Chapter 1

Quality-driven Industry 4.0

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Abstract

We are witnessing the Fourth Industrial Revolution and the developments of the digital transformation in the service and manufacturing sectors. The emphasis in manufacturing is on technological developments (CPS, robotics and additive manufacturing) and in the service sector there is a focus on data (AI, data analytics and big data). What is lacking is research on the importance of Quality Management within these developments.

Research relating to the relationship between Industry 4.0 and Quality Management is limited, with the two dominant lenses progressing research in different directions. The purpose of this chapter is to explore the need for a more focused approach towards Quality Management in the current technology-driven era of Industry 4.0.

The findings are presented in the form of a critical evaluation of the literature identified through a systematic literature review exploring the different perspectives which contribute to the current understanding of the relationship between technology and Quality.

The conclusions of the analysis indicate that Total Quality Management (TQM) can be the strategic focus for Industry 4.0. TQM is technology-independent, it encompasses a strategic outlook, a customer focus and consideration of quality tools and techniques. Further, it is suggested that the focus of Industry 4.0 research needs to change to a Quality 4.0-driven strategy in order to achieve its full potential.

This chapter advances our understanding of both Quality and Industry 4.0 by going beyond the established boundaries, synthesizing the fields to map out a state-of-the-art knowledge of these important areas.

Keywords: Industry 4.0; Quality Management; Quality 4.0; systematic literature review; TQM.

1. Introduction

We are currently experiencing unprecedented changes in both the service and manufacturing sectors which have been driven through the widespread use of digital technologies. These changes go beyond the use of computers and automation in developing products and services in an organisation. What we are experiencing is the ability of service providers and manufacturers to respond to customers' needs and desires in a smart and effective way. For example, our expectations in online home delivery have moved from expecting delivery in 3–4 weeks to next day or in some cases same-day delivery. Many delivery companies have online tracking systems to enable the customer to see exactly where the driver is at any time. Another example in the service sector is the way that Uber has completely changed the business model of taxi firms. In manufacturing, we are able to customise our product orders, and manufacturers are looking at ways to embed sensors and technology into their products for self-monitoring and self-healing.

What is behind these developments and trends is the use of Artificial Intelligence (AI) and machine learning, greater connectivity, the development of 5G networks and the widespread use of sensor technology/cyber physical systems (CPS). These aspects, alongside Additive Manufacturing (AM) and Augmented Reality, form the core elements of the Fourth Industrial Revolution, often referred to as Industry 4.0 (Vaidya *et al.*,

2018). Whilst publications on Industry 4.0 in academic journals have increased exponentially in the last few years (Galati and Bigliardi, 2019), the dominant focus still remains on the advancement and impact of the technologies involved. However, from past experiences in the automation and robotics era, we have learnt that technology alone does not provide the expected benefits and gains. A management system and relevant processes are also needed to realise the potential of the new technologies. A key and vital element in any manufacturing operation is the quality of the products and the robustness and consistency of the manufacturing process. Whilst the Industry 4.0 environment provides the potential to improve the quality of the products produced, it isn't an automatic benefit and attention is also needed to develop the Quality Management and Quality Engineering aspects to realise the full benefits of the advancements in technology (Goh, 2011).

As Industry 4.0 applications and environments mature, we are experiencing a shift of emphasis in its implementation, impact and benefits. The focus is moving from specific discussions around the technologies and building blocks to a broader outlook of embedding the technologies in business, the development of new business models and the implications of Industry 4.0 developments (Rojko, 2017; Galati and Bigliardi, 2019). The increasing importance of technology and the need to remain focused on the continuous development of Quality in the 21st century was highlighted by Feigenbaum (1999) and more recently Rowlands (2018), Rowlands and Milligan (2019) and Hyun Park *et al.* (2017) emphasise that the full benefits from technological advancements can only be realised through robust management systems and clear quality focus.

The quality focus in Industry 4.0 publications, up until recently, has been confined to discussions on the role of the customer (Neugebauer *et al.*, 2016; Qin *et al.*, 2016; Schönsleben *et al.*, 2017). Additionally papers are also emerging on related topics such as linking quality and lean approaches to Industry 4.0 developments (Prinz *et al.*, 2018), the development of a quality scorecard for Industry 4.0 (Shin *et al.*, 2018) and the role of Quality Management in the Industry 4.0 era (Hyun Park *et al.*, 2017). Nevertheless, research relating to the relationship between Industry 4.0 and Quality is limited, with the two dominant lenses progressing research in different directions. However, ideas and developments in Quality 4.0 are emerging (Ngo and Schmitt, 2016;

Kubat, 2018; Rowlands and Milligan, 2019), where Quality 4.0 is seen as a Quality-driven strategic focus for Industry 4.0 implementation.

The purpose of this chapter is to address the need for a more focused approach towards Quality/Continuous Improvement and Quality Management in the current technology-driven era of Industry 4.0. To achieve this goal, a systematic literature review (SLR) exploring the theoretical and practical advancements of Industry 4.0 through the lens of Quality Management was carried out. The SLR approach adopted is that proposed by Tranfield *et al.* (2003). Whilst other authors have also carried out a review of Industry 4.0 literature, using a SLR (Lu, 2017; Liao *et al.*, 2017), using a text mining approach (Galati and Bigliardi, 2019) and a bibliometric analysis (Muhuri *et al.*, 2019), this chapter takes a fresh view of the literature from a Quality Management and Continuous Improvement perspective. In addition, a broader view of the literature relating to technology and digital transformation applications is considered to see if new perspectives and implications for Industry 4.0 implementation can be identified.

The structure of the chapter is as follows: Section 2 provides a context from the Industry 4.0 and Quality perspectives, identifying the differences and considering the developments from each perspective; Section 3 provides a description of the SLR approach used; Section 4 is organised around key themes that emerged from the literature review; Section 5 includes a discussion of the research implications and research gaps identified with conclusions and recommendations for future work.

2. Industry 4.0 and Quality Perspectives

2.1 *Industry 4.0*

There is no single common definition of Industry 4.0 in the literature with terms such as CPS, Internet of Things (IoT), Cloud Computing, AM, Big Data and Big Data Analytics (BDA) being the most commonly used terms in describing an Industry 4.0 environment (Oliff and Liu, 2017; Schönsleben *et al.*, 2017; Zhong *et al.*, 2017). Where there is consistency is in the understanding that Industry 4.0 involves an AI element often

referred to as intelligent manufacturing or intelligent systems (Liu and Jiang, 2016; Oliff and Liu, 2017; Zhong *et al.*, 2017). Other terms used in this regard are smart systems and smart manufacturing at the systems level (Neugebauer *et al.*, 2016) or intelligent sensors at the component level (Berger *et al.*, 2016).

It is widely cited that the concept of Industry 4.0 was developed in Germany in 2011 (Qin *et al.*, 2016; Roblek *et al.*, 2016; Stock and Seliger, 2016; Lu, 2017; Schönsleben *et al.*, 2017). Whilst some industries have been implementing Industry 4.0 concepts since 2011, the academic literature has lagged behind and only in recent years has there been a sharp increase in the number of papers published (Lu, 2017). Whilst more and more academic publications are considering Industry 4.0 developments, in general the focus to date has been very much on CPS, interoperability and the broader technologies used in Industry 4.0 (Monostori, 2014; Shariatzadeh *et al.*, 2016; Murmura and Bravi, 2017).

Lu (2017) carried out a systematic review of 88 papers related to Industry 4.0 categorising the papers under the following five key areas: (1) Concepts and perspectives, (2) CPS, (3) Interoperability, (4) Key technologies and (5) Applications. The author identifies current research trends and developments in these areas. Whilst Lu (2017)'s discussion is based on the technologies and tools, the author does recognise the importance of related integration methods and techniques such as Business Process Management (BPM), Workflow Management and Supply Chain Management.

Table 1 summarises the above discussion to capture the wide range of Industry 4.0 definitions and their scope. In addition, Table 1 provides an indication of the future research focus identified by the authors. Already we can see a shift of emphasis in the focus of future research from technology (intelligent sensors) and networking (cloud computing) towards a systems-level model focus.

A road map for strategic positioning suggested by Paulus-Rohmer *et al.* (2016) implies a developmental journey for companies from a technology focus to a strategic outlook and a business model focus. Further research is needed to explore this area and to fully embed the business strategic focus for the adoption and implementation of Industry 4.0 technologies.

Table 1. Summary of Industry 4.0 definitions, scope and research focus.

Broad Definition and Scope	Research Focus	Reference
Combining embedded production system technologies with intelligent production processes. Manufacturing systems updated to an intelligent level	• Framework for intelligent manufacturing • Data-driven manufacturing models	(Zhong <i>et al.</i> , 2017)
Digitisation and autonomous decision-making	• New products • Customer needs	(Schönsleben <i>et al.</i> , 2017)
Embedded systems used to integrate humans, intelligent machines and production lines. Intelligent networked and agile value chain	• Maturity models	(Schumacher <i>et al.</i> , 2016)
Intelligent manufacturing	• Better utilisation of data using intelligent systems	(Oliif and Liu, 2017)
Smart factory. Whole layer model from production to business	• Smart systems optimisation • Fulfilling customerness	(Neugebauer <i>et al.</i> , 2016)
Smart factory. Horizontal integration, end-to-end engineering, vertical integration	• Sustainable value creation	(Stock and Seliger, 2016)
Connecting humans, objects and systems. Smart objects.	• Real-time information	(Landherr <i>et al.</i> , 2016)
Additive production		

2.2 Quality focus

The concept of quality has been an important feature of the manufacturing industry throughout the last century (Bergman and Klefsjo, 1994). However, the trends and thinking have evolved from predominately an inspection focus during the mass production era towards a more strategic focus with an emphasis on Total Quality Management (TQM). This evolution of Quality has been captured by Brown (2013) and Zairi (2013) who have reflected on the work and contribution of quality Gurus such as Shewart, Deming, Juran, Feigenbaum, Crosby, Imai, Ishikawa, Taguchi and Shingo. TQM is the most recognised and most widely used strategic quality approach (Wankhade and Dabade, 2006; Agus and Hassan, 2011; Kruger, 2001) and encapsulates many of the ideas and philosophies of the above Gurus. In this regard, Quality thinking has evolved and matured from a product focus (inspection and tools oriented) to a strategic

approach (TQM) with a clear customer focus within a TQM framework (Wankhade and Dabade, 2006).

Coleman (2013) takes a statistical look at quality developments covering the Taguchi approach, Six Sigma and SPC, all of which have a strong foundation and basis in statistical methods. The Six Sigma focus on quality improvement provides both a structure to deploy quality methods through the DMAIC model and a training focus in terms of skills needed to understand and implement the tools and techniques in a practical environment (Sokovic *et al.*, 2010). Goh (2011) reflected on 25 years of Six Sigma acknowledging its statistical foundations. The benefits and success of Six Sigma have been discussed by many authors and more recently captured by Smętkowska and Mrugalska (2018) and Swain (2018).

Lean manufacturing has also played a prominent role in the development of process improvement with a clear focus on process flow and Value Stream Mapping (VSM) (Hines *et al.*, 2004). Alhuraish *et al.* (2017) compare the success of Lean and Six Sigma approaches and concludes that a sequential or integrated application is superior to individual implementation of Six Sigma or Lean approaches. This integrated approach is referred to as Lean Six Sigma (LSS) (Lande *et al.*, 2016; de Freitas *et al.*, 2017).

A timeline highlighting these developments in quality approaches can be seen in Figure 1.

In summary, quality issues remain important for the service and manufacturing industries. The introduction of new technologies provides an opportunity to revisit quality tools, techniques and their deployment.

2.3 Quality and Industry 4.0

Recent research has focused on the important role of the customer in shaping Industry 4.0 developments (Schönsleben *et al.*, 2017; Neugebauer

Figure 1. A timeline of quality developments.

Table 2.   A comparison of the Industry 4.0 and Quality 4.0 perspectives.

	Industry 4.0	Quality 4.0
Concept/focus	Technology-centric	Customer-centric
Technology	Key driver	Enabler
Benefits	Flexibility	Productivity
Enabler	AI	Data
Evolution	From automation to smart manufacturing	From process to customer

et al., 2016; Qin *et al.*, 2016) Neugebauer *et al.* (2016) also talks about fulfilling customerness as the benefit of Industry 4.0 implementation. Whilst this is recognising the role of Quality in Industry 4.0, the focus remains predominately on the technology and networking side. Table 2 compares the Industry 4.0 and Quality 4.0 perspectives.

Whilst the goal of Industry 4.0 is to improve efficiency and productivity (Lu, 2017), Brettel *et al.* (2016) suggest that Industry 4.0 is about productivity gains through the use of CPS. Of course, this can't be achieved without a consideration of product and process quality. Brettel *et al.* (2016) acknowledge this by introducing the concept of reducing variance of products in his concept of self-optimising production systems (SOPS), which resonates with the work of Taguchi on reducing variation through statistical methods using Design of Experiments and Orthogonal Arrays (Ross, 1998).

Some authors provide a different emphasis with the recognition that technology on its own is not enough to achieve the gains and full benefits of Industry 4.0. Prinz *et al.* (2018), whilst recognising the value of a Lean approach, discusses the fundamental differences between Lean and Industry 4.0. The authors support the earlier point that Industry 4.0 is technology driven and propose a holistic approach where a training concept is used to focus on Lean principles within an Industry 4.0 environment. The authors do however recognise that there remains the challenge to fully integrate Lean within Industry 4.0. A similar argument could also be developed for the role of Six Sigma within Industry 4.0; it should have a closer alignment, due to the statistical focus of Six Sigma, with the data-driven elements within Industry 4.0. Table 3 takes the broad Industry 4.0 elements and maps these to Quality enablers and associated business levels.

Table 3. Industry 4.0 perspective and related quality concept and focus.

Industry 4.0 Perspective	Description/Use/ Challenge	Quality Enabler/ Solver	Quality Concepts/Level
CPS	Intelligent sensors	SPC, Six Sigma	Process level
AM	Design to manufacture	Design for Six Sigma	Product level
Big data	Data analysis	Six Sigma	ZD/Management level
Cloud manufacturing	Management of data	TQM	Management level

This section has demonstrated a clear and complementary link between quality concepts and industry 4.0 perspectives. The next section explores these two areas in more detail through a systematic literature review.

3. Systematic Literature Review

In order to design a more focused approach towards Quality/Continuous Improvement and Quality Management in the current technology-driven era of Industry 4.0, a SLR of the theoretical and practical advancements on Industry 4.0 from the angle of Quality Management was carried out. To organise and analyse the relevant literature, the multi-step approach to completing a proposed by Tranfield *et al.* (2003) was adopted (Figure 2). This approach consists of a number of stages that are designed to provide a systematic and transparent framework to guide the literature review process.

The SLR process shown in Figure 2 was simplified to a five-step approach that was then used in this work (Figure 3).

The starting point of this approach is the formulation of an appropriate research question, as this will ultimately determine whether or not a paper should be selected for inclusion in the data review (Greenhalgh and Peacock, 2005). In this case, the research question was developed based on the need to consider Quality Management/TQM and Continuous improvement as the central focus for technology and digital technology implementation, especially in the Industry 4.0 era. To move the research in this field forward, the question “What is the role of technology in establishing continuous improvement?” was adopted.

Figure 2. The SLR process of Tranfield *et al.* (2003).

Planning	Research question: “What is the role of Technology in Continuous Improvement?”
Search	Keyword search (see Table 4)
Selection Criteria	Apply explicit selection criteria to reduce the data set
Evaluation	Review abstract to ensure quality and relevance.
Extraction and Synthesis	Use of NVIVO as organization tool to aid management of 1st order codes

Figure 3. The five-step SLR process (adapted from Tranfield *et al.* (2003)).

The second stage of the review process is to generate a keyword search based on the research question. To ensure a thorough search of all the relevant literature, the bibliographic databases ABI/Inform Global, Business Source Complete, Emerald and Scopus were used. The primary search terms “Quality Management”; “Continuous Improvement”; and “Total Quality Management” were utilised alongside the secondary search terms “technology”; “digital transformation” and “Industry 4.0” in full text searches within these databases. To ensure optimum inclusivity within the search, both the possible phrases Industry 4.0 and the fourth

Table 4. Number of articles generated by keyword search.

Search Terms	Number of Articles
Quality Management & technology	3978
Quality Management & digital transformation	2
Quality Management & Industry 4.0	128
Continuous Improvement & technology	8639
Continuous Improvement & digital transformation	15
Continuous Improvement & Industry 4.0	22
Total Quality Management & technology	4613
Total Quality Management & digital transformation	2
Total Quality Management & Industry 4.0	16
Total number of articles	17,415

(4th) industrial revolution were used. To avoid arbitrarily excluding material, there was no search limitation relating to year of publication.

The initial keyword search yielded 17,415 articles, quantified as shown in Table 4.

These articles are from academic publications representing a large variety of organisational and management perspectives and disciplines. Given the broad search parameters employed, such a large number of matches from the initial search is to be expected. However, not all of the articles from the initial keyword search were relevant with regard to the research question. To identify those of relevance, the next stage in the review process was to screen the titles and abstracts of the articles for those which had a dominant focus on technology and Quality Management. This included the removal of articles that were not relevant to new technology.

The next stage of the process is to apply explicit selection criteria to reduce the data set to a more manageable number. The explicit criteria applied were: only articles published in English; the removal of book chapters and conference proceedings. The subject of the research was the next explicit criterion to be applied. In accordance with the research question, only articles with a continuous improvement focus were included. This resulted in a set of less than 200 articles that satisfied the inclusion criteria and were relevant to the research question.

The final sorting stage is the evaluation stage, where the abstracts of the articles were reviewed to ensure quality and relevance of the final set.

This resulted in a final set of 54 papers that met all of the inclusion criteria and none of the exclusion criteria.

Here is a summary of the selection criteria steps described above: screening the titles and abstracts of papers for relevance to the research question led to the removal of around 16,500 articles from the review set, leaving approximately 1000 articles. Most of the articles excluded at this stage were done so because they did not discuss new technology. Of the articles remaining, there was a dominant focus on technology and Quality Management/Total Quality Management. The next round of selection was to apply the explicit criteria that all articles must be published in English, must be peer-reviewed journal articles and must be from the management domain exploring technology and quality. The application of this criteria removed a further 800 articles, leaving approximately 200 articles in the review set. The final filtering of the abstracts for quality and relevance resulted in a final review set of 54 journal articles.

Once the review set had been established, the next stage was the extraction and synthesis of data. To facilitate the identification and analysis of the key themes in extant research the review articles were thematically coded using NVIVO (version 12) software. The extraction process generated a long list of topic-related categories. These categories were created by an iterative process of reading and categorising the content of an article. The articles were then re-read to validate the initial categorisation and to allow the opportunity to code all articles against all available categories. This coding and categorisation then formed the basis for the identification of core themes and subsequent synthesis.

A fundamental element of the sixth stage, extraction and synthesis, was to complete a descriptive analysis of the review data (Tranfield *et al.*, 2003), which is covered in the next section.

4. Thematic Analysis and Discussion

The search terms for this review (Table 4) included Quality Management, TQM and Continuous Improvement as primary terms with technology, digital transformation and Industry 4.0 as secondary terms. The themes that emerged from the papers were naturally dominated by these terms.

The discussion in the following sections is organized around the key primary themes of TQM (also encompassing Quality Management) and Continuous Improvement. The TQM and Continuous Improvement

themes are closely related, with considerable overlap between these themes. In many cases, Continuous Improvement and Quality Improvement are used interchangeably and therefore both terms form the heading of this theme. Many of the traditional Quality tools and techniques are covered and discussed within the papers, including Six Sigma, Kaizen, Lean, QFD and FMEA. The Six Sigma approach has dominated and is included as an additional theme in this analysis.

The following sections cover the discussion of the key themes identified above: TQM and Quality Management; Continuous Improvement and Quality Improvement; Six Sigma.

4.1 TQM and quality management

TQM is the cornerstone of quality principles and philosophy. Dereli *et al.* (2011) used a to analyse papers published in the *Journal of TQM & Business Excellence* between 1995 and 2008, which captures the history and focus of research in all areas of TQM publications during this period. The number of papers dominated by manufacturing applications were four times the number of service-orientated papers. The content analysis revealed a number of subject areas or groups: (1) TQM and its derivations, (2) Customer satisfaction, (3) Service focus, (4) Performance measures and indicators, (5) Organization and resources, (6) Standards, (7) Six Sigma, (8) Business focus, (9) Leadership, (10) Process, (11) Business excellence models, (12) Management and (13) Quality.

Delić *et al.* (2014) recognise that TQM and IT are the most valuable resources and assets of a business. They identified eight key dimensions of TQM: (1) Leadership, (2) Quality planning, (3) Employee management, (4) Supplier management, (5) Customer focus, (6) Process management, (7) Continuous Improvement and (8) Learning. They expanded these 8 dimensions to a set of constructs for a Structured Equation Modelling (SEM) analysis. Their research confirmed that TQM has a positive impact on organizational performance. Whilst IT was identified as having a positive impact on TQM implementation, direct application of IT didn't have a significant impact on performance. In relation to Industry 4.0 this finding has a significant implication in supporting the objective of this paper in suggesting that a Quality Management/Continuous Improvement focus is necessary to gain positive benefits from Industry 4.0 developments where technology alone will not produce significant benefits.

Chih and Lin (2009) distilled TQM into four key principles: (1) Senior management leadership, (2) Supplier partnership, (3) Customer-driven improvement and (4) Continuous improvement. However, Aoun and Hasnan (2017) see the principles of TQM as being based on teamwork and employees' participation, emphasizing the soft skill aspects of TQM in terms of human skills, leadership and teamwork.

Lobo *et al.* (2012) produced a Quality Management Assessment Framework (QMAF) which covers many of the TQM elements but with a different perspective. The framework was used to assess the QM capabilities of companies. The key drivers identified are leadership, culture, innovation, knowledge and communication. Their model also includes a strategic, HRM and partnership (with suppliers and customers) aspect. Tools and techniques include Continuous Improvement in support of the Business Processes (BP). The use of Quality Tools (QT) was not widespread in the survey with a gap in the companies' understanding of their customers' needs. Wong (2013) also proposes a BPM model. BPM is described based on Management concepts and an IT innovation stream. Whilst the model describes IT in a supporting role in managing the business process, this research area could be developed further to describe the interface between TQM and Industry 4.0.

Table 5 compares the focus and orientation of the five papers discussed above.

From Table 5, Leadership is the only common attribute of TQM identified by all authors. Customer focus is identified by 4 of the 5 authors as being important, with Management issues also featuring in 4 of the 5 papers.

Whilst there is commonality in some of the attributes, each of the 5 authors has taken a different perspective of key TQM features. For example, Aoun and Hasnan (2017) are the only authors to consider teamwork as an important attribute and Lobo *et al.* (2012) are the only authors to consider culture as an important factor. Also innovation and communication are highlighted by Lobo *et al.* (2012) as key factors, whereas Dereli *et al.* (2011) highlight resources, standards, business and service focus as important factors. In reality, many of the factors identified in the table are interrelated and there is substantial agreement between the authors on the key TQM attributes. Note also that the authors have identified Continuous Improvement and Six Sigma as important TQM-related aspects, which are discussed in more detail in Sections 4.2 and 4.3.

Table 5. Comparison of TQM key attributes.

(Dereli <i>et al.</i> , 2011)	(Delić <i>et al.</i> , 2014)	(Chih and Lin, 2009)	(Aoun and Hasnan, 2017)	(Lobo <i>et al.</i> , 2012)
Leadership	Leadership	Senior management leadership	Leadership	Leadership
Customer satisfaction	Customer focus	Customer-driven improvement	—	Partnership — customer focus
Management	Employee management	—	Employees participation	HRM — employee empowerment, employee development
Management	Supplier management	Supplier partnership	—	Partnership — supplier focus
	Continuous improvement	Continuous improvement	—	Continuous improvement
Process	Process management	—	—	BP
TQM and its derivatives	—	—	—	Strategic
Quality	Quality planning	—	—	
Six Sigma	—	—		Total quality tools
Performance measures and indicators	—	—	—	Performance outputs
Business excellence models	—	—	—	QMAF
	Learning	—	—	Knowledge
	—	—	Teamwork	—
Organisation and resources	—	—	—	—
Standards	—	—	—	—
Business focus	—	—	—	—
Service focus	—	—	—	—
	—	—	—	Culture
	—	—	—	Innovation
	—	—	—	Communication

TQM is a universal concept. TQM adoption by organisations is a result of operational antecedents and current environmental cues. As a result, TQM strategy will attend to different priorities in different

Figure 4. Conceptualization of TQM.

organisations/sectors. This lack of conceptual clarity is not helpful, as it results in a weak theoretical foundation upon which to develop knowledge of the topic. An abstraction of the above characteristics and a synthesis of the literature leads to a conceptual framework of TQM (Figure 4).

Adopting the perspective that organisations are open systems explains the inherent discrepancies witnessed in the literature. Organisations wishing to pursue a TQM strategy will adopt contingent responses based on internal factors, such as IT capability, culture, and process capability; and external factors, such as consumer demand and competitor activity. These reactions will vary according to the factors that have shaped the organisation historically and the resources available to them at present. The result is different yet equally effective implementations of TQM.

4.2 Continuous Improvement and Quality Improvement

Continuous Improvement and Quality Improvement are an integral feature within the TQM paradigm. Continuous Improvement-focused applications identified in the literature search pool included examples in healthcare (Sinha and Kohnke, 2009; Lindsay *et al.*, 2014; Queenan *et al.*, 2016; Aoun and Hasnan, 2017; Gardner *et al.*, 2017; Barata *et al.*, 2018), and high-tech companies in Taiwan (Chung *et al.*, 2008; Chih and Lin, 2009; Chung and Hsu, 2010), manufacturing industries in Australia (Karim *et al.*, 2008; Lobo *et al.*, 2012), and IT service management/IT help desk (Li *et al.*, 2011; Huang *et al.*, 2013), construction industry (Sacks *et al.*, 2010), job shop manufacturing (Li, 2010), batch production process (Agarwal and Baker, 2010) and food industry in Thailand (Pipatprapa *et al.*, 2017).

Themes emerging from the healthcare studies include emphasis on the importance of the human element during the introduction of new technologies into the workplace (Lindsay *et al.*, 2014) and the importance of cultural aspects (Queenan *et al.*, 2016). The emphasis on soft skills is a particular focus in the healthcare studies, which is to be expected; however, soft skills are often neglected within manufacturing applications. The editorial of a special issue on Quality Management in the 21st century (Gunasekaran *et al.*, 2019) also emphasises the importance of human aspects in Quality as one of the four key themes for future research. Other themes include economic aspects, business models and decision models.

4.3 Six Sigma

There has been a great deal of attention relating to the implementation of Six Sigma. Park *et al.* (2009) discuss a new paradigm for Six Sigma called Knowledge-based Digital Six Sigma; (KDSS). The authors propose that data analysis and data mining are integrated within the Six Sigma process and a DMAMP (Define, Measure, Analyse, Model and Predict) cycle is proposed to replace the standard DMAIC (Define, Measure, Analyse, Improve and Control) cycle. The key difference is the introduction of a modelling and prediction phase. Since data analysis, data mining, modelling and prediction form key elements within Industry 4.0 implementation, there is, therefore, the potential to explore in more detail the integration of the adapted Six Sigma approach as a key part of Industry 4.0 analytics.

Martin (2008) discussed a process performance management aligned with the DMAIC process, Gardner *et al.* (2017) emphasise the importance of organizational performance, and Chung *et al.* (2008) and Chung and Hsu (2010) look at the Critical Success Factors (CFS) in Design for Six Sigma (DFSS) in high-tech organizations. The authors identified that implementation of DFSS has a positive influence on business competitiveness and on product development, highlighting the importance of DFSS.

Hyun Park *et al.* (2017), whilst considering the future of TQM in Industry 4.0, extend the traditional one-way flow which is based on the Six Sigma process to a multi-way flow model with AI and the IoT at the centre and feeding data to each stage of the flow model. Whilst Six Sigma has been used in many applications including its use in improving the quality of service of a company's IT department (Li *et al.*, 2011),

Table 6.   Six Sigma research areas.

Concept	Literature Stream	Citations
Six Sigma model	DMAMP, multi-dimensional flow model	(Park <i>et al.</i> , 2009; Hyun Park <i>et al.</i> , 2017)
Six Sigma CSF	CSF in DFSS	(Chung <i>et al.</i> , 2008; Chung and Hsu, 2010)
Six Sigma Governance	Integrated Enterprise Model, quality index, quality scorecard	(Jochem, 2009)

Jochem (2009) considers an Integrated Engineering Modelling approach (IEM) based on an enterprise quality scorecard, with Six Sigma playing a central role in linking and integrating the model and the quality scorecard in what the authors call quality governance.

The review of a Six Sigma focus on CI/QI (Continuous Improvement/Quality Improvement) reveals a wide range of Six Sigma applications, developments and enhancements to the traditional Six Sigma model. These papers have indicated potential areas for the development of the Six Sigma approach when applied to the Industry 4.0 environment. Table 6 summarises the key areas for future research development of Six Sigma in Industry 4.0.

5. Conclusions and Future Research

The focus on technological developments has dominated academic papers relating to Industry 4.0. There is however a shift of emphasis towards the enabling process and management topics. Nevertheless, papers on Quality Management relating to Industry 4.0 remain sparse. What has been lacking is a focus on quality and the important role of quality techniques, methods and management not only to support the technological developments but also as a central theme driving the change. By changing the emphasis to a quality-driven Industry 4.0 concept through a Quality 4.0 focus, there is the opportunity to design quality into the systems and processes rather than seeing it as an added extra.

This chapter raises the profile of the Quality focus and moves the discussion away from a technology focus. What the technology has done, on the one hand, is to make life easier for techniques such as Six Sigma which relies on data for its analysis. Of course, the widespread use of CPS

throughout the process has created the opposite problem in that we now have too much data and the challenge is to interpret this vast amount of data. This chapter contributes to the Quality Management literature by identifying a quality-driven strategy (Quality 4.0) which will help organisations focus on what data is needed and in collecting the right data at the right time in a systematic way. Quality 4.0 is not an alternative to the existing quality paradigms; instead, it marks the evolution of Quality Management. Through the strategic application of technology to these paradigms, organisations can adopt a truly customer-centric approach to quality. Quality 4.0 is characterised by less waste, faster decisions, faster set-up, reduced lead time, less product recalls and greater strategic agility.

The road map for strategic positioning of companies suggested by Paulus-Rohmer *et al.* (2016) implies a developmental journey for companies from technology (CPS) to a strategic outlook and a business model focus. Whilst this captures the importance of a strategic business approach, the paper emphasises that this should be taken a step further in terms of fully integrating quality concepts and techniques across the whole roadmap elements and also proposes a different focus in that the roadmap of the ecosystem should start with the strategic quality elements so that it is very much a design-in aspect rather than the traditional developmental or add-on focus. This is consistent with the focus of this chapter and is a good starting point for further research into the next level of integration and analysis.

The work presented in Sections 3 and 4 is based on a of literature relating to Quality Management and Continuous Improvement-related concepts and principles. Other papers have carried out reviews of the literature relating to Industry 4.0; however, the central purpose of this chapter was to shift the focus to a more Quality-related theme. The search terms revealed a large number of papers dominated by “technology” which were filtered to a manageable number for review through explicit exclusion criteria. The discussion focused on major themes derived from the search and literature. These papers have revealed new insights into Industry 4.0 applications from a Quality perspective and new avenues of research to be explored have been identified. Whilst some of the more recent papers are emerging with this focus, further insights have been gained by considering a broader scope within the literature search. Only the main themes from the literature review have been considered in this chapter. Future work will continue to develop an in-depth analysis and evaluation of other themes and topics extracted from the review papers.

In addition to the major themes discussed, other themes have emerged which need further in-depth consideration. For example, Dietrich and Cudney (2011) use the concept of Technology Readiness Levels (TRL) to support the development of a manufacturing strategy for aerospace organisations. Based on Manufacturing Readiness Level (MRL) and Manufacturing Readiness Assessment (MRA), the authors have developed an assessment approach using a QFD model. Lee *et al.* (2009) explore the TRL measure from a customer perspective. Their research and analysis indicate that there is a relationship between TRL and service quality, and product quality and price. Kim *et al.* (2017) also explore TRL with a focus on customer segmentation.

Customer technology readiness (Kim *et al.*, 2017), Technology Function Deployment (TFD) (Chandra and Kumar, 2012) and Voice of the Customer (VoC) for the development of emerging technologies (Dietrich and Cudney, 2011) provide a research thread around customer focus for future exploration.

Shin *et al.* (2018) developed a Quality Scorecard specifically for the Industry 4.0 era. Whilst their model is based on the Balanced Score Card (BSC), the model is shifted to a quality perspective and a quality framework. Within their framework they utilize Cost of Quality (CoQ) aspects (prevention and appraisal costs) as well as utilizing QFD to map relationships. Their Cost of Quality Framework (COQF) focuses on preventing and reducing waste, which is consistent with the principles of a Lean Manufacturing approach. The Quality Scorecard wheel (Shin *et al.*, 2018) provides a detailed framework for analysis based around the prevention, appraisal, and results approach and is suggested as an appropriate framework for use in Industry 4.0 applications. The authors acknowledge that the wheel was not explicitly linked to Continuous Quality Improvement (CQI) but instead claim that the management principles of CI are embedded within the principles of the system.

The central focus of Industry 4.0 is the use of AI. Whilst this has featured in only a small number of the publications considered in this review, future consideration should be given to AI integration with Quality Tools and analysis to fully explore a Quality 4.0 approach for Industry 4.0. The use of AI techniques integrated with quality tools is not new, for example, Six Sigma (Johnston *et al.*, 2000); QFD (Bouchereau and Rowlands, 2000; Kahraman *et al.*, 2006; Abdolshah & Moradi, 2013); SPC (Zorriassatine and Tannock, 1998; Rowlands and Wang, 2000) and

Taguchi (Lin *et al.*, 2002; Tsai *et al.*, 2004; Tsai *et al.*, 2006). However, many of these approaches are now being revisited, such as, Six Sigma (McMahon *et al.*, 2019); QFD (Yazdani *et al.*, 2019); SPM (He and Wang, 2018) and Taguchi (Li and Zhu, 2019) and this is a clear research focus for the future.

The study of Quality Management focuses on the misalignment between the function of an organisation (what goods or service it provides) and its operational ability to perform that function better than the competition and at a level that adds value to the customer. To gain further knowledge of Quality 4.0, future research should focus on the various interfaces inherent in this functional/operational relationship, such as the role of AI in Quality Management, and the role of Big Data and Six Sigma in Quality Management. The future challenge for both Quality 4.0 and Industry 4.0 domains will be to integrate AI within each domain for the ultimate goal of a Quality 4.0 strategic approach to Industry 4.0 based on the integration of traditional statistical methods with AI and machine learning techniques.

In conclusion, TQM can be the strategic focus for the future of Industry 4.0. It is technology independent and can be applied to any system and process as has already been demonstrated by many. TQM encompasses a strategic outlook, a customer focus and consideration of quality tools and techniques. This chapter has developed and presented an argument that the focus of Industry 4.0 research needs to change in order to achieve the full potential of the advanced technological developments towards a Quality 4.0-driven strategy with the key element of TQM as its framework.

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