., 2016).

Industry 4.0 is characterized by three key features; ***Interconnection***, ***integration***, and ***big data*** (Wang et al., 2017). ***Interconnection*** is the core feature of Industry 4.0, it means that all kinds of machines doing various jobs are interconnected together, forming an intelligent digitized value chain, where the product can hold readable information that can be understood by machines, thus, the machines can process the product, and when it is needed, it can

re-adjust, diagnose, and repair production tactics until achieving an optimal situation (Zhou et al., 2016).

Integration is the ability of Industry 4.0 to perform vertical, horizontal and end-to-end integration. ***Vertical Integration***, refers to the networked smart business units; e.g.: smart factory, smart logistics, smart marketing, and services (Mrugalska & Wyrwicka, 2017), where manufacturing units are coordinating and communicating smoothly. ***Horizontal Integration*** over the value chain, refers to the forward to backward (customer to supplier) integration. Horizontal Integration enabled the manufacturing environment to become collaborative during the stages from development to production, resulting more efficient, reliable and effective manufacturing. ***End-to-End*** integration is the total integration of the entire process, performing a decentralized system where all participating entities have real time access to information and control is distributed to the production floor instantly (Keller et al., 2014).

The rapid development of internet and networking, produced huge amount of information which needed innovative methods and tools to handle (Blanchet & Rinn, 2015). ***Big Data*** and cloud computing granted the ability to conduct quick and efficient management for the constantly growing databases. Big Data consists of four dimensions: Volume, Variety, Velocity, and Value. These so called (4Vs) refers to the characteristics which allow Big Data to analyze data at a more advanced level than traditional tools (Witkowski, 2017).

The above described features, enabled the Industry 4.0 to provide solutions for different fields in the industry, advanced monitoring and analysis techniques, process and functional optimization, decision supporting at different organizational levels, moving from centralized to decentralized model of management, and upgraded the management approach from the traditional popular model to a modern one at several sides. This advancement came synchronized with the recent global trends in business, where the world is becoming more connected; global business models are expanding, and customers are more open to online shopping, demanding innovative products, with more personalized specifications. Moreover, new emerging economies are coming as key players at the global industrial stage, leading industrialized economies are experiencing key challenges, such as aging communities, the open competition with Asian economies of scale. All these challenges became the foundations of adopting Industry 4.0 technologies (Blanchet & Rinn, 2015; Federal Ministry of Education and Research-Germany, 2014).

To sum up, Industry 4.0 aims to obtain a flexible and automatic adaption of 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, human and resources. Furthermore, it aims to optimize production and to provide advanced level of interaction and coordination between different resources.

3. Total Quality Management (TQM)

Quality is defined as "the conformance of a product to customer requirements", this implies that all tasks and activities made during the production fulfill the specifications translated from the requirements of the customer. Quality is a continuous approach aims to satisfy customers, it is not limited to screening out defective products, but also to reduce defects completely through building up enough knowledge about processes and functions (Kanji, 1990).

Total Quality Management (TQM) is a managerial approach that leads an organization to achieve a world-class position by insuring that its products and services satisfies customers, meeting their requirements and expectations (Yusof & Aspinwall, 2000). The Term "Total Quality Management – TQM" was first suggested and leaded by the American scientist Deming, who traveled from the United States of America to Japan to help the Japanese industrial firms to recover from the World War II. During his work, he implemented the statistical quality control and process control, as tools to trace production errors and to identify the source of products' defects (Kanji, 1990). Later, he met with Juran, who was stressing to focus on customers' satisfaction through producing fit-to-use products that fulfills the customers' needs. Shortly, both Deming and Juran successfully caught the attention of market all over the world, their innovative ideas increased the production rates in Japan, and contributed very strongly to the Japanese well-known successful industrial miracle (Kanji, 1990).

Since then, the philosophy of TQM has been enhanced and expanded, several TQM approaches were suggested to guide the good implementation of TQM at organizations. The goal was to benefit business stakeholders, where everyone at the organization as well as the business processes are cooperating to produce value-for-money products and services, that fulfils and positively exceeds customers' expectations (Dale, 2015). Researchers found strong evidences that TQM has improved the organizational effectiveness, flexibility, competitiveness, excellence, creating positive attitude, and a source of creating continuous improvement culture at the organization (Anu P. Anil & Satish, 2016).

Generally, the successful implementation of any managerial practice is measured by several success factors and the well implementation of several practices (Mrugalska & Wyrwicka, 2017). Based on several literatures, there are several approaches to achieve TQM, the most popular practice to attain TQM principles are those identified in (ISO 9001: 2015) model, which highlights the following practices to be the most effective for application: Customer focus, Leadership, engagement of people, process approach, improvement, evidence-based decision making, and relationship management (International Organization for Standardization, 2015).

Other practices were identified in different literature, such as; top management commitment, Continuous improvement, supplier quality management, employees' involvement and empowerment, education and training, strategic management, utilizing statistical quality control and quality assurance techniques, developing the quality culture among the organization, benchmarking, process and product management (Anu P. Anil & Satish, 2016). However, it should be emphasized that these practices are finally aiming to support the competitive advantage of the organization by producing high quality products or services and enhancing customer satisfaction.

4. Influencing Total Quality Management by Industry 4.0

The features of Industry 4.0 provided a solid rock for supporting business excellence; interconnectivity provided the ability of businesses to perform more efficiently by utilizing networking technologies, sensors and actuators. The whole value chain of production became interconnected, machines are connected to each other as well as to products and labor. Production processes can re-adjust itself to the optimal production scenario even when an urgent change occurs, early maintenance alerts are better to predict, logistics, warehousing, resources are allocated efficiently and effectively.

Integration of all business units, customers, and business partners (horizontal, vertical, and end-to-end integration) reformed the business model from linear to networked form, where all business units are connected to each other, and flow of work is running smoothly and efficiently.

In terms of Quality Assurance, the utilization of Industry 4.0 will upgrade the employees' role from routine activities, to higher level of control and regulation for the manufacturing process, based on situation and context sensitive targets. The employees focus will be on creating innovative and value-added activities, which will be reflected to improve the quality assurance practices (Henning, Wolfgang, & Johannes, 2013). Moreover, Industry 4.0 will provide

a real-time process monitoring to ensure that quality specifications are met during processing. Real time quality control will also enhance the quality control activities and will provide an early alarm for changes in products' quality. Internet connectivity will also provide the ability to track the product even after sale and gather information about its performance during operation. (Lee, Kao, & Yang, 2014)

Industry 4.0 can influence the best practices of implementing Total Quality Management principles. As mentioned before, TQM practices are known to be like the ISO 9001:2015 model, which are: customer focus, leadership, engagement of people, process approach, improvement, evidence-based decision making, and relationship management (International Organization for Standardization, 2015). Industry 4.0 will be able to serve the successful implementation of these principles as following:

- **Customer Focus**: Industry 4.0 will enable organizations to improve their customers' satisfaction through improving their products and services, fulfilling and innovate new products that exceed customers' requirements and expectations. Industry 4.0 will enable industries to provide customized products at a regular time, away from the complexity of changing mass production systems. Moreover, Industry 4.0 will provide businesses with early forecasting about consumption behavior and trends, thus, providing a competitive advantage for the business by providing proper products at the proper time.

- **Leadership**: Evidences showed that Industry 4.0 had a significant impact on information flow over the production line, integrating the business processes and supporting the ERP systems to optimize manufacturing management (Lee et al., 2014). Industry 4.0 will provide transparent production processes, thus, aligning resources such as labor and machines to demand will be efficient and optimized.

- **Engagement of people**: Industry 4.0 will support the communication and collaboration of all players inside the organization, it will stimulate innovation, encourage individual contributions. Data provided by Industry 4.0 outcomes will help people at their functional positions to use this data to avoid risks and suggest solutions, hence, be more initiative.

- **Process approach**: Industry 4.0 will support the transparency of business and production processes in the organization, it will help to optimize processes, improve efficiency and resources allocation. Industry 4.0 will provide the possibility to simulate processes in a virtual environment, adjust and modify virtually before real implementation on the floor, this will enhance processes to achieve optimum situation (Husti, Daroczi, & Kovacs, 2017). Moreover, Industry 4.0 will facilitate tracing production bottleneck, defects' sources, and minimize production cost. Additionally, it will improve the supply chain responsiveness, through total integration from market demand back to suppliers (Wang et al., 2017). Industry 4.0 will provide accurate information about processes (time, risks, resources, critical constraints) thus, it will help the planning level of key-processes to maintain continuity and efficiency.

- **Improvement**: Industry 4.0 will provide a basis for continuous improvements at the product, process and the business level for an organization. Totally connected production and supply chain will improve performance and responsiveness of the system. Experiments showed the ability of products (automobile industry as an example) to send information to the producing companies about operating problems, thus, enhancing future products to overcome such problems.

- **Evidence-based decision making**: Industry 4.0 and the new IT solutions such as big data, afforded a great capacity to improve the decision-making process in real time (Husti et al., 2017). Machines are self-learned, connected to each other forming a collaborative community, collecting and analyzing data, providing ability to make independent decisions. Experiments show that Industry 4.0 techniques can send earlier prognostics about machine health, reducing downtime and afford maintenance on time.

- **Relationship management**: total integration and effective communication between all stakeholders of an organization became one of the benefits of Industry 4.0. Suppliers are connected with production systems, understanding the organization needs, and responsive to markets demand more than ever before.

Accordingly, the impact of Industry 4.0 on the successful implementation of TQM will be measured by identifying a set of indicators that represent each of the TQM principles identified earlier in this paper. The following list of indicators are identified based on the TQM principles and the measurement means based on Industry 4.0 technologies. Table 1 summarizes the sets of indicators assigned to each of the TQM principles:

Table 1: Set of indicators used for measuring Industry 4.0 impact on Total Quality Management.

TQM Principles	Indicators for improvements	Industry 4.0 impact Indicators	Means of Measurement
Customer Focus	• customer satisfaction & loyalty, • growth % in customers' base, • Improved organization's reputation.	• Response time to customers' orders, product customization, and new product developments • Easy to gather customer feedback through smart product connectivity • Realtime in-field performance product monitoring	• Internet of Things, Wi-Fi and Big-Data will be utilized as data gathering and analyzing tools.
Leadership	• Unity of purpose among the organization, • Aligned strategies, policies, processes and resources, • Effective communication between all administrative levels.	• Effective allocation of different resources (operational effectiveness) • Increased revenues due to optimized allocation of resources	• Realtime resources monitoring and automatic regulation and reallocation. • System monitoring dashboards, ERP systems
Engagement of people	• Increase motivation of people, • Increasing innovative ideas, • Enhanced people satisfaction, • Self-evaluation and self-improvement culture.	• Number of innovative ideas or initiatives created or taken by employees • Increased value (%) of employees' satisfaction • Increased revenues due to less human related failures • Number of problems solved by employees	• Human Resources smart systems • Statistics and data gathered during production
Process approach	• Identify key processes and points of improvements, • Optimized performance and effective process management, • Manage processes, and interrelations, as well as dependencies.	• Number of process re-design activities made because of data analysis and enhancement decisions • Production lead time • Suppliers' responsiveness to new supply orders • In-process real time quality control activities (percentage of defects) • Decreased percentage of processing downtime	• ERP system (integrated with customers and suppliers) • Sensors and actuators within production process • Process related big-data analysis • Internet of things (machines data) • Maintenance management system
Improvement	• Responsive systems to customer requirements, • Enhanced ability to react to development of processes, products and market needs, • Support drivers for	• Enhanced percentage of response time (production lead time) • The range of customization options that can be	• ERP system and CRM system • Big-data themes • Customers feedback

	innovation.	fulfilled by the business without affecting the productivity normal rates • Number of newly developed products and time needed to introduce it to markets	
Evidence-based decision making	• Clear and agreed decision-making process, • Data availability and clarity, • Effective past decisions, • Analyze and evaluate data using suitable methods and tools.	• Increased revenues due to recently take decisions • Number of reporting and automatic recommendations learned by or from the smart production system • Ease of data mining and friendly presentation of results and recommendations	• Big-Data analysis • ERP system
Relationship management	• Stakeholders are identified and suitable communication tools to each are known, • Stakeholders are satisfied, and their feedback is considered, • Suppliers are responding to materials requests on time and at the required quality, • Supply chain is stable and no downtime due to lack supply.	• Number of received to processes communications from stakeholders. • Rate of satisfaction for stakeholders is improving continuously • Improved suppliers' responsiveness rate • Percentage of downtime due to lack of supply is in its minimum value	• ERP system (integrated with customers and suppliers) • Sensors and actuators within production process • Process related big-data analysis • Internet of things (machines data)

5. Conclusion and further research topics

Industry 4.0 positively influenced the successful implementation of Total Quality Control, technologies and approaches utilized by Industry 4.0 improved the quality assurance and quality control experience. Communication and big-data sources improved better understanding and enhanced responsiveness for customers' requirements, hence, improved their satisfaction. Smart factory, smart product, and smart machines, are new terms referring to high connectivity and integration of smart technologies in the value chain, this resulted more dynamic production processes that are able to adjust according to optimum real-time requirements.

There are several researches that mentioned the positive impact on quality, but these researches highlighted this impact briefly and in qualitative manner. However, it is important to conduct further applied research to translate the indicators suggested by this paper into active and real-time measures. It is important also to reflect the changes occurred and the capabilities offered by Industry 4.0 on the quality management models. Hence, developing a new quality management model which should be based on Industry 4.0 technologies, considering that quality requirements in the ongoing present and coming future is different and advanced

6. References

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