LUISS Guido Carli

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Master Thesis

Double Degree in Supply Chain Management

The impact of digitalization on operational efficiency: GE Healthcare case

Supervisor: Alessandro Zattoni

Co-supervisor: Maria Isabella Leone

Candidate: Annachiara Franco

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Table of contents

Table of Figures

1. Introduction

The growing technological development, through the automation of work, digitization of processes and coordination by platform, has led to a real revolution called digital revolution. New machines and digital tools allow more information to be collected, processed and communicated faster than traditional methods (Eurofound, 2018). More in depth, the greatest revolution concerns the digitization of processes, whose main drivers are Internet of Things (IoT), 3D Printing, and virtual and augmented reality (Eourofound, 2017). Furthermore, digitalization allows to optimize production processes and obtain benefits in terms of operational efficiency and in particular productivity; recently the new digital tools have been applied in the healthcare sector and have proved very useful to cope with the challenges of healthcare providers (Berwick 2002). New technologies have made it possible to improve communication between man and machine and have led to the birth of a new type of company called "Smart Factory". Although there are many benefits connected to the implementation of the Smart Factory such as higher operational efficiency and lower costs, there are also many challenges that companies face when implementing new digital tools (Sjödin et al., 2018). In fact, the digital revolution transforms work and employment and involves changing the way of working to align workers' actions with the new technological tools (Eurofound, 2018). In particular, the implementation of the new digital tools requires an assessment of employees' skills and requires them to possess new types of skills called digital skills (Konttila et al., 2018).

One of the companies that uses digitalization as a driver of innovation is General Electric. GE is considered the pioneer of a new form of organization called "The Brilliant Factory", which has been implemented for the first time in 2016 and whose main driver is digitalization (Hand, 2014). This study has been conducted in collaboration with one of GE's businesses: GE Healthcare[1]. Its goal is to improve outcomes for healthcare providers worldwide.

GE Healthcare perfectly represents the digital revolution in healthcare sector ; it is currently facing some difficulties due to the implementation of digital tools, especially with regard to the digitization of processes. Currently, GE Healthcare employees are having some difficulties in properly using new digital tools in manufacturing processes and therefore in adapting to change. Due to these difficulties, employees work more slowly or make mistakes, and this leads to a decrease in operational efficiency. In particular, GE Healthcare did not get the benefits it expected in terms of productivity. For example, many employees, especially older employees, do not have the necessary skills to use

[1] On March 31, 2020, the American multinational Danaher acquired GE Healthcare for $21.4 billion. The business is now called Cytiva and is part of Danaher's Life Sciences business. Although this change occurred during the course of the research, GE Healthcare's staff and activities have remained the same as they were during the course of the research, with no change in the value or purpose of the research.

the new digital tools and therefore use them in the wrong way or simply not for the purpose for which they were introduced. Another example is the complete change in the tasks of individual employees due to the digital transformation of the company. Many tasks are easier and faster to perform thanks to the support of the technology if used correctly, but due to the lack of skills of the staff the advantage of speed is lost, and this causes delays in operations and consequently decreases in productivity. As stated by the Responsible for the global supply chain of GE Healthcare: "As manufacturers make the journey along the digital intensity spectrum toward realizing the digital factory, workers will be expected to transform along with them".

This research aims to analyze the main drivers and barriers of digitalization in order to understand if the lack of digital skills of employees limits the positive impact that digitalization has on operational efficiency and in particular on productivity. After doing this, it will be easier to understand what challenges GE employees are currently facing. The main aim is to find practices that can be applied to eliminate the difficulties that employees are having in using the new digital tools implemented in the healthcare sector, in order to increase productivity. The link between the empirical problem and the theoretical concepts under analysis is shown in figures below.

Figure 1 : Practical problem

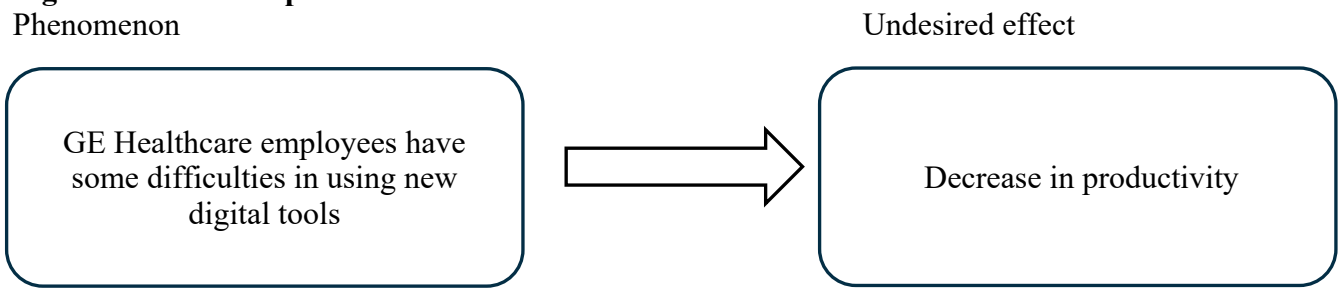
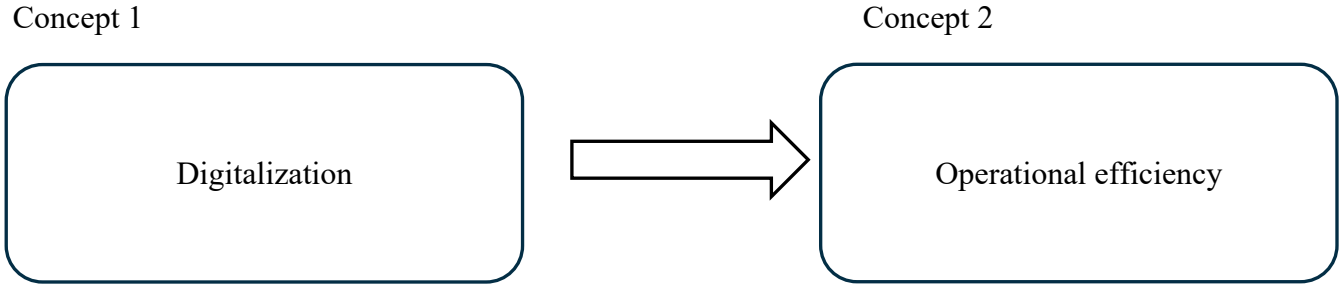


Figure 2: Conceptual model



1.1 Problem Statement

Which is the impact of digitalization on operational efficiency?

2. Theoretical framework

Many studies in the literature have focused on drivers that push a company to start a digitalization process (Horváth et al., 2019; Liere-Netherele et al., 2018); most of the time the drivers are linked to the achievement of certain benefits such as, for example, an increase in productivity, greater sustainability and so on (Sarter et al., 1997; Frohm et al., 2016; Accemoglu et al., 2018). Many other studies have instead focused on what the barriers of digitalization are, recognizing among them the lack of digital skills as one of the main barriers (Hess et al., 2016; Vogelsang et al. 2019; Fitzgerald et al., 2013; Horváth et al., 2019). However, few studies have analyzed the direct impact that one of the barriers of digitalization has on obtaining a certain benefit. The aim of this research is in fact to understand if one of the barriers to digitalization (the lack of employees' digital skills), has an impact on productivity (one of the benefits that companies want to achieve through digitalization). In order to find out if such a link exists, and what solutions can be applied to limit or eliminate the problem, the following literature review has been used. Literature review is based on four main areas of research. The first concerns the digitalization and is aimed at analyzing its main vectors of action: automation of work, digitization of processes, and coordination by platform. The second area of research concerns drivers of digitalization, and the third one analyzes the barriers to digitalization with main focus on lack of employees' digital skills. The last area of research analyzes the impact that digitalization has on productivity and tries to fill the existing gap between employees' digital skills and the new digital tools. The researcher retrieved studies from biographic databases such as Google Scholar, SSRN, ResearchGate, Tilburg University Library, and Pubmed. Among the various research papers priority has been given to the most recent ones and to the most cited ones. Additional literature has been found thanks to the reference lists of the most relevant papers. Keywords and inclusion criteria used for the research are shown in Figure 3 below.

Figure 3: **Areas of research**

Area	Initial keywords	Inclusion criteria	Final Sample
Digitalization	"Digitalization" OR "automation of work" OR "digitization of processes" OR "coordination by platform"	(1) Enablers of Digitalization (2) Benefits of digitalization (3) Work content relevant to the study	43
Drivers of digitalization	"Drivers" AND "Digitalization" OR "Digital Transformation"	(1) Work aimed at selecting digitalization drivers (2) Studies with qualitative approach (3) Studies with case study research strategy (4) Work content relevant to the study	11
Barriers to digitalization	"Digitalization" AND "Digital transformation" OR "Barriers to digitalization" AND "skills" OR "digital tools" OR "Competences" OR "HR management"	(1) Work aimed at selecting barriers to digitalization (2) Studies with qualitative approach (3) Studies with case study research strategy (4) Work content relevant to the study	10
The relationship between digitalization, skills and digital tools	"Digitalization" AND "Digital transformation" AND "Digital skills" AND "Productivity" OR "Operational efficiency"	(1) Work aimed at understanding the impact that digitalization has on operational efficiency (2) Work aimed at filling the gap between skills and technology (3) Work content relevant to the study	13

2.1 Digitalization

The continuous development of technologies, which is called "digital revolution", has brought us to the period we are currently living in, the digital age (Eurofound, 2018). The core of digital technologies is represented by computer hardware, software, and networks; these technologies are becoming more and more sophisticated and, above all, more and more integrated with each other leading to the fourth industrial revolution (Schwab, 2017). The process of digital transformation, through the implementation of digital tools in production processes, is called "Industry 4.0" (Oesterreich, 2016). According to Madsen et al. (2016) the degree of complexity has increased gradually from the first to the fourth industrial revolution. The first industrial revolution (1800) was characterized by the introduction of the steam engine (Schwab, 2016), and the second industrial revolution (1880-1920) by the use of electricity and the principles of scientific management (Taylor, 1911). Both, the first and the second industrial revolution, brought great progress in manufacturing

processes. The third Industrial Revolution (1960) was instead characterized by the development of semiconductors and the use of the internet (Schwab, 2016). The period in which we are living today is the fourth industrial revolution; the Internet and the new communication technologies (ICT) guarantee a great connectivity not only between man and machine, but also between machine and machine (Madsen et al., 2016). The digital transformation is having a strong impact on many different industries, one of which is healthcare (Liu et al., 2018); some of the most implemented digital tools in the healthcare sector are wearable devices and health portals (Konttilla et al., 2018). According to the Eurofound (2018) there are three main vectors through which digitalization acts: automation of work, digitization of processes and coordination by platforms. These elements will be described in the following paragraphs.

2.1.1 Automation of work

The work automation process consists in using machines and computers to replace human labor in a widening range of tasks and industrial processes (Acemoglu et al., 2018). Automation also reduces the time needed to perform a certain number of tasks as machines perform faster than humans (Bessen, 2016). According to Peruffo (2017), automation of work is implemented through some of the following technologies. Firstly, advanced robotics, which are mechanical devices that can perform tasks replacing humans. Secondly, Artificial Intelligence (AI), which is defined by Stone et al. (2016) as "a science and set of computational technologies, inspired by the human's way of using their bodies and nervous systems to sense, learn, reason, and take action" (Stone et al., 2016). The last technology to be considered is machine learning, which consists is the use of algorithms to obtain relevant information from data. Two learning techniques are used in machine learning. The first one is called "supervised learning"; through this technique it is possible to use algorithms to classify new data which are introduced in the system. The second one is known as "unsupervised learning" and it allows to discover existing links between data through the use of algorithms (Hahsler et al, 2005). Different benefits are linked to the application of the automation work; it reduces workload and errors and, as a consequence, it increases operational efficiency, reliability, accuracy, productivity, competitiveness in the long term, and it reduces operational costs. However, not all the promised benefits of automation of work are achieved when it is implemented, and this is due to the lack of consideration of the qualitative consequences of automation system implementation. In particular, if automation reduces many types of errors during the production phase, it also creates new types of errors. The new types of errors are particularly related to the inexperience of users because their tasks, after the introduction of autonomous machines, change in nature and they do not have the knowledge and skills to perform them (Sarter et al., 1997; Frohm et al., 2016).

2.1.2 Digitization of processes

The number of firms that use internet to conduct business is increasing; this phenomenon is called "digitization of business processes" and consists in performing activities digitally rather than by traditional methods (BarNir, 2003). More in depth, the digitization of processes allows to transform physical manufacturing process into digital information through the use of sensors (Eurofound, 2018). This mechanism allows to process, store and communicate more information than traditional methods but, at the same time, it requires that companies completely reinvent their processes through digitization (Markovitch et al., 2014). The application of digitization of processes and the use of the Internet is increasingly applied in the Healthcare sector because it allows for costs reduction "while assisting providers in the delivery of care" (Noffsinger, 2000). The three main drivers of the digitization of processes are Internet of Things (IoT), 3D printing and virtual and augmented reality (Eurofound, 2017); these will be discussed in the following paragraphs.

2.1.3 Internet of things (IoT)

Ashton (2009) has been the first to use the term "Internet of Things" to describe computers' ability to gather data about ideas and 'things'; the term "things" represent all types of objects or products. According to Gubbi (2013), the concept of "Internet of Things" can be defined in the following way: "Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications." (Gubbi, 2013). The collection and exchange of data promised by Internet of Things takes place via a platform (Bonomi et al, 2012). IoT allows to combine physical things with IT, enhancing their functions with new IT-based digital services. One of the biggest benefits of IoT technologies is the accessibility that from local becomes global (Wortmann et al., 2015). A key role in the development of the Internet of Things has been played by the development of telecommunication infrastructure with 5G connectivity that enables support for a large number of devices and provides greater security and geographical coverage (Eurofound, 2017).

2.1.4 3D printing

3D printing allows to produce an object by adding layers according to a specific design file instead of cutting the excessive material as is the norm in traditional subtractive manufacturing (Eurofound, 2017). This process is "also known as additive manufacturing, rapid prototyping, or solid free-form

technology" (Gross et al., 2014). 3D printing allows the production of very complex products, products that require a wide variety of materials, and highly customized products. The application of 3D printing makes it possible to achieve many advantages. First of all, it allows cost reduction and greater sustainability in production processes. In particular, from the manufacturing point of view, it allows to reduce lead times thanks to the integration of several functions of the company that are simultaneously dedicated to the production of a specific product for a specific customer. Furthermore, it would allow to reduce material usage, and logistical and production efforts. (Rogers et al., 2016; Kothman et al., 2016). The application of 3D printing is increasing more and more in different sectors but in particular in the healthcare sector; through this production technique healthcare providers are able to produce more customized medical instruments obtaining different benefits. The first advantage is represented by the reduction of production costs, that are lower thanks to the optimization of materials and personnel. The second advantage is the increase of operational efficiency, as lead times are reduced and therefore the delivery is carried out earlier. The last benefit is the effectiveness, as the product is more customized and better matches its purpose of use (Schubert et al., 2014; Klein et al., 2013; Ventola, 2014).

2.1.5 Virtual and augmented reality

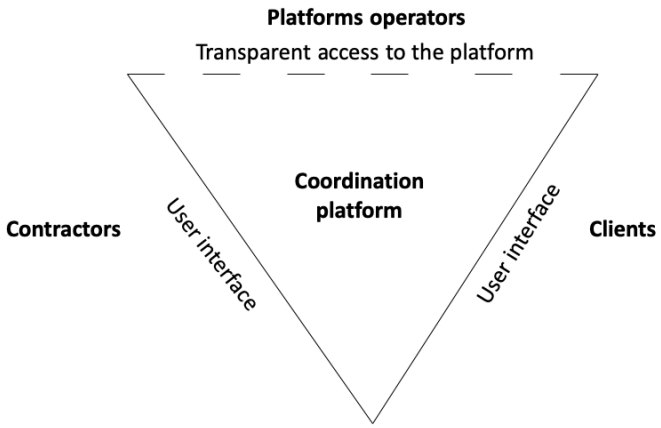
Virtual reality can be defined as a simulation tool and can be considered as a natural extension to 3D computer graphics (Nee et al., 2013; Jayaram et al., 1997). Virtual reality allows to create a digital space in the real world (Eurofound, 2017). The first applications of virtual reality in the 80s concerned flight simulation, robotics, and space-related research as they allowed to simulate risky environments and to perform training activities for those who would then have to drive an airplane or make a space trip (Schroeder, 1993). On the other hand, augmented reality can be considered as a man-machine interaction tool that allows to overlay the information generated by the computer on the real scene, guaranteeing efficient and complementary tools to assist production activities (Nee et al., 2013). Augmented reality (AR) allows to display digital or virtual images in the real world that surrounds the user. For example, augmented reality allows to project objects such as trees or buildings, superimposed on real world objects (Bradski et al., 2019). Alkhamisi et al. (2013), in their study about AR application, state that augmented reality mainly carries out four different tasks. First of all, augmented reality allows to capture a scene through two types of scene capture devices: "video-through devices" such as video cameras, and smart phones, and "see-through devices" such as head mounted displays. Secondly, augmented reality allows to identify a scene through two main technique: the marker-based technique that allows the augmented reality system to perceive reality through markers, and the non-marker-based technique, which do not use markers to identify the scene

but other kind of devices. The third task carried out by augmented reality in scene processing. It is the phase in which the system links a virtual model to each marker in the 3D. The last task is the ability of the system to reproduce the virtual image mixed with the real scene, if the marker was used as scene identification technique, or to present digital information, if non-marker-based technique was used. This task is called visualization scene. The difference between virtual reality and augmented reality lies in the complexity of the projected graphic objects. For example, augmented reality can be driven by standard and inexpensive microprocessors, and transmit images in real time but, at the same time, it has more stringent requirements than virtual reality such as the accurate recording with the physical world (Thomas et al., 1992). The application of augmented and virtual reality is increasing in several sectors, one of which is healthcare since these new devices facilitate effective communication between healthcare providers and patients (Kobayashi et al., 2018). In fact, the possibility to simulate the use of a medical machine during a dangerous situation of a patient would allow to improve the relationship between the provider and the patient, and to reduce medical errors.

2.1.6 Coordination by platforms

Platforms are digital networks that allow transactions to be carried out thanks to an algorithm that selects and coordinates the parts of the transaction in an autonomous manner (Eurofound, 2018). According to Cramer and Krueger (2016), platforms enable transactions to be carried out more efficiently and, through the use of algorithmic matching, ensure optimal coordination between operators and transparent information exchange. Coordination platforms are often defined as “two-sided markets” or “multi-sided platforms”, as there are at least two user groups present (Rochet and Tirole, 2003; Hagiu & Wright, 2015). According to Shmidt (2016), there are three parts to consider within a platform: operators, contractors and clients. The key role is played by platform operators as they are the only ones who have a complete overview of all the processes taking place on the platform and can potentially modify them in real time. On the other hand, contractors and clients have a smaller view of what is happening on the platform and this leads to information asymmetry that could be reduced only through decentralization. A visual representation of the platform architecture is shown in the figure below.

Figure 4: Platform architecture



Source: Author's elaboration based on Shmidt (2016)

According to Codagnone and Martens (2016), each user group benefits from the increase in the number of users in the other group. The matching between the users of the two groups can be done in different ways: search with fixed prices, auction mechanisms or other intermediate methods. In any case, an increase in the number of people on the platform leads to an increase in other clients wanting to join the platform, which in turn stimulates markets for service providers.

2.2 Drivers of digitalization

The digital transformation requires great innovation and constitutes an element of uncertainty and complexity for companies (Klötzer and Pflaum, 2017). An innovation is "an idea, practice, or object that is considered as new" (Rogers, 2003). Schumpeter (2000) states that the innovation process can take place at five different levels: product, method of production, customers, suppliers and organization. Based on these definitions, digital transformation can be seen as an innovation as it requires the transformation of a company's entire supply chain in order to adapt to new technologies. The drivers that drive a company to implement digital tools, and thus undertake a digital transformation, vary depending on the company that is analyzed and depend on the sector in which it operates and the benefits it hopes to achieve. For this reason, in order to establish the drivers of digitalization, the author used as landmark the findings of Liere-Netherele et al. (2018). Their study, "Drivers of Digital Transformation in Manufacturing", conducted between 2016 and 2017, had the main purpose of highlighting what are the drivers of digitalization by applying a holistic approach. The author's choice is based on two main reasons. The first concerns the methodology applied by Liere-Netherele et al. (2018) in their study: qualitative research with a case study strategy, and data

collection through semi-structured interviews; methodology is consistent with this work. The second reason is that the study applies a holistic view and analyzes different companies and thus allows a broader and more detached view of the drivers from a specific case study. Although the findings of Liere-Netherele were already quite relevant on their own, the author of this research sought to increase the reliability of the study by looking for studies that had similar findings. In particular, the research by Horváth and Szabó (2019), "Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? ", confirms all findings of Liere-Netherele although the sample of companies analyzed is different. In addition, all the findings of Horváth and Szabó (2019), are further confirmed by those of other researchers (Paritala et al., 2016; Cimini et al., 2017; Kiel et al., 2019; Bauer et., 2015; Adolph et al., 2014), thus confirming the significance of the selected drivers. Drivers can be classified in three different levels: organizational, external and internal level (Liere-Netherele et al., 2018).

2.2.1 Organizational drivers

According to Liere-Netherele et al. (2018), organizational drivers are the ones which more push innovation; these drivers are linked to the company's strategy and the achievement of a certain goal. The first two drivers concern process improvement and workplace improvement. Digital transformation would allow companies to increase production efficiency, reduce errors during production processes and improve safety by performing dangerous jobs on machines (Paritala et al., 2016). For example, predictive maintenance would allow processes to be optimized and work automation would allow machines to perform dangerous tasks rather than people. Two other fundamental drivers concern the exchange of information. The first of these two is vertical integration: through sensors it would be possible to collect information directly at operational level and then communicate it to management for processing. The second is horizontal integration: new technologies would facilitate the exchange of information between several departments of the same company. The role of management is fundamental in the implementation of a digital transformation. In fact, a well-defined strategy and a new company structure are needed; management support is fundamental (Cimini et al., 2017). The last of the organizational drivers is cost reduction. Although the initial digital transformation project together with the new digital tools represent a great investment for the company, in the long term new digital tools would allow to reduce costs by improving production processes, reducing setup-times and breakdowns (Kiel et al., 2019).

2.2.2 External drivers

External drivers are linked to all those changes and contingencies that take place outside the company's boundaries and over which the company has no control. The introduction of the new digital tools is itself an external driver of digitalization; it causes greater market pressure and pushes companies that have not yet adopted the new digital tools to do so in order to gain a competitive advantage in a market that is increasingly globalized (Bauer et., 2015). This condition is accentuated by the laws that, given the new existing technologies, require ever higher standards of sustainability and safety at work (Lins and Oliveira, 2017). Moreover, the presence of increasingly disintegrated companies requires greater collaboration along the supply chain; new technologies are seen as a necessary tool to carry out common planning and execution of operations with other companies, for example via trade fairs or conferences. The last external driver is customer demand; in fact, consumers require transparent traceability that is guaranteed by new digital tools and that allows consumers to evaluate the quality of the entire production process of a company (Adolph et al., 2014).

2.2.3 Internal drivers

Internal drivers are linked to all those changes and contingencies that take place inside the company's boundaries and over which the company has control. Unlike organizational drivers, internal drivers do not refer to the strategy of the company but to the its operational aspect. According to Liere-Netherele et al. (2018), there is one main internal driver of digitalization that is employee support. The new digital tools increase safety at work and help employees to perform their tasks. Thanks to the new digital tools, employees can increase their digital knowledge and develop new skills that are essential for the effective implementation of digitalization. The involvement of employees is as important as that of management. In particular, employees play a key role not only as driver of innovation but also for the successful implementation of digitalization. It is essential that employees accept business change due to new technologies and that they have, or are able to develop, digital skills for the effective functioning of the new digital tools. Another important aspect for a successful implementation of new digital tools is system integration (Barua et al., 2001). System Integration allows to collect and analyze data along all the supply chain of a company. For example, integrated systems would allow to share data in real time and to monitor orders through shipments. Lack of system integration would cause a lack of coordination throughout the supply chain and would not deliver the promised benefits of the implemented digital tools.

2.3 Barriers to digitalization

Digital transformation strongly influences industry, industrial processes (Urbach et al, 2017), and the way of working in production (Brynjolfsson and McAfee, 2014). In fact, the term transformation means "radically changing traditional ways of doing business, redefining business processes and relationships" (Dehning et al., 2003). Despite the many benefits promised by the digital transformation, many companies are still struggling to reach the promised potential due to different barriers (Hess et al., 2016). According to Vogelsang et al. (2019), barriers to digital transformation are the “few things that can hinder or stop its successful implementation” Vogelsang et al. (2019), and understanding their nature is fundamental to be able to counter them. They classified the barriers to digital transformation into five main areas: missing skills, technical barriers, individual barriers, organizational and cultural barriers, and environmental barriers. Since the focus of this research is on digital skills, the author only focused on the area of missing skills. Vogelsang et al. (2019) have identified three main areas of challenges that companies face in the field of missing skills. The first area concerns the IT knowledge; they report a lack of necessary digital skills to reach a successful implementation of new digital skills. The second area is process knowledge; it is essential to be familiar with the processes already carried out in the company in order to successfully adapt the new technological tools. The last area is the knowledge about new technologies; most of the employees of a firm do not know how new digital tools work and which benefits they could gain from their implementation.
Another study that focused on the barriers to the digitalization process is the one of Horváth and Szabó (2019); they identified five main barriers to digitalization: human resources, financial resources and profitability, management reality, organizational factors, and technological and process integration. More in depth, as far as human resources are concerned, they highlighted two main challenges. The first one concerns the lack of digital skills of employees that will not allow them to use the new digital tools in the right way. The second concerns the training needed to prepare employees to perform their new tasks; in fact, training represents a great expense in terms of cost and time.

What has been written so far is summarized in the table below with attached quotes from the interviews of the respective studies.

Figure 5: Barriers to digitalization

Research's author	Factor	Barrier	Quotes
Vogelsang et al. (2019): "Barriers to digital transformation in manufacturing"	Missing Skills	IT Knowledge	"Lack of necessary competencies in informatics" and "technological shortcomings"
		Process Knowledge	"Digital Transformation cannot be successful if you implement the new technology without questioning your processes."
		Knowledge about new technologies	"Companies also do not know which possibilities they have and there is lack of transparency regarding things which are already possible today or the huge range of technologies."
Horváth and Szabó. (2019): "Driving forces and barriers of Industry 4.0"	Human Resources	Lack of appropriate competences and skilled workforce	"One major challenge in implementing Industry 4.0 technologies is that companies do not currently have skilled workers with the competences required in future."
		Longer learning time (training of staff)	"It may also be challenging to retrain employees, because this takes a long time, increasing costs."

As the table shows, the visions between Vogelsang et al (2019) and Horváth and Szabó (2019) are in agreement. Moreover, for both of them, the main barrier to digital transformation has proved to be the area of "missing skills". Fitzgerald et al. (2013) confirm that one of the greatest difficulties in making a successful digital transformation happen is the management of human resources, both employees and managers. In fact, according to Adolph et al. (2014) and Erol et al. (2016), workers should have competencies that allow them to adapt their work in a very flexible way to market demand; they must be able to interact with new machinery and make important decisions in a very complex and volatile environment. This vision is also confirmed by Hoberg et al. (2017); they argue that two of the main problems for the realization of a digital transformation are the lack of digital talent (i.e. workers who have adequate digital tools such as big data analytics skills), and the fact that recruitment and training programs applied by companies, aimed at bridging the gap between workers' skills and new digital tools, are to be considered a rarity. Only the presence of employees' digital skills can allow the reduction of errors in production processes and in this way reduce lead times, thus increasing operational efficiency. Finally, according to Gupta (2018), the role of human resources (HR) management is changing and is increasingly crucial to make sure that the digital transformation takes place within a company. In fact, HR management has to select a new class of well-trained workers with appropriate digital skills and to help and support workers already within the company during the change phase.

2.4 The relationship between digitalization, skills and productivity

2.4.1 Impact of digitalization on productivity

According to literature, the digital transformation of a company brings numerous benefits. In particular, from the point of view of operational efficiency, many improvements can be achieved through the implementation of new technologies. As already stated so far, thanks to new technologies and digital tools it is possible to reduce production costs, for example by producing larger quantities of a certain product; to produce more customized products, for example by using 3D printing; to reduce human errors during production processes, thanks to work automation; to reduce the emission of harmful substances for the environment and thus make the company more sustainable. More specifically, however, in this research the focus of operational efficiency is placed on the impact that digitalization has on productivity. In literature, the impact that automation of work has on productivity is very evident. New machines, which replace humans in production processes, are able to produce faster. This speed is not only due to the technological factor, but also to the fact that, for example, a machine can move much heavier materials than a human. In conclusion, work automation has a positive impact on productivity. Despite this, productivity decreases when employees are unable to perform the new skills assigned to them after the introduction of autonomous machines (Sarter et al., 1997; Frohm et al., 2016). A further relationship that is highlighted in literature is an indirect link between digital skills and productivity. When employees have the digital skills needed to perform their tasks, errors during production processes are reduced and productivity increases (Acemoglu et al., 2018). In conclusion, according to Sjödin et al. (2018), the new digital tools increase productivity by facilitating the recognition of bottlenecks in the production process, which can then be eliminated. Furthermore, new machines make it much easier to measure production times and recognize errors during the production phase; making it possible to reduce downtime and optimize production capacity.

Relationships between the variables described so far, which have emerged from literature, are summarized in the table below.

Figure 6: **Patterns from literature**

First variable...	Productivity increase/decrease	Explanation
Lack of digital skills with autonomous machines implemented in a company	Decrease	The positive impact that automation has on productivity is limited by the lack of employees' digital skills.
Lack of digital skills	Decrease	The lower the digital skills, the more errors, the lower the productivity.
Digital tools (AI, IoT)	Increase	Digital tools allow to recognize errors, reducing downtime, thus increasing productivity.

2.4.2 Bridging the gap between skills and digital tools

The development of new digital tools has led to the creation of new work tasks. In order to perform these new tasks, new skills are needed from workers. If the workforce does not possess digital skills, the potential benefits of new technologies will not be achieved because workers' skills are complementary to new technologies and their absence will lead to a decrease in productivity (Acemoglu et al., 2018). In literature the terms digital/internet skills, literacies and competences are often used as synonyms, but these have different meanings. Competence is "the ability to apply knowledge and skills to different contexts, such as work, leisure, or learning" (Ala-Mutka, 2011); "literacy is a set of competences and knowledge, whereas skills refer to the more technical aspects of competences and knowledge" (van Deursen, 2010). To find a new workforce with the necessary digital skills may be difficult and, for this reason, the HR department plays a key role in the digital transformation as it has to assess the technological skills of the workers and design training procedures for existing and new employees (Matt et al., 2015). The workforce in the age of digitalization should be medium skilled and able to update their skills frequently in order to adapt to new technology (Eurofound, 2017). In order to ensure a workforce that has the appropriate skills to adapt to new technologies, three activities play a key role.

The first activity is the evaluation of the digital skills of workers already working in the company. According to Van Deursen et al. (2014), there are three methods for evaluating digital tools owned by workers. The first method consists of surveys that require the use of digital tools to test subjects' skills. The real problem of this method is that it only provides information about the skills possessed by the subjects and not about their real competences. The second method concerns surveys that require a self-assessment of skills. This is the most used method because it allows to collect a large amount of information in a short time and at a relatively low cost. The main disadvantage linked to this method is the fact that people often in a self-evaluation process tend to over evaluate themselves. The third method consists in carrying out "performance tests" and allows the evaluation of workers' digital skills in practical terms. Most of the time the results of these tests are analyzed using benchmarks; compared to the other two methods, the "performance test" method has been found to be the most efficient in terms of results but also the most expensive and time-consuming one.

In order to ensure that the benefits of technological progress are achieved, efforts must be directed at improving the digital skills of a large part of the workforce (Dolphin, 2015). According to that, a key role is played by education which aims to train the workforce of tomorrow. In this respect, collaboration between the human resources of companies and universities should be fostered in order to provide students with more specific skills regarding digitalization processes and to enable them to acquire the digital skills needed to find a job more easily. In fact, according to Konttila et al. (2019): "appropriate and successful technology usage requires regular education that considers individuals' competence".

The last activity is training, which is becoming increasingly important (Degryse, 2016). In fact, the European Commission has stated that one out of two workers in Europe does not have the appropriate skills to adapt to new technologies. This lack will lead to an imbalance between the demand for work and the number of workers available on the market. According to that, Brynjolfsson and McAfee (2011), argue: "we need not only organizational innovation, orchestrated by entrepreneurs, but also a second broad strategy: investment in complementary human capital - the training and skills needed to get the most out of our racing technology".

3. Methodology

In this section the methodology used to conduct the research will be described. In particular, the focus will be on the choices made regarding the research design and strategy, data collection, data analysis and sampling. In addition, information about the quality of the data will be examined with particular attention to reliability and validity.

3.1 Research Design

This is a theory supported inductive research. Induction is also known as "bottom up" approach because it implies to move from the specific to the general (Burney and Saleem, 2008). The goal of this research is to formulate new theory on the basis of an empirical analysis of GE Healthcare business, that could be generalized to other firms and that could be valuable if added to the existing literature. Since the aim of this study is to analyse a problem in order to understand which its causes are, the research objective can be defined as exploratory (Saunders et al., 2011). The inductive approach well matches with the qualitative research. In fact, qualitative research allows to analyse real phenomena on the basis of existing literature, and to generate new theories (Bryman and Bell, 2011; Denzin and Lincoln, 2011). Qualitative approach proved to be the most suitable for the purpose of the present work for the following reasons. The first reason is that the topic of the research is qualitative in nature as it aims to analyse the impact that the lack of digital skills of GE Healthcare employees has on productivity. The second reason is that this research does not aim to test a theory that already exists but wants to create a new theory and find out if a link between the selected variables actually exists or not.

3.1.1 Research strategy

The strategy selected for this study is "case study". Robson (2002) defines it as "a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real-life context using multiple sources of evidence" (Robson, 2002). "Case study methodology provides tools for researchers to study complex phenomena within their contexts" (Baxter and Jack, 2008). The case study strategy well matches with qualitative research, since it allows to analyse a phenomenon, and to generate new theory; it also enables the generalization of results to enrich current theory (Gersick, 1988). In fact, the case study strategy has made it possible to study a qualitative phenomenon within GE Healthcare and to seek empirical evidence of a theory that is not yet covered

in literature. The study of the digitalization process at GE Healthcare and the relationship that exists between the digital skills of employees and the level of productivity are phenomena of a qualitative nature that meet well with the strategy of the case study. Furthermore, the digitalization process varies according to many variables such as the business in which the company operates, the digital tools it decides to implement, the objectives and strategy of the company and the external environment; according to that, the analysis of a digitalization process is “case-dependent”.

3.2 Data collection

Both, primary and secondary data have been used. They have been collected from both internal GE Healthcare sources such as reports and company websites, and from external sources such as journals and other researches. Primary data were mainly collected through interviews which are one of the most suitable approaches to a qualitative study. Interviews were semi-structured. “Semi-structured interviews are simply conversation in which the interviewer knows what he/she wants to find out about, but the conversation is free to vary and is likely to change substantially between participants” (Fylan, 2005). Furthermore, these kinds of interviews are useful for finding out “Why” rather than “How many or How much” and that makes them more suitable for a qualitative study. In fact, the semi-structured interviews with GE Healthcare managers have been very useful to derive causal relationships between the different research variables. All the “Why?” asked during the interviews have been fundamental to connect qualitative information between each other. Initially, the researcher was put in contact with interviewees via e-mail by GE Healthcare's SC function team leader, Jairaj Thakkar. Subsequently, the researcher contacted each interviewee individually by e-mail in order to introduce herself, introduce the research objective and make an appointment for the interviews. Due to the impossibility of meeting in person for COVID-19, internet mediated interviews have been conducted (through Skype and Microsoft Teams) in order to maintain the visual contact. Interviews were one-to-one to make the interviewee as much free as possible, and each of them lasted about an hour and a half. Some interview protocols (Appendix A) have been prepared; the author started with introductory questions, going on with probing and specifying questions in order to get more and more detailed information. Moreover, in order to obtain some quantitative information, questions such as the following one have been asked: "How important is this driver to you on a scale from 1 to 5?”.
All interviews were recorded with the consent of the interviewee and then transcribed (Appendix B) for data analysis.

3.2.1 Sampling

For what concerns the sampling strategy, non-probability sampling has been used; this sampling strategy “is often associated with case study research and qualitative research” (Taherdoost, 2016). Furthermore, “case studies tend to focus on small samples and are intended to examine a real-life phenomenon, not to make statistical inferences in relation to the wider population” (Yin, 2009). In particular, a purposive sample has been selected. “Purposive sampling is a strategy in which particular settings persons or events are selected deliberately in order to provide important information that cannot be obtained from other choices” (Maxwell, 1996). According to Malhotra and Birks (2006) a purposive sampling strategy is convenient in terms of costs and time and is ideal for exploratory research design. More in depth, the selected sample is a heterogeneous and critical sample. A sample composed in this way has allowed to select people whose role in the company is consistent with the objective of the study, and to generate many insights by collecting data from people who have different roles and maybe different points of view. The first person the researcher had contact with was Alessia La Croce, HR manager for the marketing function. Thanks to her help, it was possible to contact GE Healthcare's global HR manager for SC, Thakkar Jairaj. Finally, Mr. Thakkar contacted his team and asked them to participate in the research project. Each of the people selected was fundamental in collecting and analyzing the data and provided a different viewpoint on the digitalization process. In fact, the different role of the interviewees within the company allowed to analyze in detail all the variables of the research: productivity, digital tools and digital skills. A list of all the informants is shown in the table below.

Figure 7: Informants

Informants		
Name	Surname	Role inside the company
Jairaj	Thakkar	Global Supply Chain manager
Alessia	La Croce	Global Marketing manager
David	Morel	GM Operational Excellence
Alder	Cory	Operations Project Leader
Hannes	Stadlmayr	Plant Manager
Mike	Cooper	Site Manager
Erich	Prungraber	Project Manager
Christophe	Suizdak	Global Operations manager
M.	H.	Supply Chain Digitization Leader

3.3 Data analysis

The process of data analysis consists of working with the data collected in order to obtain results that are consistent with the purpose of the research and therefore, above all, useful to answer to the research questions (Gibson et al., 2009).

The theory used as a basis for data analysis is “Grounded Theory”. This theory is based on a continuous analysis of the data collected during the research, among which patterns must then be highlighted in order to thoroughly analyze the phenomenon of study and generate new theory (Strauss et al., 1997). In addition, in order to increase the richness of the data collected, a comparative approach has been applied (Eisenhardt, 1989); first of all, the data collected concern the fifteen GE Healthcare production sites and then form a first basis for analysis. In addition, the data collected was then compared with findings from other similar research for study purposes and methodology. According with the qualitative nature of data, a coding scheme (Appendix D) has been used. Then, data have been inserted in a data display (Appendix E). The two main areas of the data display are the two main concepts of the conceptual model: Digitalization and Operational Efficiency. Each of the two main categories has been subdivided into sub-categories based on the information found in the literature and the theoretical framework of this research. In particular, the sub-categories into which the "digitalization" category has been divided are: “digital tools”, “benefits”, “drivers”, “barriers”, “digital skills”. On the other hand, for the "operational efficiency" category, the only sub-category that has been created is "productivity" as it is the only variable that is analyzed in this research. The data display is like a table in which horizontally the main categories were listed with their sub-categories and vertically the names of the respondents were listed. On the basis of the sub-categories created, the data from the nine interviews have been included in the data display; more specifically for each interviewee the data from the interviews have been included in each of the sub-categories. The data obtained from the interviews were then shortened in order to have an easier to read and shorter data display. The researcher, in rewriting the data obtained from the interviews, tried not to modify the original meaning of the data, guaranteeing the validity of the data analysis itself. For example, in one of the interviews, the Global Operations Manager (Christophe Suizdak) said that GE Healthcare uses Artificial Intelligence to prevent machine failures; this data has been entered in the coding scheme as “AI to prevent machine failures” in the main category “Digitalization”, in the sub category “digital tools”. Once all the data had been entered into the data display the author analyzed the similarities and differences between the data belonging to the same category trying to reach findings that were relevant. The last step of the data analysis was to evaluate the relationship between the data belonging to the first category "digitalization" and "productivity". All the patterns emerged from the data analysis were then compared with other studies in the literature.

3.4 Reliability

Reliability concerns the authenticity of the findings. According to Bryman and Bell (2011), two concepts of reliability can be considered: if another researcher carries out this research and comes to the same results, internal reliability is verified; while external reliability means that repeating the study, the same results will be obtained. In fact, in order to increase the reliability of the data analysis author granted stability, repeating more than once data analysis, and reproducibility, trying to confirm results if someone else develops the same data analysis.

In order to develop a reliable research, all steps taken during the research have been documented. For example, interviews have been recorded, with the consent of the interviewees, and then transcribed thus reducing the risk of misconception. The application of data triangulation has allowed to increase the reliability of the research too. "Triangulation means that the researcher uses data from a variety of sources applying a variety of methods; doing so, the researcher gains knowledge that is more reliable due to the variety of approaches" (Bryman and Bell, 2011). In fact, different sources were analyzed: data provided by respondents, existing literature, company reports, other research carried out in the same field. Triangulation has also been used to reach data saturation point. Moreover, reliability has been increased also reducing both, interviewer and interviewee bias and errors. Interviews have been conducted in a rigorous way avoiding any kind of distraction and interviewer's personal opinion.

3.5 Validity and generalization

According to Yin (2009), three kinds of validity exist: concept validity, internal validity and external validity. Concept validity refers to the match between the literature and the empirical findings of the research. In this study the literature review has been performed aiming at supporting the practical problem of GE Healthcare and also to structure the interviewees. "Internal validity refers to the degree of confidence that the results obtained are true within the case situation" (Sekaran and Bougie, 2013). The internal validity of the study guarantees robust and concrete solutions; in order to ensure internal validity all interviews were recorded and transcribed to give other researchers the opportunity to replicate the research. Finally, external validity refers to the degree of generalizability of study. The higher the external validity, the easier findings can be generalized to other cases. According to Yin (2009), ensuring generalizability of a research based on a case-study approach could be difficult. In

fact, the case study approach is based on the analysis of an empirical phenomenon and for this reason the findings of the research will be strongly linked to the company being studied. Nevertheless, it is possible that the theory behind the research is relevant and that it can be applied to other companies operating in the same field. This research in fact analyses the link between different variables that are part of the digitalization process and the impact they have on the operational efficiency of the company. Although the findings of the study are related to the particular tools implemented by GE Healthcare, it does not mean that they are not relevant for other companies that are implementing a digital transformation. Moreover, the concept of digitalization is very broad and embraces different businesses; although the company being analysed operates in the field of healthcare, the findings can be easily extended to companies operating in different fields but implementing the same digital tools used by GE Healthcare (AI, 3D printing, Automation of work ...) even if with different purposes. Moreover, according to Yin (2009) it is possible to guarantee the generalizability of research by demonstrating that it fills a gap in the literature. As explained in the chapter of the theoretical framework, in fact, there are many researches that analyse the different elements of the digitalization process, but there are very few that identify cause-effect relationships between them. Based on what has been written so far, the author believes that this research can be easily generalized and can be a starting point for further research in the future.

4. Empirical Findings

This chapter provides an analysis of all the data collected during the interviews. The analysis will follow the same order as in the theoretical framework, which in fact is the basis of the whole analysis. In the first part the company will be introduced. Then, the digital tools that GE Healthcare uses to implement the digitalization process will be described. Next, the drivers and barriers to digitalization will be presented. Finally, the impact that the lack of digital skills of GE Healthcare employees has on productivity will be analyzed. This section provides the basis for the conclusions.

4.1 General Electric Healthcare

General Electric (GE) is an American conglomerate, whose mission is to bring real progress worldwide. GE acts in more than 130 countries, being present in Africa, Americas, Middle East, Asia, Australia, and Europe. It is built on ten different businesses: GE Additive, GE Aviation, GE Capital, GE Healthcare, GE Lightning, GE Power, GE Renewable Energy, GE Research, and Business Innovations. As stated above, GE is considered the pioneer of a new form of organization called "The Brilliant Factory", which has been implemented for the first time in 2016 and whose main driver is digitalization (Hand, 2014).

GE Healthcare wants to continuously improve its capacity and productivity in order to achieve better patient outcomes. As stated by the President & CEO of GE Healthcare, "late diagnosis, misdiagnosis, treatment with the wrong medicine represent a great opportunity for the business in terms of growth". GE Healthcare's goal is to constantly seek incremental improvements that increase efficiency and quality.

4.2 GE Healthcare digital tools

GE Healthcare has always been a revolution paper company until now. Its main priority is to produce high quality products investing in manufacturing abilities such as advanced automation. In its global manufacturing sites in UK, Germany, and Chine GE invested in autonomous machine for paper filters production reaching an increase in productivity and quality. Ge Healthcare also deployed automated bottling lines for aseptic liquids. It was a highly skilled and highly repetitive process where operator had to move hands in a very specific way to ensure product was not contaminated during filling. Thanks to automated bottling lines have, the number of errors during production decreased and

productivity increased. Automated process manufacturing lines are controlled by closed loop SCADA solutions (ISA 95 Level 2) to monitor process parameters every second and to make adjustments to keep process within specific parameters. Precise control ensures high quality products, to keep chemical reactions optimal, and to reduce manufacturing lead times and scrap.

IoT is used for temperature control of finish good shipment. More in depth, IoT allows to monitor water quality and water usage to ensure GE Healthcare is meeting regulatory limits for wastewater and eliminate fines for exceedances.

3D printing is used for spare part production and prototype production. 3D printing allows to print complex parts as a single part instead of many separate pieces that have to be assembled. This typically allows for a much lighter and cheaper part to be produced. Lead times are also often reduced as these parts were typically machined and assembled at specialty supplier with long lead time and instead can be printed directly in house. An example is a metal manifold that is 3D printed.

As far as augmented reality is concerned, some augmented reality systems have been experimented but have not been implemented. An example is the on-body solution "Oculus", an augmented reality system that has the shape of simple eyeglasses. Despite this, this system was too heavy to wear and limited in its durability. Instead, virtual reality is mainly used for training and to provide technical support in the field and instructions for the operator.

AI has also been implemented at GE Healthcare to perform preventive maintenance. The AI system in fact, runs twin bin engine to anticipate equipment failures. Ai is also used to plan POC in supply chain.

4.3 GE Healthcare’s drivers of digitalization

During the interviews each of the interviewees was asked which the main drivers of digitalization were and to quantify the importance of each driver on a scale from 1 to 5. All respondents stressed the importance of two drivers that they quantified with a value of 5.
The first is to be competitive in the market. In fact, digital tools have allowed GE Healthcare to improve efficiencies and yields, maintaining its leading position on the market. According to that, GE Healthcare’s goal is to find disruptive technologies that can be incorporated into manufacturing to improve economics of manufacture in order to increase its competitive power.

The second important driver which emerged from interviews is regulatory pressure which requires GE Healthcare to demonstrate to be able of controlling its supply chain. Digital tools allow to meet these requirements more efficiently (versus a paper based manual process).

At a later stage of the interview, each interviewee was asked to quantify the importance of the drivers of digitalization that emerged from literature and to explain whether they were drivers for GE Healthcare or not.

4.3.1 GE Healthcare's organizational drivers

The following table shows the values from 1 to 5 that each respondent assigned to the organizational drivers. An average value has been calculated for each driver analyzed.

The driver that obtained the lowest value is "cost reduction" (Average value:2); in fact, respondents claim that the savings in production thanks to digital tools are balanced by additional cost to maintain the tools. As a result, it can be concluded that digitalization does not lead to lower costs.

Two other drivers with a low average value are "process improvement" (Average value: 2.4) and "workplace improvement" (average value: 2.3). GE Healthcare managers argue that improving production processes and the workplace are already part of the company's DNA and therefore have not been a driver for the implementation of the new digital tools. Nevertheless, some of them see digital tools as an opportunity to improve processes and the workplace. For example, new digital tools allow for workplace improvement eliminating manual labor and repetitive tasks.

"Vertical integration" and "Management support" obtained the same medium-high value (Average value: 3.6-3.8). For what concerns vertical integration, a lot of GE Healthcare metrics are still manually tabulated allowing for variations between sites. Preparing reports and metrics is wasted time that could have been used to act on data. Furthermore, sensors could help in the future when will replace the manufacturing equipment, but it will take time. Management support has been evaluated as very important because managers have to guide the digitalization process and are responsible for the decision-making; the use of digital tools would simplify data management and speed up decision-making processes.

"Horizontal integration", which aims at facilitating the exchange of information between more departments of the same company, has been ranking with the highest value (Average value: 4.3). According to that, GE Healthcare implemented Business Process Management (BPM) tools to

digitize processes that span multiple employees or departments. The benefit is that it is possible to create repeatable processes with clear ownership.

Figure 8: **Organizational drivers**

(Scale 1-5)	**Name and surname of the interviewee**									**Average value for each driver**
Drivers	Jairaj Thakkar	Alessia La Croce	David Morel	Alder Cory	Hannes Stadlmayr	Mike Cooper	Erich Prungraber	Christophe Suizdak	M. H.	
Process improvement	**3**	**3**	**2**	**3**	**2**	**2**	**2**	**2**	**3**	**2.4**
Workplace improvement	**3**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**2.1**
Vertical integration	**4**	**4**	**4**	**2**	**4**	**4**	**4**	**3**	**4**	**3.6**
Horizontal integration	**5**	**5**	**4**	**4**	**4**	**5**	**4**	**4**	**4**	**4.3**
Management support	**3**	**4**	**4**	**5**	**4**	**3**	**4**	**4-5**	**3**	**3.8**
Cost reduction	**2**	**1**	**3**	**3**	**2**	**2**	**1**	**1**	**3**	**2**

4.3.2 GE Healthcare's external drivers

The following table shows the values from 1 to 5 that each respondent assigned to the external drivers. An average value has been calculated for each driver analyzed.

"New digital tools available in the market" were ranked with the lowest value among the external drivers (Average value: 1.6). According to most of the interviewees it would be difficult to look at the market continuously because technology is constantly evolving, and it would be too expensive to implement all the digital tools existing on the market. For this reason, digital tools are chosen on the basis of the company's strategy and the goal it wants to reach. If a process can be carried out through a simple manual activity it will surely be preferred to digital tools that require training and costs.

The driver "laws/government" (Average value: 4.6) turned out to be the most important external driver for GE Healthcare. It operates in a complex regulatory environment and digital solutions can

help the company ensure that it is compliant. Digitized processes can be outsourced to 3rd party expert who continually keep their systems up-to-date to meet new regulations.

"Customers demand" is also considered as an important driver for digitalization at GE Healthcare (Average value: 4.5). The company has customers who are interested in exchanging data and managers are closely working with them to understand and support their requests. In this case the best benefit of implementing digital tools is that they help to differentiate company's offerings.

Figure 9: External Drivers

(Scale 1-5)	**Name and surname of the interviewee**									**Average value for each driver**
Driver	Jairaj Thakkar	Alessia La Croce	David Morel	Alder Cory	Hannes Stadlmayr	Mike Cooper	Erich Prungraber	Christophe Suizdak	M. H.	
New digital tools available in the market	**2**	**2**	**1**	**1**	**2**	**1**	**2**	**2**	**2**	**1.6**
Laws/Government	**5**	**5**	**5**	**4**	**5**	**5**	**4**	**4**	**5**	**4.6**
Customers demand	**5**	**5**	**4**	**5**	**4**	**5**	**4**	**5**	**4**	**4.5**

4.3.3 GE Healthcare's internal drivers

The following table shows the values from 1 to 5 that each respondent assigned to the internal drivers. An average value has been calculated for each of them.

The employee support driver has been ranked with a low average value (Average value: 2.3). Employees must be involved in the digitalization process and must be able to understand the benefits that digitalization can offer. Many digital tools are made available to employees (from HR systems, to ordering office supplies) in order to streamline processes and to empower employees to solve their own issues and also to streamline processes.

The system integration driver has been ranked with a medium average value (Average value: 3.3). This driver has been rated of great importance by most employees. In fact, system integration is essential to make optimal use of new technologies and support processes throughout the supply chain.

Figure 10: Internal drivers

(Scale 1-5)	**Name and surname of the interviewee**									**Average value for each driver**
Driver	Jairaj Thakkar	Alessia La Croce	David Morel	Alder Cory	Hannes Stadlmayr	Mike Cooper	Erich Prungraber	Christophe Suizdak	M. H.	
Employee support	**4**	**3**	**2**	**3**	**2**	**1**	**2**	**1**	**3**	**2.3**
System Integration	3	3	4	4	3	3	4	3	3	3.3

4.4 GE Healthcare's barriers to digitalization

The analysis of the barriers to the digitalization process was slightly more complicated than that of the drivers. It was not possible to categorize the barriers as it was done for the drivers. In fact, the barriers were much more specific than the drivers and very related to GE Healthcare's activity, and therefore it was difficult to group them together. Many of the barriers highlighted by the Vogelsang et al. (2019) and Horváth et al. (2019) studies did not prove to be such for GE Healthcare, with the exception of two categories: lack of employees' skills and technical barriers. More specifically, GE Healthcare managers argue that when the business strategy is clear and well defined, there are no barriers that can prevent the implementation of digital tools, except for those that are explained below.

For what concerns technical barriers to the implementation of the new digital tools, GE Healthcare's main problem is to adapt the new digital tools to production systems. GE Healthcare in fact tries to standardize digital and non-digital processes in all the various business units but often the solutions are not optimal and do not adapt well to the systems. For example, there is a digital solution called Manufacturing Execution System (MES), which allows to connect the company's management system to its electronic equipment. This system allows to control business processes and helps managers in data analysis and process optimization. GE Healthcare intended to implement this system in all 15 of its manufacturing facilities, but the implementation of the MES was successful in only

one of the facilities. Problems like this, and those of even larger projects, can lead to the loss of millions of dollars if they are not successful.

The most surprising findings of this study are two and they are those concerning the digital skills of employees. The first concerns a relationship between the size of production sites and employees' digital skills. In particular, GE Healthcare found that general digital skills are not a problem at larger production sites. In fact, GE Healthcare's management was able to identify employees at larger production sites with an IT or programming background. These employees were critical in developing and implementing projects based on the new digital tools. In contrast, GE Healthcare found that the lack of digital skills of employees is a barrier to digitalization at smaller production sites, particularly those with fewer than 50 employees. At these production sites, GE Healthcare found low-skilled employees and training was not sufficient to develop competences necessary to manage new digital tools. For the implementation of very complex projects, GE Healthcare employs external suppliers.

The second finding relates to GE Healthcare's difficulty in advanced analysis for production. This requires employees who understand the analytic, have the skills to build large data models, and above all who are familiar with the production process. Therefore, according to GE Healthcare managers, the fact that employees know the business is as important as the fact that they have digital skills. As a consequence of what has been written so far, it turns out that dual skills (business knowledge and digital skills) are more important than digital skills alone.

4.5 The relationship between digitalization, skills and productivity at GE Healthcare

4.5.1 Digitalization impact on productivity at GE Healthcare

The benefits that GE Healthcare intended to achieve through the digitalization process are as varied as: improve product quality, reduce risk, improve financial performance, increase profits, and increase productivity. In particular, the focus of this study is on the impact that digitalization has had on productivity. GE Healthcare measures productivity in terms of savings in $, and it was able to improve productivity with new digital tools saving $180K. This productivity benefit was achieved primarily through new work automation machines. Work automation has enabled GE Healthcare to increase productivity by facilitating the recognition of bottlenecks and errors in the production processes and making it possible to reduce downtime and optimize production capacity. These findings confirm what has been stated in the literature, in particular the findings of the studies by Sarter et al. (1997), Frohm et al. (20169), and Sjödin et al. (2018).

On the contrary, the findings related to the impact of the lack of digital skills of employees on productivity are in contrast with the findings of the Acemoglu et al. study (2018). While the study by Acemoglu et al. (2018) argues that digital skills can reduce errors in production processes, thereby increasing productivity, GE Healthcare managers argue that there is no direct relationship between employee skills and productivity. In fact, according to them, the increase in productivity is due to the application of Lean Management, which streamlines and simplifies operations by eliminating waste during the production process. Despite this, GE Healthcare managers have recognized that employees with greater digital skills make fewer mistakes and have fewer difficulties in performing new tasks related to the new digital tools.

4.5.2 Bridging the gap between skills and digital tools at GE Healthcare

Some digital tools implemented by GE Healthcare are overly complicated; this leads to employee frustration and mistakes. For example, GE Healthcare's shipping solution requires employees to enter data on 5-6 different screens and to submit programs to screen orders for export compliance. This process takes several minutes; in fact, employees have to enter same data on multiple screen and sometimes also they have to enter data into 3rd party freight forwarder systems. If the employee gets interrupted, it's not easy to figure out what step has been completed and mistakes are easily made. Also transposing data from one system to another can lead to missed/truncated values. A better solution would be a single screen where the employee doesn't have to enter same information multiple times and can clearly see what information was already entered and what's missing.
As it emerges from what has been written so far, although the managers of GE Healthcare do not consider the pre-existing employee's digital skills as fundamental to carry out their new tasks, they consider it essential to ensure that their employees are able to develop these skills so that they do not make mistakes. In order to do this GE Healthcare has involved its employees in the digitalization process from the very first moment, providing them with specific training activities to help them with the new tasks.

The last finding of this study is that the relevance of digital skills is highly dependent on the role of the employee. Roles may require no digital skills (like an assembler on the manufacturer floor) while roles in engineering or research will require high level of digital skills to be able to perform their roles. However, these skills are highly specialized and may not readily translate across roles. Often, GE Healthcare find that it's far quicker and cheaper to rely on an external company who has resources with the required skills. GE Healthcare can leverage these experts to design the right

solution to put in place to be used by functional users. GE Healthcare relies on a mixed team of IT and functional users who have digital skills to help translate functional requirements to IT requirements and identify the right solutions. In conclusion, there is certainly a need to have employees with good digital skills within the company, but majority will not need to have high level of skills.

Currently GE Healthcare managers don't measure the competence level of its employees; the author proposed this solution to evaluate the skills of employees in order to associate the right employee with the right role in the production process. Managers seemed to be very interested in the proposal and in particular in developing a competence model by job type. For example, a materials buyer person will be asked questions to understand various skills like negotiating skills or time management skills as well as digital skills required to perform their jobs. Managers don't plan to evaluate everyone on their digital competence level rather only focus on digital skills they need to perform their roles.

5. Discussion

The findings of this research turned out to be very interesting because they do not fully agree with the existing literature and therefore could serve as a basis for further studies in the future.

GE Healthcare drivers were compared with the drivers emerged from other studies (Liere-Netherele et al., 2019; Horváth and Szabó, 2019; Paritala et al., 2016; Cimini et al., 2017; Kiel et al., 2019; Bauer et., 2015; Adolph et al., 2014). All the selected researches have been chosen because they are consistent with the goal of this research and because they are based on the analysis of several companies that can be considered a representative sample. Drivers confirmed by GE Healthcare managers are: vertical integration, horizontal integration, management support, laws/government, customer demand, and system integration. The most important driver for GE Healthcare is to be competitive in the market; this driver was not considered by existing studies.

Regarding the barriers to digitalization, GE Healthcare argues that there are not many challenges a company faces in implementing new digital tools if it has a clear strategy and well-defined processes. This view is at odds with the existing literature, which argues that there are too many barriers to digitalization which prevent the implementation of digital tools. In order to compare the findings of the research with the existing literature, the studies of Vogelsang et al. (2019) and Horváth et al. (2019) have been chosen as a term of comparison because they are consistent with the goal of this work and because they are based on a strategy of "multiple-case approach" and therefore rich in empirical evidence. Two main barriers have been found analyzing GE Healthcare: technical barriers and human resources barriers. For what concerns technical barriers to the implementation of the new digital tools, GE Healthcare's main problem is to adapt the new digital tools to production systems. This barrier is confirmed by existing literature. The most surprising findings of this study are two and they are those concerning the digital skills of employees. In particular, GE Healthcare found that the lack of digital skills of employees is a barrier to digitalization at smaller production sites, particularly those with fewer than 50 employees. The second finding is that, according to GE Healthcare managers, dual skills (business knowledge and digital skills) are more important than digital skills alone. The interesting thing about these last two findings is related to the existing literature. Other researches in fact confirm that the lack of digital skills of employees can be a barrier to the implementation of digital tools, but no link with the size of the production sites is mentioned. Moreover, the literature does not specify a distinction in terms of relevance between digital skills and dual skills in the digitalization process.

For what concerns productivity, the digital tools that have had the greatest impact on productivity at GE Healthcare are work automation machines. Work automation has enabled GE Healthcare to increase productivity by facilitating the recognition of bottlenecks and errors in the production processes and making it possible to reduce downtime and optimize production capacity. These findings confirm what has been stated in the literature, in particular the findings of the studies by Sarter et al. (1997), Frohm et al. (20169), and Sjödin et al. (2018). On the contrary, the findings related to the impact of the lack of digital skills of employees on productivity are in contrast with the findings of the Acemoglu et al. (2018) study. While the study by Acemoglu et al. (2018) argues that digital skills can reduce errors in production processes, thereby increasing productivity, GE Healthcare managers argue that there is no direct relationship between employee skills and productivity.

The last finding of this study is that the relevance of digital skills is highly dependent on the role of the employee. This means that there is certainly a need to have employees with good digital skills within the company, but majority will not need to have high level of skills.

Figure 11: Contribution of the study

Areas of research	Findings	Contribution
Digital tools	The main digital tools implemented by GE Healthcare are automation of work, AI, and IoT.	As already stated in the literature, this study has made it clear that the implementation of one digital tool rather than another depends on the product, the industry in which the company works, and the benefits it wants to achieve through digitalization.
Drivers of Digitalization	-Vertical integration, horizontal integration, management support, laws/government, customer demand. -Be competitive in the market.	Not all drivers in the literature have been confirmed by GE Healthcare managers and vice versa, some of the drivers that are fundamental to GE Healthcare are not mentioned in the literature. In this area, therefore, the research has filled gaps in the literature, confirmed findings from other researches, and opened the door for future research.
Barriers to Digitalization	-HR barriers: Lack of employee's digital skills has been recognized has a barrier in manufacturing sites with less than 50 employees. -Technical barriers: the difficulty is in granting the	According to GE Healthcare managers, there are no barriers that cannot be overcome when the company has a clear and defined strategy. This finding opens the door to future studies on the impact that the company's strategy has in overcoming barriers to digitalization. Studies in the literature analyze different types of barriers to the digitalization process but no link to the strategy is analyzed.

	match between the digital tools and the manufacturing site.	
Benefits of Digitalization	-Increased productivity. -Increased quality. -Reduced risks. -Increased profits	This study confirmed findings from existing literature. There are many benefits that can be achieved through the implementation of new digital tools and this research confirms that one of the main ones is the increase in productivity.
Digital skills	The relevance of digital skills depends on the role of the employees. Dual skills are more important than digital skills alone.	This study highlighted the importance of a new variable that has not yet been considered in literature: dual skills. Many studies in fact recognize the importance of skilled workers to ensure the success of the digitalization process but few researches focus on how important it is that they also know the business in which they operate.
Productivity	GE Healthcare measures productivity in terms of savings in $. The main driver of productivity is Lean Management.	As stated in literature, the digitalization process has a positive impact on productivity. In particular, the digital tools that have the greatest impact on productivity are work automation machines. Moreover, contrary to what is stated in literature, there is no direct link between the lack of digital skills of employees and productivity. In fact, according to GE Healthcare managers, digital skills can be easily learned by employees; more specifically, it is not employee skills that drive productivity but their ability to streamline production by eliminating waste and thus Lean Management.

6. Conclusion, Limitations, and Future research

6.1 Conclusion

The digitalization process is a very recent phenomenon and includes many challenges that companies have to face in order to have a successful implementation of the new digital tools. The drivers and barriers of digitalization are numerous and depend on the business in which the company works and the strategy it decides to adopt. Drivers can be grouped into three main categories. The organizational drivers are the ones which more push innovation and are: process improvement, workplace improvement, vertical integration, horizontal integration, management support, and cost reduction. The second category are the external drivers: new digital tools available in the market, laws/government, and customer demand. The last category are the internal drivers: employee support and system integration. For what concerns the barriers to the digitalization process, these were more dependent on the environment in which the company operates than drivers. Examples of barriers in the literature are: missing skills, technical barriers, individual barriers, organizational and cultural barriers, environmental barriers, and availability of financial resources.

The main digitalization driver for GE Healthcare is to be competitive in the market. In fact, digital tools have allowed GE Healthcare to improve efficiencies and yields, maintaining its leading position on the market. This driver is not mentioned in the literature. The organizational drivers confirmed by GE Healthcare managers are vertical and horizontal integration, and management support, while the external drivers confirmed by managers are laws/government and customer demand. Only one on the internal drivers has been confirmed by GE Healthcare's managers: system integration. On the other hand, three main barriers to digitalization emerged for GE Healthcare. The first one is a technical barrier due to the difficulty of granting the match between system technology and the production site. Another barrier was found to be the lack of employee's digital skills in production sites with less than 50 employees. The last barrier is the lack of dual skills employees inside the firm. According to the literature, due to the lack of digital skills, employees make more mistakes and therefore the increase in productivity promised by the new digital tools is limited. However, this has not been confirmed by GE Healthcare managers who have stated that there is no direct relationship between digital skills and productivity.

In conclusion, the author looked for possible solutions to help GE Healthcare employees to develop the digital skills needed to perform their tasks in order to reduce errors in production processes. The first solution proposed by the author is the involvement of workers from the very first moment of the digitalization process to help them understand why GE Healthcare has chosen to implement the new digital tools and to help them during the change phase. The second proposal is to provide

training services to help employees develop the digital skills needed to perform new tasks. Both solutions are already implemented at GE Healthcare. The last proposal was to map skills for GE Healthcare employees in order to assess their skills and associate each employee with the task most suitable for them. This last solution was very interesting for GE Healthcare managers who were ready to implement it.

6.2 Recommendations

Although research has led to the understanding that there is no direct relationship between employee digital skills and productivity, managers have confirmed that the lack of digital skills leads employees to have difficulties in performing new tasks and making more mistakes. Based on what has been said so far, the author has three main recommendations to make to GE Healthcare. The first is to involve employees in the digitalization process from the very first moment to help them cope with the change. The second recommendation is to carry out a mapping of skills to assess employees' digital skills and associate the most suitable tasks to each of them. The last recommendation is to associate training to results of the competence mapping. The training should therefore be done mainly for those employees who have a low level of digital skills; this would save costs and time

6.3 Limitations

One of the limitations of this research is that it does not quantify the impact that digitalization has on operational efficiency because the research is qualitative in nature. Moreover, this research analyses only some of the variables of the operational efficiency and of the digitalization process, i.e. digital skills and productivity, but excludes other challenges related to digital tools and other elements of operational efficiency such as quality or delivery on time. In fact, many variables contribute to a successful digitalization process. Among all these variables there are links and cause-effect relationships that future studies could try to analyse in order to get a more complete picture. The last limitation to be considered is the fact that in this research only one case has been analysed. Even if, as explained in paragraph 3.5, the research is valid and generalizable, the use of a multiple-case approach could increase the generalizability and significance of the findings. In particular, this study analysed a case study from a global strategy point of view; the company owns fifteen production sites, each of which followed a specific pattern in the digitalization process. The data provided in the

research are therefore a summary of the company's global performance that could be analysed more specifically in the future to increase the significance of the findings.

6.4 Future research

Future research should fill the gaps of the present work. It would be useful to analyze which of the existing digital tools on the market has the greatest impact on productivity. Furthermore, future research could replicate the present study by trying to quantify the information obtained in terms of cost, productivity and digital skills. The research topic turned out to be interesting and very different from the ones treated in the literature and present in existing research; the findings the author has come up with are almost completely absent in the literature. Based on what has been said so far it would be useful to study other cases with the same framework of this research to consolidate new emerging theories.

References

Acemoglu, D., & Restrepo, P. (2018). Artificial intelligence, automation and work (No. w24196). National Bureau of Economic Research.

Adolph, S., Tisch, M., & Metternich, J. (2014). Challenges and approaches to competency development for future production. Journal of International Scientific Publications–Educational Alternatives, 12(1), 1001-1010.

Ala-Mutka, K. (2011). Mapping Digital Competence: Towards a Conceptual Understanding (Technical Note No. JRC67075-2011). European Commission Joint Research Centre, Institute for Prospective Technological Studies.

Alkhamisi, A. O., Arabia, S., & Monowar, M. M. (2013). Rise of augmented reality: Current and future application areas. International journal of internet and distributed systems, 1(04), 25.

Ashton K. (2009), "That 'Internet of Things' Thing", RFID Journal. Available at: http://www.rfidjournal.com/articles/view?4986

BarNir, A., Gallaugher, J. M., & Auger, P. (2003). Business process digitization, strategy, and the impact of firm age and size: the case of the magazine publishing industry. Journal of Business Venturing, 18(6), 789-814.

Barua, A., Konana, P., Whinston, A. B., & Yin, F. (2001). Driving e-business excellence. *MIT Sloan Management Review*, *43*(1), 36.

Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The qualitative report*, *13*(4), 544-559.

Bauer, W., Hämmerle, M., Schlund, S., Vocke, C., 2015. Transforming to a hyper-con- nected society and economy – towards an "Industry 4.0.". Procedia Manuf. 3, 417–424.

Berwick, D. M. (2002). "A user's manual for the IOM's 'Quality Chasm' report", Health Affairs, (21:3), pp. 80-90.

Bessen, J.E. (2016), "How Computer Automation Affects Occupations: Technology, Jobs, and Skills", Boston University School of Law, Law & Economics Working Paper No. 15-49, Boston University.

Bonomi, F., Milito, R., Zhu, J. and Addepalli, S. (2012), "Fog Computing and Its Role in the Internet of Things", MCC' 12 Proceedings of the First Edition of the MCC Workshop on Mobile Cloud Computing Pages, pp. 13–16.

Bradski, G. R., Miller, S. A., & Abovitz, R. (2019). U.S. Patent No. 10,203,762. Washington, DC: U.S. Patent and Trademark Office.

Bryman A., Bell E., (2011). Business research methods. 3rd Edition. Oxford university press.

Brynjolfsson, E., McAfee, A. (2014). The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies. W. W. Norton & Company, New York City, NY, USA.

Burney, S.M.A; Saleem, H., (2008). Inductive & Deductive Research Approach.

Cimini, C., Pinto, R., Pezzotta, G., Gaiardelli, P., 2017. The transition towards industry 4.0: business opportunities and expected impacts for suppliers and manufacturers. In: Advances in Production Management Systems. The Path to Intelligent, Collaborative and Sustainable Manufacturing. APMS 2017. IFIP Advances in Information and Communication Technology Springer, Cham, pp. 119–126.

Codagnone, C. and Martens, B. (2016), Scoping the Sharing Economy: Origins, Definitions, Impact and Regulatory Issues, available at: https://ec.europa.eu/jrc/sites/jrcsh/files/JRC100369.pdf

Cramer, J. and Krueger, A. B. (2016), 'Disruptive change in the taxi business: The case of Uber', American Economic Review, Vol. 106, No. 5, pp. 177–182.

Degryse, C. (2016). Digitalisation of the economy and its impact on labour markets. ETUI Research Paper-Working Paper.

Dehning, B., Richardson, V.J., Zmud, R.W. (2003). The Value Relevance of Announcements of Transformational Information Technology Investments. MIS Quarterly, vol. 27, no. 4, pp. 637– 656.

Denzin, N. K., & Lincoln, Y. S. (Eds.). (2011). The Sage handbook of qualitative research. Sage.

Dolphin, T. (Ed.). (2015). Technology, globalisation and the future of work in Europe: Essays on employment in a digitised economy. London, UK: IPPR.

Eisenhardt, K. (1989). 'Building theories from case study research'. Academy of Management Review, 14, 532–50.

Erol, S., Jäger, A., Hold, P., Ott, K., & Sihn, W. (2016). Tangible Industry 4.0: a scenario-based approach to learning for the future of production. Procedia CiRp, 54(1), 13-18.

Eurofound (2017), Automation of work: Literature Review, Publications Office of the European Union, Luxembourg.

Eurofound (2017), Digisation of processes Literature Review, Publications Office of the European Union, Luxembourg.

Eurofound (2018), Automation, digitisation and platforms: Implications for work and employment, Publications Office of the European Union, Luxembourg.

Eurofound (2018), Coordination by Platforms-Literature Review, Publications Office of the European Union, Luxembourg.

Fitzgerald, M. et al. (2013) 'Embracing Digital Technology: A New Strategic Imperative', MIT Sloan Management Review, pp. 1–12. Available at: http://sloanreview.mit.edu/projects/embracing-digital-technology?switch_view=PDF.

Frohm, J., Lindström, V., Winroth, M., & Stahre, J. (2006). The industry's view on automation in manufacturing. IFAC Proceedings Volumes, 39(4), 453-458.

Fylan, F. (2005). Semi-structured interviewing. A handbook of research methods for clinical and health psychology, 5(2), 65-78.

Gersick, C. J. (1988). Time and transition in work teams: Toward a new model of group development. Academy of Management journal, 31(1), 9-41.

Gibson, W. J., & Brown, A. (2009). Working with qualitative data.

Gross, B. C., Erkal, J. L., Lockwood, S. Y., Chen, C., & Spence, D. M. (2014). Evaluation of 3D printing and its potential impact on biotechnology and the chemical sciences.

Gubbi, J., Buyya, R., Marusic, S. and Palaniswami, M. (2013), "Internet of Things (IoT): A vision, architectural elements, and future directions", Future Generation Computer

Gupta, S. (2018). Organizational Barriers to Digital Transformation.

Hagiu, A. and Wright, J. (2015), “Multi-Sided Platforms”, Working Paper No. 15, March 16, Harvard Business School.

Hahsler, M., Grün, B., Hornik, K., Wien, W. and Buchta, C. (2005), “Introduction to arules – A computational environment for mining association rules and frequent item sets”, Journal of Statistical Software, Vol. 14 No. 15.

Hand, A. (2014). GE Drives The Brilliant Factory Concept Home.

Hess, T., Matt, C., Benlian, A., F. Wiesböck, F. (2016). Options for Formulating a Digital Transformation Strategy. MIS Quarterly Executive, vol. 15, no. 2, pp. 123–139.

Hoberg, P., Krcmar, H., Oswald, G., & Welz, B. (2017). Skills for digital transformation. URL: http://idt. in. tum. de/wp-content/uploads/2018/01/IDT_Skill_Report_2017. pdf [05.02. 2019].

Horváth, D., & Szabó, R. Z. (2019). Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities? Technological Forecasting and Social Change, 146, 119-132.

Jayaram, S., Connacher, H. I., & Lyons, K. W. (1997). Virtual assembly using virtual reality techniques. Computer-aided design, 29(8), 575-584.

Kiel, D., Müller, J., Arnold, C., Voigt, K.-I., 2017b. Sustainable Industrial Value Creation: Benefits and Challenges of Industry 4.0. International Society for Professional Innovation Management (ISPIM), Vienna, pp. 1–21.

Klein, G. T., Lu, Y., & Wang, M. Y. (2013). 3D printing and neurosurgery--ready for prime time? World neurosurgery, 80(3-4), 233-235.

Klötzer, C., Pflaum, A. (2017). Toward the Development of a Maturity Model for Digitalization within the Manufacturing Industry’s Supply Chain., in Proceedings of the 50th Hawaii International Conference on System Sciences, pp. 4210–4219.

Kobayashi, L., Zhang, X. C., Collins, S. A., Karim, N., & Merck, D. L. (2018). Exploratory application of augmented reality/mixed reality devices for acute care procedure training. Western Journal of Emergency Medicine, 19(1), 158.

Konttila, J., Siira, H., Kyngäs, H., Lahtinen, M., Elo, S., Kääriäinen, M., ... & Utsumi, M. (2019). Healthcare professionals' competence in digitalisation: A systematic review. Journal of clinical nursing, 28(5-6), 745-761.

Kothman, I., & Faber, N. (2016). How 3D printing technology changes the rules of the game. Journal of Manufacturing Technology Management.

Liere-Netheler, K., Vogelsang, K., & Packmohr, S. (2018). Drivers of digital transformation in manufacturing. The Digital Supply Chain of the Future: Technologies, Applications and Business Models.

Lins, T., Oliveira, R.A.R., 2017. Energy efficiency in industry 4.0 using SDN. In: IEEE 15th International Conference on Industrial Informatics (INDIN), pp. 609–614 Emden.

Liu, K., Nakata, K., Li, W., & Baranauskas, C. (2018). Digitalisation, Innovation and Transformation. In 18th IFIP WG (Vol. 8, pp. 16-18).

Madsen, E. S., Bilberg, A., & Hansen, D. G. (2016). Industry 4.0 and digitalization call for vocational skills, applied industrial engineering, and less for pure academics. In Proceedings of the 5th P&OM World Conference, Production and Operations Management, P&OM.

Malhotra, N.K. and Birks, D. (2006) Marketing Research: An Applied Approach.

Markovitch, S., & Willmott, P. (2014). Accelerating the digitization of business processes. McKinsey-Corporate Finance Business Practise, 1-4.

Matt, C., Hess, T., & Benlian, A. (2015). Digital transformation strategies. Business & Information Systems Engineering, 57(5), 339-343.

Maxwell, J. A. (1996). Qualitative Research Design: An Interactive Approach.

Nee, A. Y., & Ong, S. K. (2013). Virtual and augmented reality applications in manufacturing. IFAC proceedings volumes, 46(9), 15-26.

Noffsinger, R., & Chin, S. (2000). Improving the delivery of care and reducing healthcare costs with the digitization of information. Journal of healthcare information management: JHIM, 14(2), 23-30.

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. Computers in industry, 83, 121-139.

Paritala, P.K., Manchikatla, S., Yarlagadda, P.K., 2016. Digital manufacturing applications past, current, and future trends. Procedia Eng 174, 982–991.

Peruffo, E. (2017), A literature review on the implications of digitisation for work and employment, Eurofound, Dublin.

Robson, C. (2002). Real World Research: A Resource for Social Scientists and Practitioner-Researchers (2nd ed.). Oxford: Blackwell Publishers Ltd.

Rochet, J.-C. and Tirole, J. (2003), "Platform competition in two-sided markets", Journal of the European Economic Association, Vol. 1 No. 4, pp. 990–1029.

Rogers, E. M. (2003). Diffusion of innovations. 5th ed., Free Press, New York, NY.

Rogers, H., Baricz, N., & Pawar, K. S. (2016). 3D printing services: classification, supply chain implications and research agenda. International Journal of Physical Distribution & Logistics Management.

Sarter, N. B., Woods, D. D., & Billings, C. E. (1997). Automation surprises. Handbook of human factors and ergonomics, 2, 1926-1943.

Saunders, M. N. (2011). Research methods for business students, 5/e. Pearson Education India.

Sekaran, U., & Bougie, R. (2013). Edisi 6. *Research Methods for Business*.

Schmidt, F.A. (2016), Arbeitsmärkte in der Plattform-ökonomie–Zur Funktionsweise und den Herausforderungen von Crowdwork und Gigwork, Friedrich Ebert Stiftung.

Schroeder, R. (1993), "Virtual reality in the real world. History, applications and projections", Futures, Vol. 25 No. 9, pp. 963–973.

Schubert, C., Van Langeveld, M. C., & Donoso, L. A. (2014). Innovations in 3D printing: a 3D overview from optics to organs. British Journal of Ophthalmology, 98(2), 159-161.

Schumpeter, J. A. (2000) “Entrepreneurship as innovation”, Entrepreneurship: The Soc. Sci. View, pp. 51- 75.

Schwab, K. (2016), “The Fourth Industrial Revolution”, World Ecomomic Forum, Geneva.

Schwab, K. (2017), The fourth industrial revolution, Crown Publishing, New York.

Sjödin, D. R., Parida, V., Leksell, M., & Petrovic, A. (2018). Smart Factory Implementation and Process Innovation: A Preliminary Maturity Model for Leveraging Digitalization in Manufacturing Moving to smart factories presents specific challenges that can be addressed through a structured approach focused on people, processes, and technologies. Research-Technology Management, 61(5), 22-31.

Stone, P., Brooks, R., Brynjolfsson, E., Calo, R., Etzioni, O., Hager, G., Hirschberg, J., et al (2016), Artificial Intelligence and life in 2030, Stanford University.

Strauss, A., & Corbin, J. M. (1997). Grounded theory in practice. Sage.

Taherdoost, H. (2016). Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research. International Journal of Academic Research in Management (IJARM) Vol. 5, No. 2, 2016, Page: 18-27

Taylor, F. W. (1911), “The Principles of Scientific Management”, Harper & Brothers Publishers, NY.

Thomas, P. C., & David, W. M. (1992). Augmented reality: An application of heads-up display technology to manual manufacturing processes. In Hawaii International Conference on System Sciences (pp. 659-669).

Urbach, N., Drews, P., Ross, J.W. (2017). Digital Business Transformation and the Changing Role of the IT Function. MIS Quarterly Executive, vol. 16, no. 2, pp. 2–4.

Van Deursen, A. (2010). Internet skills vital assets in an information society. Enschede: University of Twente [Host].

Van Deursen, A. J., Helsper, E. J., & Eynon, R. (2014). Measuring digital skills. From digital skills to tangible outcomes project report.

Ventola, C. L. (2014). Medical applications for 3D printing: current and projected uses. Pharmacy and Therapeutics, 39(10), 704.

Vogelsang, K., Liere-Netheler, K., Packmohr, S., & Hoppe, U. (2019, January). Barriers to digital transformation in manufacturing: development of a research agenda. In Proceedings of the 52nd Hawaii International Conference on System Sciences.

Wortmann, F., Flüchter, K. (2015). Internet of things. Business & Information Systems Engineering, 57(3), 221-224.

Yin, R. K. (2009). Case Study Research: Design and Methods (4th ed.). Thousand Oaks, CA: Sage Publications.

APPENDICES

Appendix A: Interview protocol

1. Introduction
    - Introduction of the researcher and of the research topic

2. Background
    - Do you consent to use your data for academic purposes?
    - Do you consent to use data collected through this interview for purely academic purposes?
    - How long have you worked for GE Healthcare?
    - Could you please describe your role inside the company? Which are your responsibilities? Which tasks do you perform?

3. Digitalization
    - Have you already started the digital transformation in one of your production factories? If so, in which factory? When was it done?
    - What are the benefits you were hoping to gain from the digitalization process? (For example: operational efficiency, productivity, product quality, and so on...)
    - Which digital tools have you used in the digitalization process (machines to automate work, IoT, 3D printing, Virtual and augmented reality...)? Can you describe their function (practical examples)? What benefits have you obtained? In particular, what was the impact on productivity? Which digital tool had the greatest impact on productivity?

4. Drivers of Digitalization
    - What were the main drivers that pushed GE Healthcare towards a process of innovation based on the implementation of new digital tools? Are the drivers related to a particular benefit you wanted to get? (example: productivity, operational efficiency...)
    - I will list some of the digitalization's drivers found in the literature; for each of them can you tell me if it was also a driver for GE Healthcare? If so, can you explain why? Could you tell me how important 1 to 5 drivers are to you? (process improvement, workplace improvement, vertical integration, horizontal integration, management support, cost reduction, new digital tools available in the market, laws/government, customers demand, employee support)

5. Barriers to Digitalization

- What were the main barriers/challenges to digital transformation for GE Healthcare? Is the lack of digital skills one of them? Please explain why the elements you indicate are considered barriers.
- Have you highlighted a relationship between each barrier and the potential benefits you could have gained from the new digital tools?
- What were the barriers that had the greatest impact on productivity? Is the lack of digital skills one of them?
- Does the lack of digital skills of employees have an impact on productivity? If so, how? can you give me some practical examples?

6. Productivity

- What units of measurement do you use at GE Healthcare to measure productivity?
- How has productivity changed before and after the implementation of the new digital tools?

7. Employees

- What were the main difficulties employees had in managing the new digital tools? Please give some practical examples (they made errors, they were not able to perform new tasks…) of the difficulties highlighted, especially with regard to the production process.
- How do you measure the digital competence level of employees already working at GE Healthcare?
- What solution would you apply to improve employees' skills in order to better adapt them to the new digital tools?
- How important do you think it is in 2020 for a company to have a staff with high digital skills on a scale of 1 to 5? Can you explain why?

8.Conclusions

- Do you have any other relevant information?

Appendix B: Example of interview

1. Introduction

- *Introduction of the researcher and of the research topic*

  My name is Annachiara Franco, I'm a 22 years old student currently attending a master's degree in Supply Chain Management at Tilburg University. The following questions are aimed at writing a master thesis. The aim is to obtain data regarding the implementation of the new digital tools. In particular, the focus of the research is to understand the impact that the digital transformation process has had on GE Healthcare's productivity and whether this impact has been somewhat limited by the lack of digital skills of employees. In fact, many literature researches have already analyzed what are the drivers and barriers to digitalization, but few have focused on the relationship between these variables (if any).

2. Background

- *Do you consent to use your data for academic purposes?*

  Yes, I do.

- *Do you consent to use data collected through this interview for purely academic purposes?*

  Yes, I do.

- *Could you please describe yourself and your role inside the company? Which are your responsibilities? Which tasks do you perform?*
  My name is Christophe Suizdak; I support logistics and manufacturing operations and drive productivity projects across the different plants using IT technology and lean six sigma manufacturing.

- *How long have you worked for GE Healthcare?*

  More than 21 years.

3. Digitalization

- *Have you already started the digital transformation in one of your production factories? If so, in which factory? When was it done?*

  All factories started to work on their digital journey *in the last* 5 years and their maturity are different according to their initial start

- *What are the benefits you were hoping to gain from the digitalization process? (For example: operational efficiency, productivity, product quality, and so on...)*

  The main objective is operational efficiency and I don't believe that we saw real benefit which could be assigned to the digitalization.

- *Which digital tools have you used in the digitalization process (machines to automate work, IoT, 3D printing, Virtual and augmented reality...)? Can you describe their function (practical examples)? What benefits have you obtained? In particular, what was the impact on productivity? Which digital tool had the greatest impact on productivity?*

  We use these technologies machines to automate work (Paper filter production) , IoT (temperature control for Finish good shipment), 3D printing (spare part production and prototype production), Virtual and augmented reality (Training, field engineers support and operator instruction). I will add AI to your list, we run twin bin engine to anticipate equipment failures. We plan POC in supply chain with AI technology

4. Drivers of Digitalization

- *What were the main drivers that pushed GE Healthcare towards a process of innovation based on the implementation of new digital tools? Are the drivers related to a particular benefit you wanted to get? (example: productivity, operational efficiency...)*

  Stay on the market versus our competitors and use tool which could be leveraged to maintain our leading position on the market.
  Initial goal was to create a new business unit call GE Digital with specific software. We were not to catch up the GAFA and grow this business as we expect. Scale 5

- *I will list some of the digitalization's drivers found in the literature; for each of them can you tell me if it was also a driver for GE Healthcare? If so, can you explain why? Could you tell me how important 1 to 5 drivers are to you? (process improvement, workplace improvement, vertical integration, horizontal integration, management support, cost reduction, new digital tools available in the market, laws/government, customers demand, employee support)*

  Process improvement is part of the DNA company and we did not wait for the digital era to work on this topic, it just open new opportunity (Scale 2).
  For workplace improvement is the same (Scale 2).
  For vertical integration: sensors are not heavily issue across GE Healthcare except GE energy and it could help in the future when will replace the manufacturing equipment, but it will take time (Scale 3).
  I think that horizontal integration is a key benefit of the digitalization and I would say it's where you could make the difference versus your company. This vertical integrate should not stop at the company and you must integrate your ecosystem to get the real benefit of the digitalization (Scale 5).
  Management support is fundamental to support and provide the funding to move ahead (Scale 4-5).
  Personally, I never see real cost reduction after IT tool implementation. You may automate tasks, but you need more rigor on the data management. At the end, your saving is balanced by additional cost to maintain the tool (Scale 1).
  It requires a lot of effort to look at the different tools available on the market. The key element is your strategy and where you want to be in 3 to 5 years from now (Scale 2).
  Laws/government *is* one of the key drivers. You get more and more request from regulatory officer and your team will dead under the paperwork if you don't do anything (Scale 4).
  Customers demand is rare, but it could happen mainly for EDI or API setup (Data exchange) (Scale 5).
  Employees should be engaged in the digitalization process, but they are not part of the stakeholders (Scale 1).

5. Barriers to Digitalization

- *What were the main barriers/challenges to digital transformation for GE Healthcare? Is the lack of digital skills one of them? Please explain why the elements you indicate are considered barriers.*

  I don't see a lot of barrier over our journey. The key element is your strategy / vision and where you are today (for each site).
  According to that you could build your tactical plan and the resource is just an element of your road map. It could delay your project plan but you will deliver it

- *Have you highlighted a relationship between each barrier and the potential benefits you could have gained from the new digital tools?*

  No

- *Does the lack of digital skills of employees have an impact on productivity? If so, how? can you give me some practical examples?*

  The lack of skill is not on the digital side, it's on the lean 6 sigma side. Before talking about any IT change, you must lean your process. If not, you just burn money/resource for nothing

6. Productivity

- *What units of measurement do you use at GE Healthcare to measure productivity?*

  Saving in dollar.

- *How has productivity changed before and after the implementation of the new digital tools?*

  Digital tools do not provide productivity, it's enabler to drive actions to smooth and lean your operations. The productivity is coming from these two actions

7. Employees

- *What were the main difficulties employees had in managing the new digital tools? Please give some practical examples (they made errors, they were not able to perform new tasks…) of the difficulties highlighted, especially with regard to the production process.*

  I will say None and it's mainly driven by the fact that we engage the employees at overall steps of the process change. It's a basic in the change management, if they are not part of the design process you just spend money for nothing as they won't use, or they will find a way to go around it.

- *How do you measure the digital competence level of employees already working at GE Healthcare?*

  From my knowledge, we don't measure it. Each employee has a yearly evaluation with his manager, and he may suggest specific training or his manager could do it to improve his skills.

- *What solution would you apply to improve employees' skills in order to better adapt them to the new digital tools?*

  They need to be part of the project from the beginning to the end. Thought meeting, training or active action on the project itself. They would learn while they work

- *How important do you think it is in 2020 for a company to have a staff with high digital skills on a scale of 1 to 5? Can you explain why?*

  I will say that it's low. You need people who understand the new technologies and its requirements where you could apply in the business. They are there to translate the business requirement in specification which could be understand by the IT guy. They are doing the bridge between 2 worlds which does not speak the same language. This kind of person are critical in the organization.
  High digital skill could be purchased offshore or you could buy an apps which meet your requirement. The technology is moving so fast that investing in high skill resource is not the right thing to do but you clearly need people who got this dual skill Business and Technology
  Scale 5 = Dual skill resource Scale 1 = High digital skill

- *Do you have any other relevant information?*

  Digitalization is opening the doors asking for more interaction globally; only in this way it will be possible to increase productivity for your business.

Appendix C: Example of interview

1. Introduction

- *Introduction of the researcher and of the research topic*

  My name is Annachiara Franco, I'm a 22 years old student currently attending a master's degree in Supply Chain Management at Tilburg University. The following questions are aimed at writing a master thesis. The aim is to obtain data regarding the implementation of the new digital tools. In particular, the focus of the research is to understand the impact that the digital transformation process has had on GE Healthcare's productivity and whether this impact has been somewhat limited by the lack of digital skills of employees. In fact, many literature researches have already analyzed what are the drivers and barriers to digitalization, but few have focused on the relationship between these variables (if any).

2. Background

- *Do you consent to use your data for academic purposes?*

  No

- *Do you consent to use data collected through this interview for purely academic purposes?*

  Yes, I do.

- *Could you please describe yourself and your role inside the company? Which are your responsibilities? Which tasks do you perform?*
  Work with manufacturing sites to develop & execute their digitization roadmap that aligns with break through objectives. Ensure that due diligence has been done and processes are leaned (Lean & 6 Sigma methodology) before we invest in digitization to avoid digitizing waste. Coordinate between IT, Digital & Supply Chain organizations to ensure global roadmap is aligned across the organization and ties to business objectives.

- *How long have you worked for GE Healthcare?*

  More than 22 years.

3. Digitalization

- *Have you already started the digital transformation in one of your production factories? If so, in which factory? When was it done?*

  General Electric announced "Brilliant Factory" initiative about 5 years ago with an intent to leverage IOT & Industry 4.0 concepts across its manufacturing sites. We have looked at opportunities at all our factories and benchmarked capabilities against a digital maturity model to be able to identify areas for improvement.

- *What are the benefits you were hoping to gain from the digitalization process? (For example: operational efficiency, productivity, product quality, and so on...)*
  Productivity improvement
  Increased regulatory compliance
  Reduction in defects & rework
  Manufacturing lead time reduction & reduction in in-process inventory (WIP)
  Build digital product pedigree integrating raw material information from supplier with our in-process data.
  Offer digital data to customers as a competitive advantage to gain market share.
  Improved OEE
  Moving from historical data trending to real time SPC to predictive analytics

- *Which digital tools have you used in the digitalization process (machines to automate work, IoT, 3D printing, Virtual and augmented reality...)? Can you describe their function (practical examples)? What benefits have you obtained? In particular, what was the impact on productivity? Which digital tool had the greatest impact on productivity?*

  Automation:
  We have deployed automated bottling lines for aseptic liquids. It was a highly skilled and highly repetitive process where operator had to move hands in a very specific way to ensure product was not contaminated during filling. Also, it was highly repetitive creating potential

increased risk of injury. In this case, automation eliminated scrapping due to contamination, eliminated risk of injury to employees.

We have highly automated process manufacturing lines controlled by closed loop SCADA solutions (ISA 95 Level 2) monitoring process parameters every second and making adjustments to keep process within specific parameters. Precise control ensures we are producing optimal product, can keep chemical reactions optimal, reducing manufacturing lead times and scrap.

IOT:

We have implemented water quality and water usage monitoring solutions to ensure we are meeting regulatory limits for wastewater and eliminate fines for exceedances.

3D printing:

3D printing allows to print complex parts as a single part instead of many separate pieces that have to be assembled. This typically allows for a much lighter and cheaper part to be produced. Lead times are also often reduced as these parts were typically machined and assembled at specialty supplier with long lead time and instead can be printed directly in house. An example would be a metal manifold that is 3D printed.

Augmented Reality:

We have experimented with augmented systems, but nothing was implemented in production. As is, on-body solutions like Oculus are fairly heavy and limit duration of use. Technology is improving and there are specific use cases where it can make sense.

4. Drivers of Digitalization

- *What were the main drivers that pushed GE Healthcare towards a process of innovation based on the implementation of new digital tools? Are the drivers related to a particular benefit you wanted to get? (example: productivity, operational efficiency...)*

  To remain competitive, we continuously have to improve efficiencies and yields. We are also looking at disruptive technologies that can be incorporated into manufacturing to improve economics of manufacture.

  There is also regulatory pressure on our customers in the Pharma industry to demonstrate control on their supply chain. Having digital tools allows to meet these requirements more efficiently (versus a paper based manual process).

- *I will list some of the digitalization's drivers found in the literature; for each of them can you tell me if it was also a driver for GE Healthcare? If so, can you explain why? Could you tell*

me how important 1 to 5 drivers are to you? (process improvement, workplace improvement, vertical integration, horizontal integration, management support, cost reduction, new digital tools available in the market, laws/government, customers demand, employee support)

Process improvement:
3: As said before, we have Lean and Six Sigma in place for process improvements. This ensures that we don't digitize waste.
Workplace improvement:
2: I may be misunderstanding this question, but I think digital is just one of the ways of improving a workplace along with EHS, Facilities, H&R and other organizations. We can of course eliminate manual labor, repetitive tasks, but "soft" items like an inclusive work environment are just as important.
Vertical integration (to facilitate the exchange of information between management and workers for example through the use of sensors):
4: This is an area of interest. We see value in being able to roll up metrics across the business. A lot of our metrics are still manually tabulated allowing for variations between sites. Preparing reports & metrics is wasted time that could have been used to act on data.
Horizontal integration (to facilitate the exchange of information between more departments of the same company):
4: This is an area of interest. We have Business Process Management (BPM) tools to digitize processes that span multiple employees or departments. The benefit is that we can create repeatable processes with clear ownership.
Management support:
3: Reporting and analytics is an area that can support decision making for management. As mentioned before, some of this is still done manually wasting employee's time.
Cost reduction:
3: Digital is one of the levers we can utilize when addressing cost, but as mentioned previously the basis is Lean and 6 Sigma.
New digital tools available in the market:
2: We don't digitize for digitization's sake. If the process is lean and can benefit from a digital solution, then we will consider. However Lean strives for simplicity, if there's a simple, intuitive, manual solution it is probably better than a digital solution that that can break or requires training.
Laws/government:

5: Most important: We operate in a complex regulatory environment and digital solutions can help us ensure that we are compliant. Digitized processes can be outsourced to 3rd party expert who continually keep their systems up-to-date to meet new regulations.

Customers demand:

4: It is important. We have customers who are interested in exchanging data and we are closely working with them to understand and support their requests. As mentioned previously, digital solutions can help us differentiate our offerings.

Employee support:

3: We have many digital solutions to enable our employees to self service their requests. From HR systems, to ordering office supplies. It is a way to empower employees to solve their own issues and also to streamline processes.

5. Barriers to Digitalization

- *What were the main barriers/challenges to digital transformation for GE Healthcare? Is the lack of digital skills one of them? Please explain why the elements you indicate are considered barriers.*

GE strives to standardize digital and non-digital processes across all the various business units. This one size fits all approach often drives suboptimal solutions that are not a good fit. In many cases we had only a single tool to implement. For example, there is a corporate MES solution that only fits 1 or 2 plants out of 15 plants where we want to implement MES. We successfully implemented this solution in one of our plants, but we could not use it in our other plants, because the solution simply doesn't support our needs. We were not allowed to select another solution.

General digital skills don't seem to be an issue at our larger manufacturing sites, we were able to identify employees at most of our sites with an IT or programming background. These employees can help us drive many projects for a given site. We have faced issues at smaller sites (<50 people), where people don't have the background our already performing multiple roles and don't have time to support. For more complex projects, we can typically align a central resource or contract an outside vendor to help.

The area where we struggle is advanced analytics for manufacturing. You need somebody who is familiar with the manufacturing process, understands analytics and has the skills to build up big-data models. We have tried several approaches including leveraging external companies, but not had been successful. Overall, big data analytics is very difficult,

typically it is very specific to a given issue and is not readily translatable to other parts of the business.

- *Have you highlighted a relationship between each barrier and the potential benefits you could have gained from the new digital tools?*

  We have benefits calculations for projects that were considered in the past but were not implemented due lack of digital tools or failed during implementation. Just thinking about larger projects, missed benefits are in millions of dollars a year.

- *Does the lack of digital skills of employees have an impact on productivity? If so, how? can you give me some practical examples?*

  I don't think this is a concern. If a digital tool is enabling an employee to be more efficient and is well designed, the employee will be vested to learn how to use it. Otherwise digital tools is not a good fit and the process should be optimized.

6. Productivity

- *What units of measurement do you use at GE Healthcare to measure productivity?*

  $ savings
  Year over year percent improvement (eg: 10% reduction in unit cost)
  Cost avoidance (eg: increased equipment efficiency eliminates capacity bottleneck and need for additional equipment)

- *How has productivity changed before and after the implementation of the new digital tools?*

  We had mixed results, some digital solutions are driving clear benefits, and others we struggled to implement.
  Moving from paper-based product documentation to electronic data collection has helped us realize many benefits. For example:

Reduction in defects & rework: Electronic Batch Records (eBR) and Electronic Device History Records (eDHR) eliminate many documentation errors (~70%) that would otherwise require various levels of reworking the product or potentially scrapping it.
We gain visibility into the processes and can identify products stuck in rework, but not being worked on.
It allows for lead time improvements as some steps can be eliminated, for example: manual review and verification of batch records can be eliminated since we can systematically ensure that there are no missing data points, no data points are outside of specifications, no expired calibrated equipment is being used during manufacture. Documentation no longer has to be printed & managed. When implementing changes, paper documents no longer have to be collected & destroyed from the shop floor to be replaced with latest revision.
Ability to provide electronic pedigree has been a requirement from at least one customer to secure new business. In Pharma, understanding the properties of raw materials and their impact on the manufacturing process can have great impact on process yields and stability. Pharma companies are looking to source more and more raw material information to optimize their manufacturing processes. GE Healthcare was one of the key members to establish an industry standard to enable exchange of raw material information in a standard XML format between customers and suppliers.
We struggled with analytics with moving from historical data analysis towards predictive analytics. Partially this is due to the platform selected, but also due to weakness with data sciences. We implemented OEE solutions at couple different sites, but were not able to move onto SPC or predictive analytics.

7. Employees

- *What were the main difficulties employees had in managing the new digital tools? Please give some practical examples (they made errors, they were not able to perform new tasks…) of the difficulties highlighted, especially with regard to the production process.*

Unfortunately, we do have digital tools that are overly complicated. This leads to employee frustration and mistakes. An example is, our shipping solution requires employees to enter data on 5-6 different screens and to submit programs to screen orders for export compliance. This process takes several minutes, entering same data on multiple screen and sometimes also requiring users to also enter data into 3rd party freight forwarder systems. If the employee gets interrupted, it's not easy to figure out what step has been completed and mistakes are easily made. Also transposing data from one system to another can lead to missed/truncated values.

A better solution would be a single screen where the employee doesn't have to enter same information multiple times and can clearly see what information was already entered and what's missing.

- *How do you measure the digital competence level of employees already working at GE Healthcare?*

  We currently don't measure competence for employees, but we are in the process of developing a competence model by job type. For example, a materials buyer person will be asked questions to understand various skills like negotiating skills or time management skills as well as digital skills required to perform their jobs.
  We don't plan to evaluate everyone on their digital competence level rather only focus on digital skills they need to perform their roles.

- *What solution would you apply to improve employees' skills in order to better adapt them to the new digital tools?*

  Most users have general skills to perform their tasks. We can help them by designing intuitive tools that require minimal training. Also, we can pair employees with others who have the required skills to help them learn on the job.

- *How important do you think it is in 2020 for a company to have a staff with high digital skills on a scale of 1 to 5? Can you explain why?*

  I think this is highly dependent on the role of the employee. Roles may require no digital skills (like an assembler on the manufacturer floor) while roles in engineering or research will require high level of digital skills to be able to perform their roles. However, these skills are highly specialized and may not readily translate across roles.
  Often, we find that it's far quicker and cheaper to rely on an external company who has resources with the required skills. We can leverage these experts to help us design the right solution to put in place to be used by functional users. We rely on a mixed team of IT & functional users who have digital skills to help us translate functional requirements to IT requirements and identify the right solutions.
  So, there is certainly a need to have employees with good digital skills within the company, but majority will not need to have high level of skills.

Appendix D: Coding scheme

Category	Subcategory	Description	Example
Digitalization	Digital tools	Informants indicated and described the digital tools implemented in the company.	We have deployed automated bottling lines for aseptic liquids. In this case, automation eliminated scrapping due to contamination, eliminated risk of injury to employees. Having digital tools allows to meet these requirements more efficiently (versus a paper based manual process).
Digitalization	Benefits	Informants indicated what were the main benefits they wanted to achieve through the digitalization process.	The main objective is operational efficiency. Examples of benefits we wanted to reach are: increased quality and increased productivity.
Digitalization	Drivers	Informants indicated the main drivers to the digitalization process.	To remain competitive, we continuously have to improve efficiencies and yields. We are also looking at disruptive technologies that can be incorporated into manufacturing to improve economics of manufacture. There is also regulatory pressure on our customers to demonstrate control on their supply chain.
Digitalization	Barriers	Informants indicated the main barriers to the digitalization process.	We have faced issues at smaller sites (<50 people), where people don't have the background our already performing multiple roles and don't have time to support.
Digitalization	Digital skills	Informants indicated what digital skills are required by the company and focused on whether or not they represent a barrier to the implementation of new technology and what impact they have on productivity.	Most users have general skills to perform their tasks. We can help them by designing intuitive tools that require minimal training. Also, we can pair employees with others who have the required skills to help them learn on the job.
Operational efficiency	Productivity	Informants indicated how productivity within the company is measured, and which digital tools have the greatest impact on productivity.	We measure productivity in terms of savings in $. We had mixed results, some digital solutions are driving clear benefits, and others we struggled to implement.

Appendix E: Data Display

	Digitalization					Operational efficiency
	Digital tools	**Benefits**	**Drivers**	**Barriers**	**Digital skills**	**Productivity**
Jairaj Thakkar	-3D printing for specific production -Virtual reality for training -AI and IoT to support production -Automation of work	-productivity -quality	-Competitive advantage -laws/government (Scale 5) -customers demand (Scale 5) -employee support (Scale 4)	-No many barriers if your strategy is well defined	-Employees who do not have digital skills make more mistakes than others -Lack of digital skills has not a direct impact on productivity	-Savings in $ -Lean management and automation as main drivers
Alessia La Croce	-Many different tools are implemented -The most used are IoT for production processes, AI to help in managing data, and virtual reality for training	-operational efficiency -productivity	-Be competitive -vertical integration (Scale 4) -horizontal integration (Scale 5) -management support (Scale 4) -laws/government (Scale 5) -customers demand (Scale 5)	-Sometimes it is difficult to grant the match between production sites and systems	-Dual skills are more important than digital skills	-Savings in $ -Lean management helps to increase productivity
David Morel	-3D printing for some customized products -AI -IoT -Automation of work	-increase safety -reduce risks -improve data management -productivity	-Be competitive -vertical integration (Scale 4) -horizontal integration (Scale 4) -management support (Scale 4) -laws/government (Scale 5) -customers demand (Scale 4)	-It is difficult to find people with dual skills -some technical barriers	-The relevance of digital skills depends on the role of the employee. They are not always necessary	-Savings in $
Alder Cory	-Historian – machine connectivity for data collection during manufacturing processes -LIMS – Laboratory Information Management System to capture data from the laboratory testing. Seeing good results and savings so far. -APM – Asset performance management -Tableau – Visualization	-improve productivity -reduce risks -improve quality and robustness -improve financial performance	-Be competitive -horizontal integration (Scale 4) -management support (Scale 4) -cost reduction (Scale 5) -laws/government (Scale 4) -customers demand (Scale 5)	-Management support, -money to invest, -find the right solution for a business.	-It is not a barrier, if there is lack of digital skills we can solve it with training	-Cost Conversion productivity (CCP). -Measure of output compared to cost & benefits. -As a program we also measure KPIs to show how we are doing from a project perspective as well as the digital tools being implemented.

	through reports -MES- electronic batch records. This will have by far the greatest impact on productivity.					
Hannes Stadlmayr	-IoT for data collection during manufacturing processes -LIMS and Tableau to capture data from the laboratory testing and to simplify visualization through reports -MES. It has the greatest impact on productivity, but we had some difficulties to implement it in some production sites.	-quality and productivity are the main benefits we want obtain	-Be competitive -vertical integration (Scale 4) -horizontal integration (Scale 4) -management support (Scale 4) - laws/government (Scale 5) -customers demand (Scale 4)	-lack of digital skills in smaller plants -difficulties in implementing some digital tools because they do not fit for a specific production site	-For some complex operations, digital skills are necessary to avoid mistakes. -Dual skills are fundamental	-Savings in $ -Automation increases productivity
Mike Cooper	-Not all the production sites implement the same digital tools -The use of digital tools varies on the basis of the product -Most important is IoT; in particular, AI.	-productivity -reduce risks	-Be competitive -vertical integration (Scale 4) -horizontal integration (Scale 5) - laws/government (Scale 5) -customers demand (Scale 5)	-Not many barriers -Top management involvement is important to drive the implementation	-Lack of digital skill has not a direct impact on productivity -training helps to develop employees' digital skills	-Savings in $ -Automation and lean management
Erich Prungraber	-Virtual reality for training -3D printing to assemble several components at once	-quality -productivity	-Be competitive -vertical integration (Scale 4) -horizontal integration (Scale 4) -management support (Scale 4) - laws/government (Scale 4) -customers demand (Scale 4)	-If you have financial resources and a good strategy there are not barriers that you cannot overcome.	-It is not necessary that digital skills pre-exist; it is sufficient to train employees on a "as-needed basis"	-Savings in $
Christophe Suizdak	-machines to automate work (Paper filter production) -IoT (temperature control for Finish good shipment)	-Operational efficiency -Benefits are not produced by digitalization	-Stay on the market versus our competitors (Scale 5) -horizontal integration (Scale 5) -management support (Scale 4-	-No barriers if you have a clear plan to act	-Digital skills are not a barrier (Scale 1) -Dual skill are more important than digital skill (Scale 5)	-Saving in dollar -Lean management increases productivity, not digitalization

	-3D printing (spare part production and prototype production) -Virtual and augmented reality (Training, field engineers support and operator instruction) - AI to anticipate equipment failures.		5) - laws/government (Scale 4) -customers demand (Scale 5)			
M. **H.**	-automated bottling lines for aseptic liquids -highly automated process manufacturing lines controlled by closed loop SCADA solutions - IOT for water quality and water usage monitoring -3D printing allows to print complex parts as a single part instead of many separate pieces that have to be assembled. - We have experimented with augmented systems, but nothing was implemented in production.	-Productivity improvement -Increased regulatory compliance -Reduction in defects & rework - Manufacturing lead time reduction & reduction in in-process inventory (WIP) -Offer digital data to customers as a competitive advantage to gain market share. -Moving from historical data trending to real time SPC to predictive analytics	-Remain competitive -vertical integration (Scale 4) -horizontal integration (Scale 4) - laws/government (Scale 5) -customers demand (Scale 4)	-They struggle in advanced data analytics for manufacturing	-Lack of digital skills in not a problem for larger manufacturing sites but it is for smaller ones (less than 50 people) and complex projects -The level of necessary digital sills depends on the role of the employee	-Productivity is measured in terms of $ savings, year over year % improvement, cost avoidance -They had mixed results in terms of productivity after the implementation of new digital tools - Lean/6 Sigma is the main driver for productivity. They can readily leverage external resources if we are lacking skills internally.