A Study of Quality Tools and Techniques in the Context of Industrial Revolution 4.0 in Malaysia. What's New?

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Abstract

The purpose of this article was to explore a systematic pattern for selecting quality tools and techniques in industrial revolution 4.0 particularly in smart manufacturing context. This study asked, "What are the appropriate Quality Management tools and techniques in the context of the Industrial Revolution 4.0 particularly for smart manufacturing?" To answer this question, multiple case study and in-depth literature review were employed as the research design approach. Two key data collection methods (qualitative methods) were used: (1) Primary data from face-to-face interview with Toyo Memory Technology and Intel Malaysia (2) Secondary data from previous study. This review coupled with the case study analysis led to the identification on the real implementation of quality tools and techniques in the industries. Thus, the researchers gained the information on how the industries select the quality tools and techniques to manage quality performance in the organization and the researchers examined the association and prevalence of different quality tools and techniques in context of smart manufacturing. As a result, industrial revolution 4.0 for quality management practices might get high impact for the best performance assessment in which it is addressed in various ways, particularly there are very few studies in this area that have been conducted in the Malaysian manufacturing sector, and to recommend the best practices implemented from the managers' perspectives. Finally, for scholars, this article can enhance their understanding of Industrial Revolution 4.0 and quality management practices as well as highlight opportunities for further research.

Keywords: *quality management; quality tools and techniques; industrial revolution 4.0; smart manufacturing; case study.*

1. Introduction

The world is facing a tremendous 4th industrial revolution in manufacturing and production control, being dominated by the penetration of internet technologies into smart manufacturing environments and a paradigm shift from hierarchic production management to self-organization and self-optimization on the manufacturing floor, also the changes in quality control will be revolutionary (Gluck, M., Wolf, J. 2014). With the involvement of the Industrial Revolution it is important to have a good through quality management where is a source that become the competitive advantage and leadership that carry the values in the organization and successfully not neglecting the technology and the capabilities of the organization have to analyse and operationalize that data towards optimizing and benefiting the organization, (Davenport et al., 2012; McAfee and Brynjolfsson, 2012; Constantiou and Kallinikos, 2015; Henke et al., 2016).

Likewise, the advanced technical features suggest that the Industry 4.0 exhibits an attractive and promising production paradigm. It has a significant contribution to the quality improvement system as well as a product which can cope with the global challenges. As such, the customized products can be produced effectively, efficiently, and profitably (Gluck, M., Wolf, J. 2014).

In turn, measure of modern quality management aiming for sustainable success does not only mean to avoid the delivery of defective products to the customer, but seek to establish maximum efficiency in the performance of all process of the company. With such optimized procedures, products of high quality can be provided with minimum effort of time and costs (Werner and Weckenmann, 2012). For all those quality improvements to be happening, the implementation of smart manufacturing is needed. Smart Manufacturing can improve quality management through improving productivity in the production process as well as manufacturing planning (Wang & Wang, 2016).

Further, the smart manufacturing can communicate with each other under quality management system to reconfigure themselves for flexible production of multiple types of products with high quality improvement. Smart manufacturing has the potential advantage in bringing stronger integration of the top floor and shop floor and thus more intelligence and flexibility to production. An additional, smart manufacturing will allow manufacturer to improve quality system through using data from production, service, and quality control which will lead to quality improvement of both product and process.

In relation to the quality perspective, several studies have been conducted to verify the priority and importance of different tools and techniques for quality improvement. For instance, previous study conducted by Tari and Sabater (2004) found that the most frequent tools and techniques used within ISO certified firms in Spain are audits, graphs, SPC, and flow charts, respectively. On the other hand, the least used tools and techniques in the firms studied were the basic tools. Another study by Drew and Healy (2006) of Irish organisations discovered that the most and widely used quality tools were customer surveys, followed by competitive benchmarking.

In the study by Fotopoulos and Psomas (2009), it was found that two thirds of the organizations used easy to understand quality tools, which included check sheets, flow charts, and data collection, while the remaining tools and techniques had very limited implementation. Also, a study conducted by Swedish quality professionals by Lagrosen and Lagrosen (2005) revealed that the application of all quality tools and techniques was generally limited, except for flowcharts, which were used extensively. Although quality tools and techniques were used significantly more often in larger organizations (Fotopoulos & Psomas, 2009), they could be implemented in all organisations, regardless of size or type (Basu & Wright, 2012).

In most recent studies carried out by authors such as Gluck, M., Wolf, J. (2014); Mosconi, (2015) in the areas of quality management and Industrial Revolution 4.0 seem lack to see how current quality tools and techniques need to change, improvise and to be in line with development of the Industrial Revolution 4.0 particularly in the area of smart manufacturing.

Thus, all of the above literature suggests that there is an ample amount of literature review on quality management tools and techniques, the majority of studies have been conducted to measure or eliciting the view of quality management tools and techniques from customers' perspectives or with the attention given to examining quality tools and techniques practices from managers' and employees' perspectives. Consequently, based on relevant quality management review, this article contributes to the quality management literature by fulfilling the following gap:

"There are very few studies in the field of quality management that have been comprehensively conducted for selecting the appropriate quality tools and techniques in industrial revolution 4.0 particularly in smart manufacturing context".

In saying that, therefore this article aims to answer "What are the appropriate Quality Management tools and techniques in the context of the Industrial Revolution 4.0 particularly for smart manufacturing?"

The rest of the paper is structured as follows: the first section provides the literature review on the quality management tools and techniques, smart manufacturing in Industry 4.0 for quality management and quality tools and techniques of smart manufacturing in Industry 4.0. The second section discusses the methodology of the study. In the third section, the paper continues with the findings and discussion. The final section discusses the conclusion of the study.

2. Theoretical Background

2.1. Quality Management Tools and Techniques

Even though all quality tools and techniques are helpful, many companies do not utilize certain quality tools and techniques when applying them (Novak, 2005). There is increased recognition of the need to identify appropriate tools and techniques to be used in the improvement process, as there are over 400 tools and techniques in the quality management area (Basu, 2004; Charantimath, 2011). Identifying such tools and techniques could use several criteria, including: their successful implementation in different circumstances; whether or not the tools and techniques selected are required or alternate in different conditions; and whether or not they apply to the manufacturing industries (Dale, 2003).

Dale further indicates that there is an urgent need for educating employees on the various benefits of quality tools and techniques. Designing a training program on how to use quality tools and techniques is essential. Although quality tools and techniques provide significant benefits, inappropriately applying them could create more problems in the quality system. Brady and Allen (2006) and Kwok and Tummala (1998) also pinpoint that tools and techniques sometimes fail to be effectively applied because of a lack of their roles and knowing when, where, and how to apply them.

There is a need for a thorough investigation as to the reasons or preferences of using certain tools over others, and what difficulties are encountered when implementing quality tools and techniques (Bamford & Greatbanks, 2005; Fotopoulos & Psomas, 2009). A critical mistake occurs when organizations try to implement tools and techniques separately, as the major benefits of these techniques depend on their sequential implementation (Dale, 2003). In order to effectively implement quality tools and techniques in a sequential manner, they must be embedded within a systematic problem-solving approach. Among many reasons, the failure of utilizing these tools and techniques stem from the inappropriate selection of the right ones.

As such, there are abundant of studies about the degree of importance in applying various quality tools and techniques (Clegg et al., 2010; Drew & Healy, 2006; Fotopoulos & Psomas, 2009; Lagrosen & Lagrosen, 2005; Lam, 1996; Miguel, Satolo, Andrietta, & Calarge, 2012; Rowland-Jones, Thomas, & Page-Thomas, 2008; Sahran, Zeinalnezhad, & Mukhtar, 2010; Sousa, Aspinwall, Sampaio, & Rodrigues, 2005; Tari, 2005; Tari & Sabater, 2004), there are very few studies that propose a limited diagnostic methodology or a framework for implementing them (Hagemeyer et al., 2006; Miguel et al., 2012; Shahin, Arabzad, & Ghorbani, 2010; Timans, Ahaus, & Van Solingen, 2009). There are no comprehensive studies on quality tools and techniques, as many covers only a small portion of tools or one industry.

Nevertheless, according to Dale (2003) in selecting tools and techniques, he suggests to start with simpler ones, such as the seven basic quality control tools, because they are often as useful as complex techniques. Astonishingly, many Japanese companies create great benefits in quality because they utilize the seven basic quality control tools effectively together. In the West, companies tend to overlook the seven basic quality control tools by underestimating their importance or by using them inefficiently by employing them separately (Dale, 2003). While, Basu (2009) claims that one key issue for the ineffective application of tools and techniques is poor implementation, which is usually caused by the following reasons as below:

i. Tools and techniques are used routinely for work activities without full consideration to their specific roles.
ii. Using computer software exclusively for data collection and interpretation.
iii. Tools and techniques hinder change instead of causing the improvement.
iv. Tools and techniques are limited only to be used by specialists.

Thus, in the process of identifying and eliminating quality problems, it is crucial to understand that there are two types of variation that may lead to a quality problem: special causes or common causes. Special causes occur because something wrong, but controllable, has happened. On the other hand, workers cannot solve problems that occur because of common causes, because the problem is part of the system and not controlled by individuals; therefore, only management takes action to solve the problem. Quality gurus such as Deming and Juran considered that around 85% of quality problems are common causes, and that these problems can be solved by basic quality tools (Mitra, 2012; Walker, Elshennawy, Gupta, & McShane-Vaughn, 2012). Ishikawa (2012) goes further and suggested that basic quality tools can solve 95% of quality issues.

With the above background information on quality management tools and techniques, we can now turn to the quality management applications in Industry 4.0. In the following sections the researchers will illustrate on the overview of Industrial Revolution 4.0 and how this quality management tools and techniques need to correspond and in line with Industrial Revolution 4.0 particularly in smart manufacturing context.

2.2. Overview of Industrial Revolution 4.0

Modern industrial development has lasted for several hundred years and has now the era of Industry 4.0 come. The concept of Industry 4.0 was initially proposed for developing German economy in 2011 (Roblek, Mesko & Krapez, 2016; Vogel-Heuser & Hess, 2016). According to Lukac (2015), the first industrial revolution begins at the end of the 18th century and is was represented by mechanical production plants based on water and steam power; the second industrial revolution starts started at the beginning of the 20th century with the symbol of mass labour production based on electrical energy; the third industrial revolution begins in the 1970s with the characteristic of automatic production based on electronics and internet technology; and right now, the fourth industrial revolution, namely Industry 4.0, is ongoing, with the characteristics of cyber physical systems (CPS) production, based on heterogeneous data and knowledge integration.

The main roles of CPS are to fulfil the agility and dynamic requirements of production, and to improve the effectiveness and efficiency of the entire industry. Industry 4.0 encompasses numerous technologies and associated paradigms, including Radio Frequency Identification (RFID), Enterprise Resource Planning (ERP), Internet of Things (IoT), cloud-based manufacturing, and social product development (Baur & Wee, 2015; Georgakopoulos, et al., 2016; Kube & Rinn, 2014; Lasi, et al, 2014; Lin, et al., 2016; Lom, Pribyl & Svitek, 2016; Pfeiffer, 2016; Roblek, Mesko & Krapez, 2016; Singer, 2016; Thames & Schaefer, 2016; Thamsen & Wulff, 2016; Vijaykumar, Saravanakumar & Balamurugan, 2015; Wan, et al., 2016).

Scholars have defined Industry 4.0 from diverse perspectives. For instance, according to the Lu, (2017) Industry 4.0 is “the integration of complex physical machinery and devices with networked sensors and software, used to predict, control and plan for better business and societal outcomes.” Henning and Johannes (2013) define Industry 4.0 as “a new level of value chain organization and management across the lifecycle of products.” Hermann, Pentek, and Otto (2016) define Industry 4.0 as “a collective term for technologies and concepts of value chain organization.” They note that, within the modular structured Smart Factories of Industry 4.0, Cyber Physical System (CPS) monitor physical processes, create a virtual copy of the physical world and make decentralized decisions. In turn, they also point out that over the IoT, CPS communicate and cooperate with each other and humans in real time, and that the Internet of Services (IoS), both internal and cross organizational services, is offered and utilized by participants of the value chain.

Likewise, Industry 4.0 facilitates interconnection and computerization into the traditional industry. The goals of Industry 4.0 are to provide IT-enabled mass customization of manufactured products; to make automatic and flexible adaptation of the production chain; to track parts and products; to facilitate communication among parts, products, and machines; to apply human-machine interaction (HMI) paradigms; to achieve IoT-enabled production optimization in smart factories; and to provide new types of services and business models of interaction in the value chain (Shafiq et al., 2015 & 2016). While, Schmidt et al. (2015) further claim that the Industry 4.0 also brings disruptive changes to supply chains, business models, and business processes.

Further, the principles of Industry 4.0 are interoperability, virtualization, decentralization, real-time capability, service orientation, and modularity (Shafiq et al., 2015 & 2016). In terms of features, Industry 4.0 can provide more flexibility, reduce lead times, customize with small batch sizes, and reduce costs (Shafiq et al., 2015 & 2016). The key fundamental principles of Industry 4.0 include cloud/intranet, data integration, flexible adaptation, intelligent self-organizing, interoperability, manufacturing process, optimization, secure communication, and service orientation (Ji et al., 2016; Vogel-Heuser & Hess, 2016).

As such, Industry 4.0 is marked by highly developed automation and digitization processes and by the use of electronics and information technologies (IT) in manufacturing and services (Obitko & Jirkovský, 2015; Roblek, Mesko & Krapez, 2016; Yuan, 2015). Real-time integrating and analysing massive malicious data will optimize resources in the manufacturing process and will achieve better performance. Mobile computing, cloud computing, big data, and the IoT are the key technologies of Industry 4.0 (Gruber, 2013; Roblek, Mesko & Krapez, 2016; Vijaykumar, Saravanakumar & Balamurugan, 2015; Wan et al., 2016). In particular, mobile computing and cloud computing provide powerful and accurate data and service for Industry 4.0 by integrating industrial IoT networks.

An IoT system is capable of offering specific and personalized products. Users can customize products via web pages. Then, web servers transmit data to the industrial cloud and plants via wired or wireless networks. Based on the data received, the manufacturer will integrate design, and will optimize, manage, and monitor the production process in order to produce products efficiently. With the help of self-optimization and autonomous decision-making mechanism, machines and equipment will adopt more to improve the performance (Roblek, Mesko & Krapez, 2016). Since manufacturing and supply are dynamic, the life cycle of a product is changeable as well. In accordance with the changes, decentralization, self-optimization, and automation can assist the dynamic process more efficiently and effectively.

Multi-agents-based products, orders, machine processes, controls, artificial intelligence, and genetic algorithms present a comprehensive process of interoperability. The information flow is cooperated, coordinated, and communicated among the manufacturing participants and agents in CPS. Thus, the agent technology is an appropriate tool to deal with complexity and planning of manufacturing of Industry 4.0.

In addition, a fifth generation (5G) will be acquired in Industry 4.0 to accomplish latent, long, reliable, and secure communication and to meet the complex demands of emerging business paradigms (Siddiqui et al., 2016; Varghese & Tandur, 2014). Although 5G is still in its infancy, the technology of the 5G is a necessary developmental step for the Machine-to-Machine (M2M) communication associated with Industry 4.0 and with the IoT.

Furthermore, as industries are becoming more complex and more knowledge intensive, massive data appear with Industry 4.0. The drawbacks of the heterogeneous data will hamper industrial development. Thus, big data management (data mining, data classification, and data storage) becomes a large challenge. Cloud architecture can be used for analysing data depending on the security and safety structures. Machine learning algorithms for data mining associated with cloud services are a direction for future research (Mi & Zolotov, 2016; Zhou, Liu & Zhou, 2015).

In sum, all of the above arguments suggest that Industry 4.0 can be summarized as an integrated, adapted, optimized, service-oriented, and interoperable manufacturing process which is correlated with algorithms, big data, and high technologies.

2.3. Smart Manufacturing in Industry 4.0 for Quality Management

Industry 4.0 makes factories more intelligent, flexible, and dynamic by equipping manufacturing with sensors, actors, and autonomous systems (Roblek, Mesko & Krapez, 2016). Accordingly, machines and equipment will achieve high levels of self-optimization and automation. In addition, the manufacturing process has the capacity of fulfilling more complex and qualified standards and requirements of products, as expected (Roblek, Mesko & Krapez, 2016). Thus, intelligent factories and smart manufacturing are the major goals of Industry 4.0 (Sanders, Elangeswaran & Wulfsberg, 2016). Agent paradigm is recognized as one of the effective tools for smart manufacturing.

Adeyeri et al. (2015) identify the trends in the usage of agents and multi-agents in manufacturers' resource planning and offer a framework.

Industry 4.0 makes value-added integration occur horizontally and vertically in the manufacturing process (Shafiq et al., 2016; Stock & Seliger, 2016). Specifically, the horizontal procedure is integrated with value creation modules from the material flow to the logistics of product life cycle, whereas the vertical procedure integrates product, equipment, and human needs with different aggregation levels of the value creation and manufacturing systems. Intelligence and digitization are integrated from the raw material acquisition to manufacturing system, product use, and the end of product life. Lasi et al (2014) point out that Industry 4.0 drives manufacturing in two directions: the application-pull procedure and the technology-push procedure. The former induces dynamic changes caused by a new generation of industrial infrastructure. The latter requires higher level mechanization, digitalization and networking, and miniaturization.

In Industry 4.0, the manufacturing procedure will require more sensors, actors, microchips, and autonomous systems due to the quick development of technologies (Lasi et al, 2014; Oses et al., 2016; Roblek, Meško & Krapez, 2016; Rubmann et al., 2015; Sanders, Elangeswaran & Wulfsberg, 2016). Advanced methodologies of analytics, CPS, and energy conservation measures (ECM) will be implemented in manufacturing, as well (Oses et al., 2016). Based on high frequency energy metering, Oses et al. (2016) propose a model for an injection machine to estimate the adjusted baseline with lower risks and uncertainties in measuring and verifying energy conversation. Shafiq et al. (2016) propose an assimilation of virtual manufacturing at three levels: virtual engineering objects, virtual engineering processes, and virtual engineering factories. The integrated mechanism of the three levels will be helpful for building the structure of Industry 4.0 and for achieving a higher level of intelligent machines, industrial automation, and advanced semantic analytics.

2.4. Quality tools and techniques of Smart Manufacturing in Industry 4.0

Having reviewed the pertinent of Industrial Revolution 4.0 literature and its characteristic, this allows the researchers to further understand on how this Industrial Revolution 4.0 context may give the impact of respective quality tools and techniques.

A study conducted by Albers et al. (2016) analyse quality-related production with an intelligent condition monitoring-based quality control system and develop a comprehensive descriptive model. In order to achieve transparency and productivity of big data, Lee et al. (2014) address the trends of manufacturing service transformation and the readiness of smart predictive informatics tools. The prognostics-monitoring system is a trend of the smart manufacturing and industrial big data environment (Lee, Kao & Yang, 2014; Vijaykumar, Saravana Kumar & Balamurugan, 2015).

Cuihua et al. (2016) present a novel approach to simplifying the scheduling problem of job shop scheduling actively by using RFID to collect real-time manufacturing data. Tari and Sabater (2004) stated in their study that large organizations tend to use cause-and-effect diagrams, flow charts, problem solving methods, and benchmarking more than smaller organizations. Also, a study of large companies in Turkey by Bayazit (2003) indicated that the most commonly used quality tools and techniques are statistical process control, process charts, Pareto charts, cause-and-effect diagrams, quality control circles, just-in-time, quality audits, and total productivity maintenance.

Although few researchers indicated no significant difference in the application of tools and techniques between manufacturing industries (Fotopoulos & Psomas, 2009; Sousa et al., 2005), several other studies clearly showed the difference between the two industries based on the priority selection of different tools and techniques (Antony et al., 2007; Antony & Banuels, 2002; Nicols, 2006).

An example of this, a study conducted by Yau (2000), the researcher found that the manufacturing industry frequently used the seven basic quality control tools, acceptance sampling, and process capability, whereas the service industry used benchmarking, gantt charts, and quality circles the most often. In another study conducted in the Saudi food industry by Alsaleh (2007), the researcher revealed that control charts, histograms, and run charts were tools and techniques used most often. In general, manufacturing organizations more often apply quality improvement tools and techniques (Tari & Sabater, 2004).

Moreover, a study conducted by Burcher, Lee, and Waddell (2006) found that although quality managers in Britain and Australia have very limited skills in many quality tools and techniques, they do not pay a major effort to enhance their knowledge in that area. They do not use the most current quality tools and techniques, and they are perhaps not even aware of them. Quality managers in these two countries, mostly employed a very narrow collection of tools and techniques, which consisted of brainstorming, control charts, and pareto analysis.

In a nutshell, the more experienced an organization with the application of quality management, the more tendency it has to use different quality tools and techniques, particularly advanced ones (Revuelto-Taboada, Canet-Giner, & Balbastre-Benavent, 2011); and, the more an organization uses quality tools and techniques, the better performance it acquires, regardless of its size (Ahmed & Hassan, 2003).

3. Research Methodology

This paper is an exploratory qualitative study. A systematic approach to literature review is based on the knowledge that gives a major role in evidence-based practices (Denyer & Tranfield, 2008; Rousseau, Manning, & Denyer, 2008; Tranfield, Denyer, & Smart, 2003) was adapted in this research. Process in getting literature review that has been conducted include 'Industrial Revolution 4.0', 'Smart Manufacturing', quality tools and techniques in general and as well as quality tools and techniques in Industrial Revolution 4.0.

Essentially, systematic reviews are formulated around research question. In this study, our key aim is to answer the question of "What are the appropriate Quality Management tools and techniques in the context of the Industrial Revolution 4.0 particularly for smart manufacturing?".

In saying that, the researchers have reviewed the particular issues by looking in-depth at the literature via an online database journal, such as Emerald, Science Direct, and ABI/ProQuest. These online databases cover journals in the area of quality management, namely the International Journal of Operation and Production Management, International Journal of Quality and Reliability Management, California Management Review, Managing Service Quality, The TQM Magazine, Journal of Operations Management and etc.

Next, after analysing a patent of the literature, the researchers have adopted case study approach in order to illustrate how this phenomenon – the characteristics are applied to the real world context. This is supported by Yin (2003, 2012) who claims that for the evaluation research, the case can be used to document and analyses implementation process.

Moving on from this, the researchers also want to focus and be specific at the highest level possible. As a result, researchers chose Toyo-Memory Technology and Intel Malaysia, as there are one of the companies that can fit well with the Industrial Revolution 4.0 model. These two companies devote a significant amount of time and resources into fostering an Industrial Revolution 4.0 ecosystem for communities that promote the commitment and innovation in practices in their daily operation. Therefore, the key reason for selecting these two companies is based on the premise that they operate successfully in the Industrial Revolution 4.0 context (i.e. The pioneer Malaysian project for Industrial Revolution 4.0), fulfilling the criterion purpose and providing the exceptional case, as they are the stepping stones and benchmarking for the other companies to learn from them.

As a result, in conducting this research, two key data collection methods (qualitative methods) were used: (1) Primary data from face-to-face interview with Toyo Memory Technology and Intel Malaysia (2) Secondary data from previous study. Accordingly, this review on the previous study allows the researchers to establish better understanding on the pertaining issue regarding the appropriate quality tools and techniques in the context of Industrial Revolution 4.0. This review coupled with the case study analysis also led to the identification on the real implementation of quality tools and techniques in the industries.

As such, in this study, respondents were selected based on their background of manufacturer that participate and living in the environment of Industry 4.0 particularly in Smart Manufacturing context. Turner (2010) and Creswell (2007) indicated that a researcher should conduct sampling strategies to get qualified respondents that will provide appropriate and valuable information. Respondents were chosen based on certain categories and characteristics that meet the research outcomes. They have; (i) implemented quality tools and techniques; (ii) various experiences in managing issues over quality management; (iii) moving towards digital manufacturing; (iv) and living in the environment of Industry 4.0 context such as smart manufacturing, digital manufacturing, fully automation and others.

In short, the respondents consisted of experts who worked in position ranging from Engineer up to General Manager of the Toyo-Memory Technology and Intel Malaysia. In addition, respondents were selected for this study, according to the following criteria: they were currently working as a manager or engineer position. They were viewed as making significant contributions to their organizations and to the field. To ensure the quality of the interview data, the respondents' experience had to include at least three years working in the organization. Participation was voluntary, with the managers and engineer offering selections and suggestions. The respondent's details are shown in Table 1 as follows.

Respondent	Designation	Years of
General Manager 1, Toyo-Memory Technology	General Manager	30 Years
Senior Manager 2, TMT	Senior Manager, Quality Assurance	20 Years
Senior Manager 3, TMT	Senior Manager, Internal Quality	20 Years
Senior Engineer 1, TMT	Senior Engineer, Quality Assurance	15 Years
Senior Engineer 2, TMT	Senior Engineer, Quality Assurance	12 Years
Senior Engineer 3, TMT	Senior Engineer, Internal Quality	8 Years
Senior Engineer 4, TMT	Senior Engineer, Internal Quality	8 Years
Manager 1, INTEL	Manager, Strategic Integration Management (SIM), Intel	13 Years
Engineer 2, INTEL	Engineer SIM, Intel	10 Years
Engineer 3, INTEL	Engineer SIM, Intel	10Years

Table 1. Respondents Details
Source: Originated by authors (2018)

Initially, the aim of conducting these interviews was to enrich the information regarding the companies value and practices, as this allowed the researchers to better understand what people are thinking and saying. Thus, the researchers gained the information on how the industries select the quality tools and techniques to manage quality performance in the organization and the researchers examined the association and prevalence of different quality tools and techniques in context of smart manufacturing.

4. Research Findings & Discussion

In this section, the key objective of the study is to investigate and reveal the appropriate quality tools and techniques used for achieving quality performance in Industrial Revolution 4.0 particularly in Smart Manufacturing context. Throughout this section, the researchers present the tools and techniques that have been implemented in organization for achieving quality performance. In so doing, the researchers have adopted the explanation building method, as the main method to analyse the data.

4.1. Explanation Building Analysis Method

In this research, the explanation building method was used, as the main method to analyses the data. According to Monash University (2016), in qualitative research, the analysis of the data cannot be neatly presented in tables and figures like quantitative methods, but it must be shown in words. This is because, by nature, qualitative data results are usually in a large number of written materials.

The data needs to be connected back to the layers of detail to the overarching research question it relates. The data extracts can be connected back into this structure through a process of 'tell-show-tell'. In the discussion of the research findings, the researchers have an opportunity to develop the story found in the data, make connections between the analysis results as well as the existing theory and research. Further, Monash University (2016) states that the skill in writing the successful discussion is moving backwards and forwards between previous research and current research and to make it clear, the data can be display by:

i. What has been done by another researcher?
ii. What has been done by the researcher?
iii. How the data will complement each other?

In short, the researchers have analysed the data by using the explanation building method which consists of theory, findings from the empirical study; the researcher's opinion based on literature synthesising and also findings from the empirical study. See also (Yin, 2008; Saunders et. al, 2012). The key research question of this research is as follows:

"What are the appropriate Quality Management tools and techniques in the context of the Industrial Revolution 4.0 particularly for smart manufacturing?"

The quality tools and techniques that being implemented were identified from the respondents, and this includes Statistical Process Control (SPC), 7 Quality Control Tools (7 QC Tools), Failure Mode Effect Analysis (FMEA), Design of Experiment (DoE), Model Based Problem Solving (MBPS), 8 Dimension, Fishbone Diagram, YY Analysis. This is consistent with previous research in the literature such as (Clegg et al., 2010; Drew & Healy, 2006; Fotopoulos & Psomas, 2009; Lagrosen & Lagrosen, 2005; Lam, 1996; Miguel, Satolo, Andrietta, & Calarge, 2012; Rowland-Jones, Thomas, & Page-Thomas, 2008; Sahran, Zeinalnezhad, & Mukhtar, 2010; Sousa, Aspinwall, Sampaio, & Rodrigues, 2005; Tari, 2005; Tari & Sabater, 2004).

General Manager of TMT that held the position as Chief Production Officer and Chief Quality Assurance claimed that, *"TMT is working on enhancing the product and service quality* *and continually providing the highest level of satisfaction to our customers. By using various quality tools and techniques such as Statistical Process Control (SPC), Failure Mode Effect Analysis (FMEA), Voice of Customers (VOC), Six-sigma, Execution Planning, Histogram, Pareto, YY Analysis, 7QC Tools, Fishbone Diagram, Minitab and others to solving quality issues."*

(General Manager TMT)

Accordingly, Manager 2, Manager 3, Senior Engineer 1, Senior Engineer 2, Senior Engineer 3 and Senior Engineer 4 from TMT collectively agreed that the Quality tools and techniques which is Statistical Process Control (SPC), 7 Quality Control Tools (7 QC Tools), Failure Mode Effect Analysis (FMEA), Design of Experiment (DoE), 8 Dimension, Fishbone Diagram, and YY Analysis, have been used in TMT for solving the quality issues. In line with this concept, as noted by Manager 4 from Intel, *"Here at Intel, all divisions, related departments and factories have introduced and are working to actively utilize Six Sigma activities in an organized manner. We are continuing our efforts to improve the quality of our products with the targets of providing top level quality and solutions by using 7QC Tools, Design of Experiment (DoE), Model Based Problem Solving (MBPS) and others quality tools and techniques based on quality issues."*

(Manager 4, Intel)

Likewise, Engineer 5 and Engineer 6 from Intel also agreed and indicated that, *"Usually at Intel, SIM department has standardized the implementation of MBPS for solving any quality problems and followed by others quality tools and techniques such as 7QC tools, DoE, SPC, FMEA, and other tools and techniques based on quality issues that happen."*

(Engineer 5 and Engineer 6)

Based on the above discussion, it can be suggested that the implementation of Quality tools and techniques provides solutions towards quality issues. This is because, in line with the statement by General Manager TMT, the researcher recognizes that the implementation of quality tools and techniques could enhance the product and service quality and continually providing the highest level of satisfaction to customers. Based on this discussion, it also can be suggested that the key quality tools and techniques that are implemented for solving quality issues such as SPC, FMEA, DoE, MBPS and 7QC Tools.

As such, it has been highlighted that the implementation of quality tools and techniques can also be standardized across over the board between the unit and department, as those mentioned by Manager 4, Engineer 5 and Engineer 6 from Intel, *"all divisions, related departments and factories have introduced and standardized the implementation of MBPS for solving any quality problems."* This is consistent with Evans (2011) that mentioned, tools and techniques have been adapted from various disciplines to provide a strong, data-driven methodology for solving issues and improving processes.

In short, it can be suggested that the implementation of quality tools and techniques able to provide solutions towards quality issues in Industrial Revolution 4.0 based on the evidence being discussed above. Furthermore, based on the empirical finding and having reviewed the literature, all these enable for the researchers to summarize the key quality tools and techniques that have been used in Toyo-Memory Technology and Intel. Those two companies that are operating in the smart manufacturing context. The summary of the key quality tools and techniques used in TMT and Intel is as shown in Table 2 as below:

Research Objectives	**Interview data from respondents**									
Quality Tools and Techniques	GM1	SM2	SM3	SE1	SE2	SE3	SE4	M1	E1	E2
Statistical Process Control (SPC),	√	√	√	√	√	√	√	√	√	√
7 QC Tools	√	√	√	√	√	√	√	√	√	√
Failure Mode Effect Analysis (FMEA)	√	√	√	√	√	√	√	√	√	√
Design of Experiment (DoE)	√	√	√	√	√	√	√	√	√	√
Model Based Problem Solving (MBPS)								√	√	√
8 Dimension,	√	√	√	√	√	√	√	√	√	√
Fishbone Diagram	√	√	√	√	√	√	√	√	√	√
YY Analysis	√	√	√	√	√	√	√	√	√	√
Minitab	√	√	√	√	√	√	√	√	√	√
Voice of Customers (VOC)	√	√	√	√	√	√	√	√	√	√
Six-sigma	√	√	√	√	√	√	√	√	√	√
Execution Planning								√	√	√
Histogram	√	√	√	√	√	√	√	√	√	√
Pareto	√	√	√	√	√	√	√	√	√	√

Table 2. The summary of the case study (Key Quality Tools and Techniques used in TMT and Intel)
Source: Summarize by the researchers (2018)

Indicators:
GM1: General Manager, Chief Quality Assurance & Chief Production Officer, TMT
SM2: Senior Manager, Quality Assurance, TMT
SM3: Senior Manager, Internal Quality, TMT
SE1: Senior Engineer, Quality Assurance, TMT
SE2: Senior Engineer, Quality Assurance, TMT
SE3: Senior Engineer, Internal Quality, TMT
SE4: Senior Engineer, Internal Quality, TMT
M1: Manager, Strategic Integration Management, Intel
E2: Engineer, Strategic Integration Management, Intel
E3: Engineer, Strategic Integration Management, Intel

Apart from that, the respondents were also being asked about the difficulties of having many quality tools and techniques that have been used for solving certain quality issues. Accordingly, a critical mistake may occur when organizations try to implement tools and techniques separately, as the major benefits of these techniques depend on their sequential implementation (Dale, 2003).

In line with the above concept, Manager 4 from Intel points out that there should be a systematic or standardization on implementation of various quality tools and techniques by looking at the quality dimension and also industrial specifications, *"As a starting point in Intel, we have systematized conventional Quality Control and Total Quality Control activities in a more systematic and logical way, by introducing and deploying re-constructed Model Based Problem Solving (MBPS) as main tools and techniques to solving quality issues and managing every activity on a company wide basis in order to realize the highest management quality at the six-sigma level. This can help engineer from having difficulties to run many quality tools and techniques for solving quality problems at one time."*

(Manager 4, Intel)

Consistent with the statement from Manager 4, General Manager from TMT also suggested that there should be a systematic or standardization on implementation of various quality tools and techniques by mentioning, *"It is good to have* many *quality tools and techniques, because the tools and techniques can be used based on the quality issues that emerge. But it's better if having one systematically way that can consider from various quality tools and techniques. By having too many quality tools and techniques, it's difficult to engineer and production level to select suitable tools and it's also needed training and the knowledge about the tools itself."*

(General Manager, TMT)

Based on these discussions, this suggests that although there is almost 400 quality tools and techniques available (Basu, 2004 and Charantimath, 2011), it seems that companies do selecting certain quality tools and techniques when applying them. This is supported by Bamford & Greatbanks, 2005; Fotopoulos and Psomas, 2009 in saying that there is a need for a thorough investigation as to know the reasons or preferences of using certain tools over the others, and what difficulties are encountered when implementing quality tools and techniques.

As such, General Manager TMT also highlighted that, the difficulties of having too many quality tools and techniques are when the organization needs to train the worker for getting the knowledge on how to run that particular tools and techniques. In line with this, Brady and Allen (2006), claim that tools and techniques sometimes fail to be effectively applied because of a lack of their roles and knowing when, where, and how to apply them.

Based on the above discussion, it is fair to say that the implementation of various quality tools and techniques can give great advantages for industry in solving issues regarding quality performances. However, it is also highlighted that it doesn't mean using a lot of quality tools and techniques will guarantee to solve quality issues. Thus, having too many tools and techniques implemented, may affect the employee's and make it difficult for them and this can lead to the poor-quality performance issues instead.

5. Conclusions

This article has attempted to explore a systematic pattern for selecting quality tools and techniques in Industrial Revolution 4.0 particularly in smart manufacturing context. The key aim of this research is to answer, "what are the appropriate Quality Management tools and techniques in the context of the Industrial Revolution 4.0 particularly for smart manufacturing?". In so doing, the researchers have reviewed the pertinent of Industrial Revolution 4.0 literature and its characteristic particularly in the smart manufacturing environment in corresponds to the quality tools and techniques implementation and this follows with the case study conducted.

Thus, from the analysis discussed in this study, the conclusion can be reached that it is proven that the identified quality tools and techniques have a significant effect on the quality performance in the Industrial Revolution 4.0. The key quality tools and techniques identified, namely are; Statistical Process Control (SPC), Failure Mode Effect Analysis (FMEA), Design of Experiment (DoE), Model Based Problem Solving (MBPS), 8 Dimension, Fishbone Diagram, and XY Analysis. The summary of the key quality tools and techniques used in the respective companies in this case study is shown in Table 3 as follows.

Quality Tools and Techniques	Explanations
Statistical Process Control (SPC),	A method of quality control which employs statistical methods to monitor and control a process
Failure Mode Effect Analysis (FMEA)	To systematically analyse postulated component failures and identify the resultant effects on system operations
Design of Experiment (DoE)	The design of any task that aims to describe or explain the variation of information under conditions that are hypothesized to reflect the variation
Model Based Problem Solving (MBPS)	The development of the concept of model-based systems were an answer to the limitations of rule-based "expert systems", which base problem solving (e.g., Diagnosis) on a representation of experiential knowledge in a domain.
8 Dimension	Consist of 8 Quality Dimension
Fishbone Diagram	To identify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation
XY Analysis	The table illustrates using a group of columns and rows, with factor X (input) represented by the horizontal axis and factor Y (output) represented by the vertical axis.
Voice of Customers (VOC)	A market research technique that produces a detailed set of customers wants and needs, organized into a hierarchical structure, and then prioritized in terms of relative importance and satisfaction with current alternatives
Six-sigma	A methodology that relies on a collaborative team effort to improve performance by systematically removing waste
Execution Planning	Execution planning is detailed planning for the commitment of specified forces and resources
Histogram	To roughly assess the probability distribution of a given variable by depicting the frequencies of observations occurring in certain ranges of values.
Pareto	A type of chart that contains both bars and a line graph, where individual values are represented in descending order by bars, and the cumulative total is represented by the line

Table 3. Key Quality Tools and Techniques used in TMT and Intel Malaysia
Source: Summarize by the researchers (2018)

In terms of methodology, similar studies conducted in organizations similar to these respective companies are likely to yield similar results. The lessons are extracted and therefore, this on the one hand, may help quality assurance and strategic policy makers to benchmark/evaluate where their organisations are now (See Morse, 1999; Stierand & Dorfler, 2010). It also means that they do not need to start from scratch in predicting how quality management tools and techniques need to be corresponded or aligned to the Industrial Revolution 4.0 movement, as this study already provides some understanding and insights into this.

As a result of this study, the authors can confirm that the implementation of quality tools and techniques will effectively be solved many quality issues in the industry. This observation is consistent with, Revuelto-Taboada, Canet-Giner, and Balbastre-Benavent (2011) who mentioned that, the more experienced an organization with the application of quality management, the more tendency it has to use different quality tools and techniques, particularly advanced ones. Likewise, this also supported by Ahmed & Hassan (2003) that claim, the more an organization uses quality tools and techniques, the better performance it acquires, regardless of its size.

As such, all of the above discussion also suggest that although there is almost 400 quality tools and techniques available (See Basu, 2004 and Charantimath, 2011), however the key quality tools and techniques implemented by the respective companies (i.e. the case study) are mainly focused on the Statistical Process Control (SPC), Failure Mode Effect

Analysis (FMEA), Design of Experiment (DoE), Model Based Problem Solving (MBPS), 8 Dimension, Fishbone Diagram, and XY Analysis. These tools and techniques are considered relevant, practical and effective in line with the current movement of Industrial Revolution 4.0 particularly for smart manufacturing environment.

Acknowledgement

The authors wish to thank all the respective respondents during the interviews and providing data throughout this study conducted. In addition, the authors acknowledge the support given by Universiti Teknikal Malaysia Melaka (UTeM) and Gebze Technical University (GTU) for the financial support and facilities provided in completing this research. We will welcome any collaboration for this kind of research with an open arm.

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