MASTER

Design of an Industry 4.0 assessment tool for the FMCG industry

Rutten, S.

Award date:
2020

Design of an Industry 4.0 assessment tool for the FMCG industry

Master thesis

By S. Rutten
Student number: 0923733

in fulfilment of the requirements for the degree of

Master of Science in:

Innovation Management

Supervisors

dr. N. Raassens	TU/e, Industrial Engineering, ITEM
dr. A.A. Alblas	TU/e, Industrial Engineering, ITEM
P.L.J.C. Ramakers	Royal HaskoningDHV

Eindhoven, March 2020

TU/e Department of Industrial Engineering and Innovation Sciences

Keywords: Industry 4.0, FMCG industry, maturity model, assessment tool.

Confidentiality: Concerning confidentiality, the names of the companies and experts are anonymized.

Summary

Introduction. The last five years, the Fast-Moving Consumer Goods (FMCG) industry have started to explore the use of more innovative (e.g. digital) solutions in manufacturing processes. This exploration of innovative digital solutions in the manufacturing value chain could be seen as a natural development of manufacturing processes: the Fourth Industrial Revolution or Industry 4.0. The Industry 4.0 concept can be considered as the new industrial paradigm of this manufacturing age, partly based on advanced manufacturing technologies. The transformation of the FMCG industry to Industry 4.0 is at a beginning phase and the realization of its importance to implement is present. This is, because the FMCG industry is currently changing from mass production to customized and personalized production, which causes companies to innovate with rapid advancements in manufacturing technologies.

However, most FMCG companies have no clear vision, lack implementation plans, or a roadmap to be able to exploit the technological advancements of Industry 4.0. A first step could be to assess the Industry 4.0 current and target state of a company. Supportive tools such as maturity models and assessment tools are useful to assess the Industry 4.0 as-it-is and target state of a company which leads to a starting point for a strategic roadmap and more insights in Industry 4.0. There are multiple self-assessment tools, maturity models, roadmaps and frameworks, all built and researched by scientific and commercial practices, focussed on Industry 4.0, but lack the specific needs (i.e. customized version) for the FMCG companies. A customized version per industry is relevant (Moultrie, Sutcliffe, & Maier, 2015) due to specific context (i.e. specific characteristics such as large variety of products, high demand, quick turnover) the FMCG industry operates in, and hence follow different routes as other application domains. These specific needs can be customized through the selection of the relevant set of capabilities and requirements.

Therefore, the purpose of this research is to design an Industry 4.0 assessment tool for the FMCG industry, containing Industry 4.0 capabilities that are relevant for the FMCG industry. Subsequently, the following research question is answered: How can an assessment tool be designed to assess the FMCG industry on their Industry 4.0 capabilities?

Theoretical analysis. The aim of the theoretical analysis is to get an understanding of the scientific and practical knowledge on Industry 4.0, the implications for the FMCG industry and supportive tools for assessment of Industry 4.0. Before the fourth industrial revolution or Industry 4.0 emerged, three industrial revolutions took place. The first was the mechanization of production facilities, secondly the industrialization, and thirdly the computerization. The Industry 4.0 concept is analysed in two components, the technologies and the capabilities. In

order to structure the available and relevant ideas on Industry 4.0, the 14 subtypes that are proposed are listed in a table. This creates direction for the technology component. The capabilities component is a construct to measure performance or maturity of Industry 4.0 in a manufacturing process of a company. The capabilities are categorized into eight dimensions, which are based on the ideas of Schumacher, Nemeth, & Sihn (2019). The eight dimensions distinguish the organizational wide necessity (i.e. ability) to implement a fully operational Industry 4.0 factory.

With the previously discussed two components considered, a definition with characteristics of Industry 4.0 relevant within the scope of the FMCG industry is constructed. A final definition is formulated as follows: The Industry 4.0 concept forms a period of technological advancements on basis of the trends such as the customer centric approach to mass personalization in the business-to-consumer market (e.g. FMCG industry). To keep up with that customer demand the technological advancements need to be utilized. This means integration of cyber physical objects, intelligent machines, employees, the production lines and processes cross-sectional to form an agile and intelligent value chain across the whole organization i.e. horizontal and vertical integration and end-to-end engineering.

The Industry 4.0 implications for the FMCG industry are that FMCG companies should focus on the trends in the market to align the strategic investments for Industry 4.0 in order to effectively engage with consumers. With a profile tool the Industry 4.0 capability categories were verified for relevance with FMCG trends. It could be concluded that the categories and capabilities are all relevant for the FMCG industry considering the available literature analysis.

The need for supportive tools and methods for assessment is discussed, the case is made for maturity models and an overview of Industry 4.0 maturity models is presented. Second, the maturity levels and performance for assessing are discussed. Next, the comparison of design processes of maturity models is discussed. Followed by the introduction of the procedure model for development of maturity models.

Method. In order to answer the research question the design science methodology was used. For the structure of the research the regulative model cycle of Van Aken et al. (2007) was applied. It consists out of five steps, i.e., (i) problem definition, (ii) diagnosis, (iii) design, (iv) intervention, and (v) evaluation. These steps are scientific controlled actions (i.e. design) to derive a working prototype as a conclusion (Van Aken, Berends, & Van der Bij, 2007). The goal of this research is to design a science and practice-based framework that is used as a supportive tool for assessing the maturity of Industry 4.0 for FMCG companies. In order to facilitate that goal, academic and practice knowledge is required. Via literature review and qualitative empirical data from experts, practice and research design requirements were synthesised to form an initial design of the assessment tool. The initial design was tested and validated by means of alpha- and beta-testing. The testing and validating was an iterative process. The alpha-testing led to usable feedback to improve the initial design of the tool. Also, the initial design of the tool was partially validated. Next, the beta-tests were conducted in practice with two companies to gain more feedback and improve the final design of the tool.

Results. In order to reach the final design of the assessment tool an iterative approach was taken. At first the initial design which was based on literature, was alpha-tested and discussed. Next, beta-tests took place via two company case studies to further evaluate and validate the assessment tool. Lastly the final solution design of the assessment tool was presented.

The biggest adjustments from the initial design are the exclusion of three maturity items, the add-in of the dashboard worksheet, changing the order of the dimensions in the scoring and the perspective of the organization when filling in the assessment tool. With the final solution design, the assessment tool is ready for usage.

Conclusion. The Industry 4.0 assessment tool assesses the maturity of Industry 4.0 capabilities (i.e. the current state and target state) of companies in the manufacturing industry and FMCG industry. The assessment tool exists out of a dashboard, a list with the dimensions and capabilities, the assessment model and scoring charts. In the assessment tool, Industry 4.0 relevant FCMG capabilities are categorized over eight dimensions: technology, products, customers & suppliers, data & information, corporate standards, employees, strategy & leadership. The assessment tool will generate a score which can be used to fill in a report regarding the maturity score on Industry 4.0 capabilities of a company. The maturity grids with descriptions exists out of four levels designed per assessment item (i.e. capability). For the scoring of maturity i.e., the current and target state, a radar chart is utilized.

This research is relevant in addition to the literature by integrating the theory of Industry 4.0 capabilities and the literature field of maturity models applied to a specific industry (i.e. FMCG industry), since this was not done before. For future research, it would be interesting to focus on researching if insight in the performance (i.e. maturity score) makes a difference in attaining Industry 4.0 readiness. Additionally, a company strives to improve, therefore it wants to know what the best way is in increasing the performance i.e. to move to higher maturity levels, it would be recommended to research how a company can increase the success rate (i.e. maturity score).

Table of Contents

1. Introduction

Companies in the Fast-Moving Consumer Goods (FMCG) industry have been at the frontier of innovation in commercial areas such as marketing and sales (e.g. e-commerce), but have been lacking focus on the supply chain and operations (McKinsey & Company, 2016a). Since the last five years, FMCG companies have started to explore the use of more innovative (e.g. digital) solutions in manufacturing processes (McKinsey & Company, 2016a). According to McKinsey & Company (2016), this exploration of innovative digital solutions in the manufacturing value chain could be seen as a natural development of manufacturing processes: the Fourth Industrial Revolution or Industry 4.0.

The momentum behind smart manufacturing or smart factories (i.e. Industry 4.0) is, according to Capgemini (2017), encouraging. As can be seen in the figures, 40% of the consumer goods industry is enthusiastic in embracing smart factories and in a study by KPMG (2018) it is 67%. The average realized overall productivity gains from smart factories for consumer goods is 18%, and for quality 16%. In a similar research by PwC (2017a), efficiency gains from digital factories of 12% are expected. Moreover, 43% of the consumer goods companies has an operational smart factory implementation initiative (Capgemini, 2017). However, companies are facing an increasing connected and disrupted environment, and need to act to reach high standards of digital maturity. According to research on digital maturity in the FMCG industry by Capgemini (2017), 80% is still a beginner (i.e. low digital intensity, low transformation management intensity) and 5% a digital master (i.e. advanced stage in digitizing production processes, a strong foundation of vision, governance and employee skills). Almost the same results are found by PwC (2017b) in their research on digital maturity in the consumer goods industry. Furthermore, for every successful innovative company, almost three companies are struggling in their smart factory initiative. Apparently, the top challenges in implementing a smart factory strategy, following on an initiative, are lack of a roadmap, challenges in identification and prioritization of opportunities and lack of investment (Capgemini, 2017). To conclude, the transformation of the FMCG industry to smart factories or Industry 4.0 stands still at the beginning and the realization of its importance to act is present, but most FMCG companies have no clue where to start. Such a start in the transformation could be a supportive tool to capture or assess the Industry 4.0 current and target state of a company's factory plant.

Smart factories or Industry 4.0 holds a promising potential for FMCG companies, according to the commercial and advisory sector. However, most companies have no clear vision, lack implementation plans, or a roadmap to start with as discussed previously (Capgemini, 2017; McKinsey & Company, 2016a; PwC, 2017b, 2017a). Companies need to know what their "as-it-is" status is regarding Industry 4.0 maturity. Otherwise they are not able to define a solid roadmap or vision for their smart factory to be (Akdil, Ustundag, & Cevikcan, 2018; Schumacher et al., 2019). There are multiple self-assessment tools, maturity models, roadmaps and frameworks, both built and researched by scientific and commercial practices, focussed on Industry 4.0, but lack the specific needs (i.e. customized version) for the FMCG companies (Frank, Dalenogare, & Ayala, 2019; Mittal, Khan, Romero, & Wuest, 2018). A customized version per industry is relevant (Moultrie et al., 2015) due to specific context (i.e. specific characteristics such as large variety of products, high demand, quick turnover) the FMCG industry operates in, and hence follow different routes than other application domains. These specific needs can be customized through the selection of the relevant set of capabilities and requirements. In this case, a capability contains skills, ability and expertise that can be measured (Maier, Moultrie, & Clarkson, 2012). Therefore, this customized version is of interest to prevent strategic and operational difficulties when assessing (Mittal et al., 2018).

The manufacturing industry, as main domain includes FMCG industry, is currently changing from mass production to customized and personalized production, which causes companies to innovate with the rapid advancements in manufacturing technologies (Vaidya, Ambad, & Bhosle, 2018). For the FMCG industry this is no exception, as the FMCG industry is facing the same challenges (McKinsey & Company, 2016a). Digital innovation with Industry 4.0 technologies and capabilities is for the manufacturing industry the current reality to stay ahead of competition (Lasi, 2014). According to an engineering consulting company, hereafter named Company X (company name is on request by Company X anonymised), these challenges also play a subnational role in the FMCG industry, based on the questions from clients that contain problems such as determining 'as-is' state regarding Industry 4.0, failing to identify concrete action plans, and how to integrate the Industry 4.0 concepts on a strategic and operational level. For Company X it is an opportunity to advice their FMCG clients with relevant strategic, operational dashboards and roadmaps to overcome growing uncertainty and dissatisfaction regarding the Industry 4.0 concept within these FMCG companies. However, Company X lacks a supportive Industry 4.0 assessment tool. This supportive tool is useful to assess the Industry 4.0 as-it-is and target state of a FMCG factory which leads to a start for a strategic roadmap and more insights in Industry 4.0. Without such a supportive tool, it may result in Company X not being able to serve their FMCG client base with strategic guidance in Industry 4.0 and could potentially lead to losing clients and market share. This gap results in the following problem statement:

Company X does not have an Industry 4.0 assessment tool applicable for the FMCG industry.

Therefore, the aim of this thesis is to design an Industry 4.0 assessment tool for the FMCG industry, that contains Industry 4.0 capabilities that are relevant for the FMCG industry. In addition, an effort is made to operationalize the tool for FMCG industry. This results in the following research question:

How can an assessment tool be designed to assess the FMCG industry on their Industry 4.0 capabilities?

To support the research question, several sub-research questions are formulated:

- What is Industry 4.0?
- What are the implications of Industry 4.0 for the FMCG industry?
- Which Industry 4.0 capabilities are relevant for the FMCG industry?
- Which assessment tools for Industry 4.0 are applicable?
- Which aspects of the Industry 4.0 assessment tools are applicable for the FMCG industry?

In order to answer these questions, the design science methodology initiated by Simon (1996) will be used. This approach is commonly used in the academic field to find practical solutions to business problems (Van Aken et al., 2007). For the structure of the study, the regulative model cycle of Van Aken et al. (2007) is applied. The data for this research is collected through semi-structured interviews with Company X consultants. With the data an assessment tool is developed, which is structured by a procedure formed with maturity models development theory (Becker, Knackstedt, & Pöppelbuß, 2009; De Bruin, Freeze, Kaulkarni, & Rosemann, 2005; Maier et al., 2012; Moultrie, Clarkson, & Probert, 2007). Lastly, this assessment tool is tested in practice with a beta test (i.e. two case studies) consisting out of manufacturing and FMCG clients from Company X.

The managerial implication of this research is the development of an Industry 4.0 assessment tool for the FMCG industry that will be internal used by Company X. With this assessment tool, manufacturing and FMCG factories can be assessed on their Industry 4.0 as-it-is state. The customized assessment tool prevents strategic and operational difficulties for

Company X when assessing Industry 4.0 capabilities and business and operations strategies (Mittal et al., 2018). The theoretical implication is the integration of theories on Industry 4.0 capabilities and the literature field of maturity models applied to a specific industry (i.e. FMCG industry). Both literature streams i.e. maturity models and Industry 4.0 capabilities are discussed independently and not applied to the FMCG industry in a combined study. In prior research the maturity models theory focusses mainly on development procedures and on application domains such as (advanced) manufacturing (e.g. automotive, medical device) (Moultrie et al., 2015), small and medium enterprises (SME) and new product development (NPD) (Frank et al., 2019; Moultrie et al., 2007). For the Industry 4.0 capabilities theory no specific application to FMCG industry is researched either. In the current study, to create relevant Industry 4.0 capabilities for the FMCG, capabilities are selected from generic to specific. This results in Industry 4.0 capabilities which are relevant and suitable for the FMCG industry. In addition, the maturity models literature has been analysed to determine how it can be applied to a specific industry (i.e. FMCG industry), as an outcome a FMCG industry maturity model (i.e. assessment tool) is constructed.

The structure of this thesis is as follows. Chapter 2 describes the theoretical analysis as the basis for this research. In Chapter 3 a research design is presented which explains the methods applied. Next, the expert analysis by Company X consultants form the practice-based data is combined with the theoretical analysis to form an initial design in Chapter 4. Moreover, in Chapter 4 the results of the alpha and beta tests are presented followed by the final solution design (i.e. the assessment tool). Finally, Chapter 5 offers the discussion and a conclusion for this thesis.

2. Theoretical analysis

This chapter discusses the research from the literature and answers the five sub-questions. The aim of this chapter is to get an understanding of the scientific and practical knowledge on Industry 4.0, the implications for the FMCG industry and supportive tools for assessment of Industry 4.0. This chapter consist out of three sections following a funnel approach as can be seen in Figure 1. First, the Industry 4.0 concept will be analysed and defined. Next, the implications of Industry 4.0 on the FMCG industry are discussed. In the third section, the tools for assessment in Industry 4.0 are discussed.

Figure 1 – Funnel approach from broad to more specific.

2.1 Industry 4.0

In this section a literature review on Industry 4.0 is conducted. The focus is on defining Industry 4.0 by discussing the literature. Since the term Industrie 4.0 was introduced by Kagermann, Lukas, & Wahlster (2011), Industry 4.0 has been gaining attention by academia and practitioners (e.g. consultancy firms). According to Muhuri et al. (2019), who conducted a bibliometric analysis on Industry 4.0, there are a total of 194 papers in Web of Science and 1425 papers in Scopus within the time span of five years. The field of Industry 4.0, therefore, in terms of publications is very young as the first paper was published in 2012 (Muhuri et al., 2019). Next to business and research community, governments and the industry are also involved in the inception of the term Industry 4.0. For example, Accenture (2014) and Capgemini (2014) try 'to sharp the picture beyond the hype' (i.e. Industry 4.0). Governments as a consequence, released strategy outlooks for their industry such as 'Industrie 4.0' in Germany, 'Society 5.0' by Japan, and 'Chinese Manufacturing 2025' in China (Kang et al., 2016; Yin, Stecke, & Li, 2018). Thus, the term Industry 4.0 advances throughout the last decennium in manufacturing as well as in the literature.

2.1.1 The beginning

The industry advances forward on the basis of digitalization within factories, which appear to result in a new fundamental paradigm shift in industrial production. Industry is an economic activity that processes raw materials and produces material goods (Lasi, 2014). Since the beginning of the industrial era technological innovations have led to paradigm shifts, also known and ex-post named as the industrial revolution (Lasi, 2014). The first industrial revolution was the introduction of mechanical production facilities such as the breakthrough of the steam engine by James Watt. It started in the 18th century and intensified through the 19th century, this breakthrough of facilities on water and steam made it possible to advance from manual production to machine production (Wang, Ma, Yang, & Wang, 2017; Xu, Xu, & Li, 2018; Yin et al., 2018).

Next, the second industrial revolution – Industrialization – was marked by the electrification and intense use of electrical energy in the production process (Liao, Deschamps, Loures, & Ramos, 2017; Xu et al., 2018), and the division of labour (e.g. standardization and conveyor belt by Henry Ford) on basis of the principles of rationalization by Taylor (i.e. Taylorism) (Hermann, Pentek, & Otto, 2016; Yin et al., 2018). Consequently, new forms of production were possible such as mass production on basis of economies of scale (Wang et al., 2017). For the third industrial revolution, the widespread digitalization such as the development of advanced electronics (i.e. computer), automation technology, and information technology causes the further automation of production processes in industry (Hermann et al., 2016; Xu et al., 2018). This led to controlled machines such as industrial robots, flexible manufacturing systems and computer integrated systems (Wang et al., 2017; Yin et al., 2018). Also, through manufacturing systems such as enterprise resource planning (ERP), manufacturing executive system (MES), flexibility of the production increased as these systems could be modified much faster than mechanical automated systems. As a consequence, these flexible production systems increased the productivity at low cost with high variety i.e. mass customization production (Wang et al., 2017; Yao & Lin, 2016).

After the third revolution, a new industrial revolution seems to emerge on the basis of innovative technologies and a highly digitized manufacturing process (Xu et al., 2018), where decentralized systems control the information flows of the production processes, due to cyber physical systems, embedded software, and information and communication technologies (ICT). The trend of shifting the focus to customer demand for personalized products creates manufacturing challenges such as effectively solve the conflict “between demand diversification and large-scale manufacturing" with new production forms such as mass personalization (Wang et al., 2017; Yao & Lin, 2016). Therefore, this new fourth industrial revolution – Industry 4.0 – fundamentally differs as the technology push enables mass personalization production. To stay ahead of competition companies need to be more effective which can be realised through innovation of the production plant.

Tempted by this future expectation of a new industrial revolution, Kagermann et al. (2011) came up with the term "Industrie 4.0" ex-ante for the advent of the fourth industrial revolution. Thereafter, Germany, known for its strong manufacturing sector, launched the "Industrie 4.0" initiative as part of its high-tech strategy 2020. Since then, the concept Industry 4.0 was established and in 2016 it was the main topic on the World Economic Forum's agenda (Hofmann & Rüsch, 2017). Therefore, the Industry 4.0 paradigm shift in industrial production is advancing.

2.1.2 Components of Industry 4.0

In this research the Industry 4.0 concept is analysed in two components, the technologies and the capabilities (e.g. success factors, key factors, criteria, activities, items). For the technologies component, a table with types of Industry 4.0 associated technologies in literature is formed. The capabilities component is introduced, because a capability could be a construct to measure performance or maturity of Industry 4.0 in a manufacturing process of a company.

Industry 4.0 technologies. Industry 4.0 can be considered as the new industrial paradigm of this age, partly based on advanced manufacturing technologies. The advancements of technology enables manufacturing companies to tackle manufacturing issues such as efficiency of processes and customer demand for personalization. These advancements allowed the development of technologies for connected and intelligence systems through the value chain (Dalenogare, Benitez, Ayala, & Frank, 2018). Since the emergence of the third industrial revolution (computerization), various technologies have emerged and applied in the manufacturing processes such as cloud computing, flexible production processes, real-time data collection for simulation, and automation of computers (Lasi, 2014; Yin et al., 2018).

In Table 1 an overview is given of types of Industry 4.0 technologies from literature per author. As can be seen when comparing the technologies, there is no standard or accepted set of technologies defining Industry 4.0. This list of technologies is frequently associated with Industry 4.0 in literature, and is by no means meant to be exhaustive. Ghobakhloo (2018), for example, tried to identify the key technology trends of Industry 4.0 by filtering 28 articles/books. The author subtracted 14 technologies that were found in the analysis, but it is a spectrum of technologies. Still no consensus is found in the literature field on whether those 14 technologies are the right ones or should be seen as a full set of technologies. Based on the aforementioned, one might consider that the boundaries of the Industry 4.0 concept are not clearly defined or that Industry 4.0 evolves faster than scholars can write about it.

Next, several types of technologies listed in Table 1 are highlighted and explained. Advanced & autonomous robots, as shown in Table 1, are collaborative with humans in the manufacturing process via embedded sensor technologies and intelligence systems (BCG, 2015; Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018). These sensor technologies, also named Internet of Things, provide the communication to physical objects such as robots and other technologies (Alcácer & Cruz-Machado, 2019). In the manufacturing process the communication via sensors can be applied to the value chain to monitor and collect data to enhance real-time communication and decentralised decision making (Moeuf et al., 2018). With the horizontal and vertical integration of ICT systems such as MES, ERP, SCADA, simulation becomes possible. Performance of manufacturing lines can be simulated with modelling tools, which lead to optimisation of such a line (Dalenogare et al., 2018; Moeuf et al., 2018). Cyber physical systems monitor and control via algorithms integrated in the systems to operate in real-time (Moeuf et al., 2018). Thus, these types of technologies are most of the time phrased as a collection of supportive technologies. For example, Internet of Things is a collection of technologies that enables communication via sensors to connect physical objects and systems. These Industry 4.0 technologies together form the industrial paradigm that enhances manufacturing processes.

Table 1 – Overview of Industry 4.0 technologies.

Technologies	References
Advanced & autonomous robots	Alcácer & Cruz-Machado, 2019; BCG, 2015; Ghobakhloo, 2018; Gilchrist, 2016; Moeuf et al., 2018; Oztemel & Gursev, 2018
Simulation	Alcácer & Cruz-Machado, 2019; Dalenogare et al., 2018; BCG, 2015; Ghobakhloo, 2018; Gilchrist, 2016; Moeuf et al., 2018; Oztemel & Gursev, 2018
Horizontal and vertical integration	Alcácer & Cruz-Machado, 2019; BCG, 2015; Gilchrist, 2016; Moeuf et al., 2018;
The (Industrial) Internet of Things	Alcácer & Cruz-Machado, 2019; BCG, 2015; Frank et al., 2019; Ghobakhloo, 2018; Gilchrist, 2016; Moeuf et al., 2018; Oztemel & Gursev, 2018; Lu, 2017; Pereira & Romero, 2017; Xu et al., 2018; Yin et al., 2018
Cybersecurity	Alcácer & Cruz-Machado, 2019; BCG, 2015; Ghobakhloo, 2018; Gilchrist, 2016; Moeuf et al., 2018; Xu et al., 2018
Cloud computing	Alcácer & Cruz-Machado, 2019; Dalenogare et al., 2018; BCG, 2015; Frank et al., 2019; Ghobakhloo, 2018; Gilchrist, 2016; Oztemel & Gursev, 2018; Lu, 2017; Moeuf et al., 2018; Xu et al., 2018; Yin et al., 2018
Additive manufacturing	Alcácer & Cruz-Machado, 2019; Dalenogare et al., 2018; BCG, 2015; Ghobakhloo, 2018; Gilchrist, 2016; Moeuf et al., 2018; Yin et al., 2018
Augmented reality	Alcácer & Cruz-Machado, 2019; BCG, 2015; Ghobakhloo, 2018; Gilchrist, 2016; Moeuf et al., 2018; Oztemel & Gursev, 2018
Big data (collection) and analytics	Alcácer & Cruz-Machado, 2019; Dalenogare et al., 2018; BCG, 2015; Frank et al., 2019; Ghobakhloo, 2018; Gilchrist, 2016; Moeuf et al., 2018; Lu, 2017; Oztemel & Gursev, 2018; Yin et al., 2018
Digital product-service systems	Dalenogare et al., 2018;
Internet of services	Dalenogare et al., 2018; Ghobakhloo, 2018; Pereira & Romero, 2017;
Cyber-physical systems	Oztemel & Gursev, 2018; Ghobakhloo, 2018; Lasi, 2014; Pereira & Romero, 2017; Xu et al., 2018; Yin et al., 2018
Artificial Intelligence	Yin et al., 2018
Blockchain	Ghobakhloo, 2018; Xu et al., 2018

Industry 4.0 capabilities. The concept of capability emerged mainly in the field of strategic management where it seeks to define, understand, predict and measure how capabilities structure competitive advantage (Pisano, 2015; Teece, 2017; Teece, Pisano, & Shuen, 1997). There are three main perspectives in this field on how to sustain a company's competitive advantage; the resource-based perspective (main source for competitive advantage are the tangible and intangible assets that the firm can develop and control), the competence perspective (company's competence in capitalizing on resources for competitive advantage), and the capability perspective (capability are the tacit and intangible resources that provide the competitive advantage) (Maier et al., 2012; Teece, 2017; Teece et al., 1997). One could observe

the overlap of the three perspectives, because they are complementary in underlining the different aspects (e.g. recourses, competences) of the capability concept.

These different aspects are integrated in the capability concept by Teece et al. (1997). The author states that the capability concept emphasizes "the key role of strategic management in appropriately adapting, integrating and reconfiguring, internal and external organizational skills, resources, and functional competences to match the requirements of a changing environment" (Teece et al., 1997, p. 515). In the current changing business environments with Industry 4.0 technologies, capabilities are needed to keep up with new innovations such as Industry 4.0 (Schumacher et al., 2016). According to Ulrich & Smallwood (2004) and Maier et al. (2012), capabilities "are the collective skills, abilities, and expertise of an organization". In other words, "a capability is a set of learned processes and activities that enable a company to produce a particular outcome" (Teece, 2017). This is in line with Pisano (2015), as he states that "a capability is a collection of organizational routines that enable a firm to perform some set of tasks on a repeatable or consistent basis". The various definitions share aspects that are complementary such as a skill set and activities (i.e. what a company does). Therefore, this research defines a capability as collective skills and activities, abilities, and expertise of a company. This capability is about what a company does and it can be measured to observe the performance or maturity in a changing business environment.

When measuring performance or maturity, other constructs besides capabilities are also used by academia. They use success factors (Moultrie et al., 2007; Schumacher et al., 2019), criteria (Pöppelbuß & Röglinger, 2011), elements of good practice or elements based on experience from observations by practitioners (Fraser, Moultrie, & Gregory, 2002), key practices (Mettler, 2011), and items based on abstract concepts derived from literature and experience (Schumacher et al., 2019). Thus, there are multiple ways applied by academia when labelling a construct such as a capability. In this research, these labels are seen as related, because they have overlap and are used with the same goal.

In Table 2 an overview is given of Industry 4.0 capabilities per category. These categories and capabilities are proposed in the article by Schumacher et al. (2019). The categories (i.e. dimensions) form a complete structure for the assessment of manufacturing companies, because they are developed in the context of manufacturing (overarching domain of the FMCG industry) from extensive literature and empirical research which was validated in practice. Moreover, these dimensions comprise all the other categorisations or dimensions in various phrasing found in the literature. The capabilities per category are derived from various articles as can be seen in the references column from Table 2. Thus, the base (i.e. dimensions and capabilities) of Table 2 is formed by the article of Schumacher et al. (2019), and this base is verified/checked and combined/modified where possible with the input from articles (see references column in Table 2). In this case, the success factors, criteria, good practices, elements, fields or assessment items from the various articles are considered as a comparable capability. For example, the capability ‘IT systems usage’ is comparable to the field ‘IT systems’ used in Lichtblau et al. (2015).

Table 2 – Overview of Industry 4.0 capabilities by category.

Categories	Capabilities	References
Technology	Technology for information exchange, Utilization of cloud technology, Mobile devices on shop floor, Decentral information storage, Sensors for data collection, Integrated computers in machines, Integrated computers in tools, Additive manufacturing, Utilization of robots, IT systems	Akdil et al., 2018; Gokalp, Sener, & Eren, 2017; Leyh et al., 2016; Lichtblau et al., 2015; Schuh et al., 2017; Schumacher et al., 2019;
Products	Product individualization, Flexibility of product characteristics, Collection of product-use-information, Data processing components in products, Internet connection of products, Digital compatibility and interoperability of products, IT-services related to physical products	Akdil et al., 2018; Leyh et al., 2016; Lichtblau et al., 2015; Schumacher et al., 2019;
Customer & Supplier	Openness to new technology, Competence with modern ICT, Digitalization of customer contact, Customer integration in product development, Utilization of customer related data, IT-collaboration for product development, Digital contact with company suppliers, Company suppliers degree of digitalization dimension	Akdil et al., 2018; Schumacher et al., 2019;
Value Creation Processes	Process automation, Autonomy of machine park, Information exchange between machines, Remote control of machine park, Automated quality control, Databased machine maintenance, Automation object handling, Collaboration of humans and robots.	Akdil et al., 2018; Gokalp, Sener, & Eren, 2017; Lichtblau et al., 2015; Schumacher et al., 2019;
Data & Information	Digital information processes, Automated data collection, Analysis of collected data, Databased decision making, Automated information provision, Individualization of provided information, Digital process visualization, Data-driven software-simulation of future scenarios	Lichtblau et al., 2015; Schuh et al., 2017; Schumacher et al., 2019; (Schuh et al., 2017)
Corporate Standards	Monitoring of Industry 4.0 realization, Recruitment for Industry 4.0, Adjustments of works arrangements, Employee trainings for digital competences, Legal protection for digital products and services, Increased cyber security, Rules for employees in digital work environment, Technological standards	Gokalp, Sener, & Eren, 2017; Schuh et al., 2017; Schumacher et al., 2019;
Employees	Openness to new technology, Competences with modern ICT, Awareness of non-IT-employees for data, Awareness of non-IT-employees for cyber security, Willingness to flexibilize work arrangements, Autonomy of shop floor workers, Experience with interdisciplinary work, Willingness for continuous training on the job, Knowledge about employee competences	Lichtblau et al., 2015; Schuh et al., 2017; Schumacher et al., 2019;
Strategy & Leadership	Roadmap for Industry 4.0 realization, Central coordination of Industry 4.0 activities, Financial resources to realize Industry 4.0, Communication of Industry 4.0 activities, Employee objectives to realize Industry 4.0, Risk assessment for Industry 4.0, Willingness of managers to realize Industry 4.0, Manager trainings for Industry 4.0	Akdil et al., 2018; Gokalp, Sener, & Eren, 2017; Lichtblau et al., 2015; Schuh et al., 2017; Schumacher et al., 2019;

The eight dimensions behold the organizational wide necessity to implement a fully operational Industry 4.0 factory. For example, the implementation of an Industry 4.0 technology on itself is not sufficient enough. The whole organization or company has to be on point with

Industry 4.0 abilities. Thus, next to technology, employees, strategy and leadership are at least as important over the whole line of the organization. Capabilities per dimension are the backbone of the Industry 4.0 implementation. In the case of the value creation processes, the capability of information exchange between machines is necessary to fully exploit value through the value chain (Moeuf et al., 2018).

2.1.3 Definition Industry 4.0

With the advancing of the concept Industry 4.0, various conceptual and technical studies were conducted on Industry 4.0 as already was pointed out at the beginning of this chapter. These studies contain what the challenges are to be expected (Jardim-Goncalves, Romero, & Grilo, 2017; Monostori, 2014; Panetto, Iung, Ivanov, Weichhart, & Wang, 2019), how and what Industry 4.0 need to be researched and developed, what strategies are required to realize Industry 4.0 (Thoben, Wiesner, & Wuest, 2017), and try to define Industry 4.0 (Kang et al., 2016). However, there is still no consensus in the literature on a clear definition and understanding for Industry 4.0 (Hermann et al., 2016; Oztemel & Gursev, 2018; Piccarozzi, Aquilani, & Gatti, 2018). Hence, two publication streams or perspectives for Industry 4.0 can be distinguished i.e. the technical and operational approach, and the management and strategy approach.

The first perspective to discuss is the technical and operational approach. Gilchrist (2016) states that Industry 4.0 is a collective term for technologies and concepts of value-chain organizations that deploys tools provided by advancements in operational and industrial processes. Lasi (2014) argues that Industry 4.0 encounters a wide range of concepts such as automation and digitalization. But the author, moreover, defines it as a paradigm shift in the industrial production and manufacturing. Ghobakhloo (2018) focuses more on the vertical and horizontal integration of the physical and the virtual worlds. According to the author, this can be supported and enabled by technology trends such as cyber physical systems, intelligent systems and machines, IoT, and blockchain. To conclude, the technical and operational perspective is that Industry 4.0 is about technical advancements to support and enable an agile value chain across the production lines and processes.

Second, the management and strategy approach is discussed. The customer demands more voice in the personalization of products. This means a shift from customization to mass personalization (Wang et al., 2017). To be able to keep up with that kind of demand, the FMCG industry has to become more agile in the production and logistic processes (Wang et al., 2017).

Bauer, Hämmerle, Schlund, & Vocke (2015) argue that it enhances the productivity of new business models, services and products on the long term and will have a tremendous economic impact. According to Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray (2018), Industry 4.0 tools require a large investment and high level of expertise, but it is flexible as information become real time and decentralised which enhances decision making.

To conclude, when the beginning part, Industry 4.0 technologies and capabilities, and the two perspectives are taken into account a definition with characteristics of Industry 4.0 relevant within the scope of the FMCG industry could be constructed. Therefore, the definition this research uses is: the Industry 4.0 concept forms a period of technological advancements on basis of the trends such as the customer centric approach to mass personalization in the business-to-consumer market (e.g. FMCG industry). To keep up with that customer demand the technological advancements need to be utilized. This means integration of cyber physical objects, intelligent machines, employees, the production lines and processes cross-sectional to form an agile and intelligent value chain across the whole organization i.e. horizontal and vertical integration and end-to-end engineering.

2.2 Industry 4.0 implications for FMCG industry

Fast-moving consumer goods (FMCG) or consumer packaged goods (CPG) are terms that are characterised mainly by products that sell at relatively low-cost and have a constant high consumer demand (Accenture, 2014; Zou, 2016). It comprises product categories such as beverages and food, cosmetics, household and cleaning, personal care, pet food/care and tobacco. These products usually have a short shelf life of a year, are mostly non-durable explaining the term "fast-moving" and are bought frequently with recurring expenditure (Accenture, 2014; Aljunaidi & Ankrak, 2014; BCG, 2019; Francis, Dorrington, & Hines, 2008; KPMG, 2016; McKinsey & Company, 2016a; Oraman, Azabagaoglu, & Inan, 2011; Zou, 2016). In contrast, the slow-moving consumer goods (SMCG) are products with a useful life of more than a year, have a lower sales frequency and are not rotating as rapidly as FMCG such as furniture, household appliances and white goods.

The FMCG sector is labelled as the business-to-consumer (B2C) market (Aljunaidi & Ankrak, 2014). Although, a clarification for the type of consumer is necessary in this case. There is a distinction between consumers and consumers that are actually customer. According to Aljunaidi & Ankrak (2014), consumers are the end-users of the products who define the value of the product. Between the FMCG manufacturer and the end-user the customer or the retailer in this case stands. The relationship between the manufacturer and its retailer consists out of fierce price competition, because the retailer pressures the FMCG manufacturer on price and cost reduction. It pushes the FMCG manufacturer to focus on cost reduction and squeeze the margins, efficient supply chains and short term gains (Aljunaidi & Ankrak, 2014; BCG, 2019; Oraman et al., 2011). In order to have a clear distinction in the clarification of the type of consumer, this research uses chain integration to define the link between the producers, consumer, and customer.

Most FMCG companies have focussed on maximizing their value for many years, but recently a trend emerges. Focus is shifting from company's value to modern consumer demand (Wang et al., 2017). The historic formula of mass production to mass distribution to mass marketing applied by these companies is outdated (KPMG, 2016; Yao & Lin, 2016). According to Wang et al. (2017), the desire of the consumer is the key driving force of the transition leading to Industry 4.0. Innovative ideas in combination with new technologies are globally used to satisfy the increased consumption and ensuring benefits to both companies and their consumers (Deloitte, 2019; Wang et al., 2017). Although FMCG companies are generally not at the forefront of implementation of cutting-edge technologies, it is an imperative to adopt digital new technologies or risk being outdated as a growing number of their consumers research, purchase and engage with brands digitally. Disruptive competitors such as platform companies and online start-ups are investing heavily in understanding this modern consumer and offer tailored propositions to meet their specific needs. As a result, the core of competitive advantage in the FMCG industry is shifting (BCG, 2019; KPMG, 2016).

The developments in the FMCG industry as aforementioned are in part driven by their customer-centric approach on responding to market trends, understanding consumer preferences and deepening connections with customers (retailer) and consumers (end-user) (Deloitte, 2019). Thus, Deloitte (2019) argues that the pursuit of consumer centricity stands at the heart of the FMCG industry in 2019. The reason for this is that the consumer in developed markets are aging, live longer, searches digital, demand personalized products and sustainability preferences (Accenture, 2014; McKinsey & Company, 2011; Wang et al., 2017; World Economic Forum, 2016). FMCG companies are facing multiple challenges at once, i.e., redefining the consumer expectations and approach, economic pressure on margins and emergence of disruptive competitors and technological shift to digitizing the organization.

To sustain in the FMCG industry, companies should capitalize on the opportunities for growth in the digital age and evolve to a digital or Industry 4.0 prove organization (Accenture, 2014). As digitalization rewrites rules of the business and the relationships with retailers and end-users, according to McKinsey & Company (2016b) it will affect all aspects of the organization. However, leveraging digital technologies alone is not sufficient, because the entire organization needs to have Industry 4.0 strategies and technologies to enable the required consumer-centric approach (Accenture, 2014; KPMG, 2016). The implications are, therefore, that FMCG companies should focus on the trends in the market to align the strategic investments for Industry 4.0 to effectively engage with consumers.

Conclusions theory analysis. Next, as shown in Table 3, nine trends from literature are subtracted from the analysis as discussed before in this section to extract key characteristics relevant for the FMCG industry. These trends and characteristics are useful to validate the relevance of the content of an assessment tool that will be designed for the FMCG industry. The capabilities in Table 2 are combined with the FMCG trends from Table 3 to validate their relevance via a tool i.e. Harris Profile (Harris, 1961), as shown in Table 4. This Harris profile tool is a useful visualization tool to evaluate and select variables based on criteria. Moreover, the tool is used in scientific field for selection and decision making when evaluating variables with criteria.

In Table 4 the evaluation of the FMCG relevance for the Industry 4.0 capabilities per category is shown via a Harris profile tool. The categories are rated on basis of a matrix four-scale score i.e. -2=not relevant; -1=moderate not relevant; +1= moderate relevant; +2=relevant. Relevance could be defined as "something (A) is relevant to a task (T) if it increases the likelihood of accomplishing the goal (G), which is implied by T" (Hjørland & Christensen, 2002). In this research ‘Relevant’ is defined as the maximal contribution needed to a process or trend by a cluster capabilities, whereas ‘not relevant’ is defined as the opposite of relevant i.e. totally no contribution needed to a process or trend by a cluster capabilities. ‘Moderate relevant’ is defined as some contribution needed to a process or trend by a cluster capabilities, whereas ‘moderate not relevant’ is defined as partly no contribution needed to a process or trend by a cluster capabilities. For example, the capability cluster Technology is ‘relevant’ for the Smart packaging trend, because to fully exploit this trend Technology capabilities are necessary to support the Smart packaging operation. Another example regarding the Smart packaging trend is the Corporate standards capability cluster that is ‘not moderate relevant’, because for these capabilities are not that necessary to fully exploit Smart packaging.

The total score is calculated and defines the degree of relevance per category to select and decide on the added value of the capability category for the FMCG industry. Such a scheme is to a degree arbitrary, because it may reflect the judgement of the researcher when selecting and deciding on the relevance. As shown Table 4, the total score per category shows that they all are relevant for FMCG industry to some degree. For example, the trend digital operating model requires technology capabilities of a FMCG company to fully capitalize on this trend. This can be explained in the way that the categories are developed in the context of the manufacturing application domain (Schumacher et al., 2019). The manufacturing domain is an overarching domain in which the FMCG industry fits. Therefore, the categories and capabilities are all relevant for the FMCG industry considering the available literature analysis. Empirical analysis should support the relevance of the capabilities, as shown in this research, supporting the assumption of this conclusion.

Table 3 – Analysis of trends to extract FMCG industry characteristics.

Trends	Analysis	Characteristics
Mass personalization	In contrast to mass customization, defined as consumer demand for a large variety of products, consumers are actively involved in the product design process of mass personalization (KPMG, 2016; McKinsey & Company, 2016b; Wang et al., 2017).	Flexibility, efficiency, agile supply chain to pick, pack, ship products across multiple channels and D2C.
E-commerce/online shopping/Omni-channel	Historically FMCG manufacturers were present at the aisle of a grocery store, recently being present online is necessary (McKinsey & Company, 2016b). Online purchases are growing with the development of the digital consumer (World Economic Forum, 2016).	Digital organization, data leverage, efficiency.
Consumer data flow	Privacy and security of their data is valued by consumers. But when that is secure, the data flow through products/services to gain personal advancements in products is preferred by the consumer (KPMG, 2016; McKinsey & Company, 2011).	Cyber security, digital organization systems.
Digital operating model	Leveraging digital technology is necessary to stay competitive in the disruptive environment (Deloitte, 2019; KPMG, 2016). Smart factories and agile supply chains are developed, enabling mass personalization (World Economic Forum, 2016)	Industry 4.0, smart products, agile supply chain, efficiency, speed.
Experience economy	Products evolve from services to experiences enabled by data processing in smart products and logistics (World Economic Forum, 2016).	Industry 4.0 technologies, automation.
Distinct branding/Direct-to-consumer (D2C)	Brand selling direct to the consumer and skipping the retailer. The consumer-centric approach enables convenience, competitive product pricing, personalized service and co-creating products. Moreover, it generates valuable consumer data. (Deloitte, 2019).	Digital organization, consumer-centric approach, data collection, agile supply chain.
Sustainability	Consumers demand transparency on sustainability. Enabled by technology and changing consumer behaviour, consumers increasingly focus on sustainability (Deloitte, 2019).	Efficiency, efficient logistics, sustainability .
Smart packaging	Products that are connected via for example sensors or QR code, generate and leverage data to aid inventory and enhance user experience (Deloitte, 2019; McKinsey & Company, 2016b).	Industry 4.0 technologies, data and information processing.
Technology driven innovation	Innovative (smart) products enabled by new technologies (Deloitte, 2019).	Industry 4.0 technologies, smart products.

Table 4 – Verifying FMCG relevance for Industry 4.0 capability per category (Harris profile tool).

Category (capabilities) →	Technology				Products				Customer & Supplier				Value Creation Processes				Data & Information				Corporate Standards				Employees				Strategy & Leadership			
Trends ↓	-2	-1	+1	+2	-2	-1	+1	+2	-2	-1	+1	+2	-2	-1	+1	+2	-2	-1	+1	+2	-2	-1	+1	+2	-2	-1	+1	+2	-2	-1	+1	+2
Mass personalization			green	green			green	green			green	green			green	green			green	green			green				green				green	green
E-commerce/online shopping/Omni-channel			green				green				green	green			green				green			red					green				green	
Consumer data flow			green	green			green	green			green	green			green				green	green			green				green				green	
Digital operating model			green	green			green				green				green	green			green				green				green				green	green
Experience economy			green				green	green			green			red					green	green			green				green				green	
Distinct branding/Direct-to-consumer (D2C)			green				green	green			green	green		red					green	green		red					green				green	green
Sustainability			green	green			green				green	green			green			red					green				green				green	
Smart packaging			green	green			green	green			green	green			green				green			red					green	green			green	
Technology driven innovation			green	green			green				green	green			green				green			red					green				green	green
Total score	+15				+14				+16				+7				+11				+1				+10				+13			
+2 = relevant																																
+1 = moderate relevant																																
-1 = moderate not relevant																																
-2 = not relevant																																

2.3 Tools for assessment

In this section the tools for assessment are discussed. First, the need for supportive tools and methods for assessment is discussed, the case is made for maturity models and an overview of Industry 4.0 maturity models is presented. Second, the maturity levels and performance for assessing are discussed. Next, the comparison of design processes of maturity models is discussed. Followed by the introduction of the procedure model for development of maturity models.

2.3.1 Maturity models

Continual advancement of the FMCG company requires implementation of new strategies such as Industry 4.0. This demands the company to critically assess its position regarding Industry 4.0 capabilities and the quality of its goods and services. According to Becker et al. (2009), this positioning involves a comparison or assessment of the company's goals and external requirements such as customer demands and guidelines. However, to realize an objective assessment of the company's position tends to be difficult (Becker et al., 2009). The difficulty lays in the challenge to determine what needs to be measured and how, and what to compare it with, in order to assess the as-is situation and to assign it a specific degree of maturity or quality (Becker et al., 2009). Therefore, supportive tools and methods are needed for companies to assess the as-is situation, derive improvement measures and form guidelines to evaluate the progress of their Industry 4.0 implementation strategy (Becker et al., 2009; Schumacher, Erol, & Sihn, 2016).

Maturity models are mostly used to assist companies with these issues and challenges (Becker et al., 2009; De Bruin et al., 2005; Sony & Naik, 2019). According to Schumacher et al. (2016), "maturity models are commonly used as an instrument to conceptualize and measure maturity of an organization or a process regarding some specific target state" (p. 162). The term 'maturity' implies some progress in the development of a system and it can be captured qualitatively and quantitatively (Schumacher et al., 2016). Maturity models have a strong background in the IT, software and project management application domains (Felch, Asdecker, & Sucky, 2019). Often used synonymously are (technology) readiness models that have as goal to capture the starting point and allow for initializing the development process, whereas maturity assessment aims for capturing the as-it-is state during the maturing process (Schumacher et al., 2016). For the assessment of the as-it-is and target state of production companies, maturity assessment models are often used. Therefore, maturity models are applicable for assessment of the application domain Industry 4.0 and FMCG industry.

Table 5 shows an overview of assessment tools in the domain of Industry 4.0. To consider the existing literature on assessment tools in Industry 4.0, a literature review was conducted on maturity models in Industry 4.0. Hereby it was taken into account that the assessment tools are maturity or readiness models in Industry 4.0, are written in English, and display a clear assessment approach. As can be seen in Table 5, the maturity models are compared according to critical parts of such a model: the assessment approach, dimensions and items used for the framework, and the maturity levels to measure maturity.

A comparison of the models in Table 5 indicates that all the seven models have a different set up of dimensions, maturity levels and items. The dimensions are focussed on manufacturing, IT and digitalisation in relation to Industry 4.0. For example, the model by Schumacher et al. (2019) is a more comprehensive model and includes all the aspects of the organisation to engage in Industry 4.0. In this research, the model is extensively tested in the manufacturing domain in practice and improved. The author concludes that the model works in practice and that maturity models are suitable for such assessments. Other models are initiated by government programs, universities and by consultant companies such as IMPULS, Industrie 4.0 index and the Industry 4 readiness assessment tool and are thoroughly tested in practice. It can be concluded that there is no standard or one well-accepted model (Akdil et al., 2018; Gokalp et al., 2017; Schumacher et al., 2016; Sony & Naik, 2019).

The maturity items and dimensions, as presented in Table 5, have various definitions according to literature. Researchers use multiple definitions for the content of their maturity models i.e., the maturity items. According to Fraser, Moultrie, & Gregory (2002), "several maturity models are based on elements of 'good practice' derived from published studies which identify factors associated with successful outcomes. Others have an element of 'from experience', based on the observations of experienced practitioners. In that respect, a degree of 'validation' has already taken place, albeit not a rigorous one. It rather depends on the intended purpose of the maturity model". The author uses good practices, factors of success and elements from experience as definition of the items. This is in line with Schumacher et al. (2016) who argue that the items are abstract concepts derived from studies and experience. However, other researchers such as Pöppelbuß & Röglinger (2011) define it as criteria, Maier, Moultrie, & Clarkson (2012) argue for capabilities (i.e. collective skills, abilities, and expertise of an organization), and Mettler (2011) state that the items are key practices. There are multiple ways of defining the maturity items according these researchers and in broad lines they all come close to each other. Therefore, the term capability is used for defining and naming the maturity items. This research defines a capability as collective skills and activities, abilities, and expertise of a company, that can be measured with a maturity grid to observe performance (see also section 2.1.2 on Industry 4.0 capability).

2.3.2 Maturity levels and performance

What makes a capability mature? How can the performance of a capability be measured? These are questions with many possible answers, as there exist various concepts in literature for measuring maturity and performance (Fraser et al., 2002; Maier et al., 2012; Moultrie et al., 2007). The simplest means of assessing the maturity of a capability is with a binary (yes/no) response (Fraser et al., 2002; Maier et al., 2012; Moultrie et al., 2007). However, according to Moultrie et al. (2007), "this binary response provides little genuine information about good practice and offers little granularity when scoring. It is also highly subjective, and responses are open to an extremely wide degree of interpretation". Another option for assessing maturity is the Likert-scale. In this case, someone scores a statement to the extent of to which they agree or disagree. Although, the Likert-scale provides more granularity, it still gives little insight in what might be a mature capability (Fraser et al., 2002; Moultrie et al., 2007). Thirdly, the modified Likert-scale with anchor phrases can be used which describes performance or maturity at each scale (Moultrie et al., 2007). However, according to Moultrie et al. (2007), "the transition from low to high performance is not necessarily linear; thus, the scale provides little additional insight into what the intervening points might mean or how a firm might migrate to the higher levels".

The last option taken into account in this research is the maturity grid. As discussed in literature, there are multiple ways of assessing using this form. Moultrie et al. (2007) describe this option as a maturity grid with extended descriptions per scale. These descriptions per level provide insight in how a company progresses between each level. Thus, improving the objectivity when someone scores. Maturity grids were introduced in the quality control domain and are able to define levels of maturity and performance for a capability or other issue (Maier et al., 2012). Moreover, Moultrie et al. (2007) state that "the maturity grid offers a simple and user-friendly solution and is thus a more appropriate approach". Therefore, a form of maturity grids are obtained from literature to assess maturity in an assessment tool for the FMCG industry. Such a maturity grid has the advantage of simplicity in scoring, but with enough detail within the descriptions to observe the progress to improve performance or maturity.

Table 5 – Overview maturity models in Industry 4.0.

Model/Reference	Assessment approach	Dimensions and items	Maturity levels
Industry 4 readiness assessment tool. WNG, 2017	***Description:*** Self-assessment readiness tool ***Aim:*** Purpose is to provide a simple and intuitive way for companies to start to assess their readiness and future ambition to harness the potential of the cyber-physical age and Industry 4.0. ***Scope:*** Broad range of industries (all are included). ***Administration:*** Self-assessment	***Number:*** 37 (6 dimensions and 37 sub-dimensions) ***Labels:*** Dimensions: Products and services, Manufacturing and operations, Strategy and organisation, Supply chain, Business model, Legal considerations. ***Items:*** (e.g. product customisation, data-driven services, automation, digital modelling, collaboration, leadership)	Four readiness levels: 1. Beginner 2. Intermediate 3. Experienced 4. Expert
IMPULS – Industrie 4.0 readiness. Lichtblau et al., 2015	***Description:*** Project partners IW Consult and FIR at RWTH Aachen University developed an online tool and a model to measure readiness, the degree of sophistication on the road to Industrie 4.0, of companies in Germany's mechanical engineering industry ***Aim:*** Examine Industry 4.0 readiness ***Scope:*** Mechanical engineering industry (Germany) ***Administration:*** Online self-check assessment (survey)	***Number:*** 18 (6 dimensions, 18 fields) ***Labels:*** Associated fields: Strategy & Organization, Smart Factory, Smart Operations, Smart Products, Data-driven Services, and Employees ***Items:*** (e.g. Strategy, investments, Digital modelling, skill acquisition, IT security)	Six levels of readiness, to measure readiness, criteria were defined for each area. These criteria have to be met to move up to the next readiness level. 0. Outsider 1. Beginner 2. Intermediate 3. Experienced 4. Expert 5. Top performer
Industry 4.0 Maturity Model. Akdil et al., 2018	***Description:*** Maturity model with questionnaire based on Industry 4.0 principles (e.g. Interoperability, Virtualization) and technologies (e.g. Cybersecurity, Cloud). ***Aim:*** Provide companies a tool to help them understand their current state regarding to Industry 4.0 ***Scope:*** Industry sector (focus on retail sector) ***Administration:*** Assessment Questionnaire (survey)	***Number:*** 13 (3 dimensions, 3 sub-dimensions, 13 associated fields) ***Labels:*** Associated fields ***Items (example):*** Smart products & services, Production, logistics & procurement, R&D—Product development	Four stages: Level 0: Absence Level 1: Existence Level 2: Survival Level 3: Maturity

CONTINUED: Table 5 – Overview maturity models in Industry 4.0.

Model/Reference	Assessment approach	Dimensions and items	Maturity levels
Industry 4.0-MM. Gokalp, Sener, & Eren, 2017	***Description:*** Industry 4.0-MM has a holistic approach, structured on a framework SPICE that provides standardization in continuous benchmarking and improvement of businesses in the manufacturing industry. ***Aim:*** The aim of the model is to provide a means for assessing a manufacturer's current Industry 4.0 maturity stage and for identifying concrete measures to help them reach a higher maturity stage in order to maximize the economic benefits of Industry 4.0. ***Scope:*** Manufacturing industry ***Administration:*** Not mentioned	***Number:*** 5 ***Labels:*** Process area's: Asset Management, Data Governance, Application Management, Process Transformation, and Organizational Alignment. ***Items:*** -	Six levels: Level 0: Incomplete Level 1: Performed Level 2: Managed Level 3: Established Level 4: Predictable Level 5: Optimizing
SIMMI 4.0. Leyh, Bley, Schaffer, & Forstenhausler, 2016	***Description:*** (System Integration Maturity Model Industry 4.0) Maturity model that enables a company to classify its IT system landscape with focus on Industry 4.0 requirements ***Aim:*** The aim of our research is to provide a maturity model for the classification of a company's IT system landscape in the context of the Industry 4.0 requirements ***Scope:*** Businesses (focus on SME's) ***Administration:*** Self-assessment	***Number:*** 4 dimensions ***Labels:*** Components and dimensions: Vertical Integration, Horizontal Integration, Cross-sectional Technology Criteria ***Items:*** -	Five stages: 1. Basic digitization level 2. Cross-departmental digitization 3. Horizontal and vertical digitization: 4. Full digitization 5. Optimized full digitization
Industry 4.0 Maturity Model. Schumacher et al., 2019	***Description:*** A maturity model in the form of a systematic procedure model that offers companies guidance from their initial contact with Industry 4.0 until the definition of company specific fields of action, realization projects and roadmaps. ***Aim:*** Designing a novel Industry 4.0 realization model targeting industrial manufacturing companies. ***Scope:*** Manufacturing industry ***Administration:*** Questionnaire and workshops.	***Number:*** 65 ***Labels:*** 8 dimensions (Technology, products, customer&partners, value creation processes, data & information, corporate standards, employees, strategy&leadership) ***Items:*** Capabilities and abstract concepts: 65 items (e.g. IT systems, increased cybersecurity)	Maturity levels are on a maturity scale from 1 - 4 per item with multiple anchor phrases. The process maturity principle extends the anchored scale with descriptions at a number of points along the scale. These intermediary descriptions provide insight into how a firm might progress between each level and thus helps to improve objectivity when scoring (Moultrie et al., 2007).

CONTINUED: Table 5 – Overview maturity models in Industry 4.0.

Model/Reference	Assessment approach	Dimensions and items	Maturity levels
Industrie 4.0 Maturity Index. Schuh et al., 2017	***Description:*** The Acatech Industrie 4.0 Maturity Index helps companies to determine which stage they are currently at in their transformation into a learning, agile company. It assesses them from a technological, organisational and cultural perspective, focusing on the business processes of manufacturing companies. ***Aim:*** Goal of this maturity index is to provide a means of establishing companies' current Industrie 4.0 maturity stage and of identifying concrete measures to help them achieve a higher maturity stage in order to maximise the economic benefits of Industrie 4.0 and digitalisation. ***Scope:*** Manufacturing industry ***Administration:*** Workshop on site, questionnaire	***Number:*** 4 dimensions, 8 capabilities, 5 functional areas ***Labels:*** Capabilities and functional areas ***Items:*** -	Six stages: 1. Computerization 2. Connectivity 3. Visibility 4. Transparency 5. Predictive capability 6. Adaptability

2.3.3 Comparison of design processes of maturity models

Several researchers such as Becker et al. (2009); De Bruin et al. (2005); Maier et al. (2012) and Moultrie et al. (2007) extensively researched the development of maturity models, as can be seen in Table 6, where a comparison of the methodological choices for the development procedures of maturity models is shown. In these studies, procedures and methods to develop maturity models are described. According to Maier et al. (2012), they intend to aid the development of maturity models. Maier et al. (2012) find that many efforts of maturity models are ad-hoc in their development without guidance which results in poor quality. The solution, according to the author, lays in a more rigorous approach to the development of maturity models. Thus, a comparison of the design processes of maturity models suggested by several researchers results in a suitable choice for a development procedure.

Becker et al. (2009) suggests a procedure model based on designing science research guidelines (i.e. by Hevner, March, Park, & Ram (2004)) and compares information technology management maturity models as a basis for this model. From another application field, i.e. the field of new product development (NPD), Moultrie et al. (2007) discuss the design of an audit tool for small and medium-enterprises (SMEs). Moultrie et al. (2007) compares the different approaches for auditing processes. Maier et al. (2012) review existing maturity grids to provide a common reference point and suggest parameters for development of maturity grids. In the article by De Bruin et al. (2005) a generic framework is built applicable to a wide range of domains.

The guiding models for development of maturity models as presented above, all have their strengths and have roughly the same backbone and intention. Thus, for the development of a maturity model a more general mixture between the four procedures will be used. In the next section the generic procedure steps will be discussed.

Table 6 – Comparison methodological choices development procedures of maturity models.

	Becker et al., 2009	Moultrie et al., 2007	Maier et al., 2012	De Bruin et al., 2005
Aim	Propose a generic procedural model for the design of maturity models.	The development of a design audit tool that aimed to raise awareness of the importance of good design issues and to encourage improvement in practices.	Review existing maturity grids to provide a roadmap as reference point and guidance for developing maturity grids.	Presenting model development framework (i.e. generic method) applicable across a range of domains.
Context/domain	IT management	New product development (NPD) SME's	Intended for practitioners in industry and academic researchers concerned with process improvement, intervention, and change management in organizations	Knowledge management and for business process management (cross-domain).
Method	Design science method by Hevner et al. (2004).	Combination of design research and procedural action research	Design science	-
Proposed procedure steps/phases	1. Problem definition. 2. Comparison of existing maturity models. 3. Determination of development strategy. 4. Iterative maturity model development 5. Conception of transfer and evaluation. 6. Implementation of transfer media. 7. Evaluation. 8. Rejection of maturity model.	1. Exploratory study 2. Tool creation and feasibility (iterative). 3. Tool development (iterative). 4. Validation	1. Planning (Specify audience, Define aim, Clarify scope, Define success criteria) 2. Development (Select process areas, Select maturity levels, Formulate cell text, Define administration mechanism) 3. Evaluation (Validate, Verify) 4. Maintenance (Check benchmark, Maintain results database, Document and communicate development process and results)	1. Scope. 2. Design. 3. Populate 4. Test. 5. Deploy. 6. Maintain
Validation	Comparison of 6 maturity models from which a generic applicable model for development of maturity models was constructed. Illustration by development of a maturity model for IT Performance Measurement Maturity Model (ITPM).	Literature review. Exploratory, feasibility, development and validation cases (26 cases total).	Interviews of experts. Authors own experience. Reviewing 24 maturity grids. Illustration of development of a grid in communication management in engineering design	Illustrated with two examples: Business Process Management Maturity (BPMM) model and the Knowledge Management Capability Assessment (KMCA) model.
Contribution	Provides a manual for the theoretically founded development and evaluation of maturity models.	A model of good design, design audit tool.	It provides the parameters within which professional development of a maturity grid can occur.	With this framework one has the ability to develop a model that is highly generalisability and enables standardization.

Table 7 – Conclusion procedure steps development maturity model.

	1	2	3	4	5	6	7	8
Becker et al., 2009	Problem definition	Comparison of existing maturity models	Determination of development strategy	Iterative maturity model development	Conception of transfer and evaluation	Implementation of transfer media	Evaluation	Rejection of maturity model
Moultrie et al., 2007	Exploratory study	Tool creation and feasibility (iterative).	Tool development (iterative).	Validation				
Maier et al., 2012	Planning	Development	Evaluation	Maintenance				
De Bruin et al., 2005	Scope	Design	Postulate	Test	Deploy	Maintain		
Conclusion	Exploratory	Development	Validation	Implementation/maintenance				

2.3.4 Conclusion procedure model for developing maturity models

The procedure model for developing a maturity model is structured by four development models as discussed in the previous section. In order to develop a more generic procedure for the development of a maturity model, the researcher combined the four procedures of the articles as shown in Table 6. In order to visualize the procedure steps/phases of the four procedures, an overview is given in Table 7. There is variation in the number of steps/phases per procedure, as can be seen in the overview. However, when combining similar steps/phases of the procedures, one could observe a structure with the same steps/phases. In grey the exploratory phase is shown, which beholds the first phase such as defining scope and criteria (e.g. capability, items, success factors) and comparing of existing material (e.g. maturity models for an application domain). Next, in yellow, the initial development phases follow in which a iterative procedure is applied. The test phase is shown in green in which the tool is validated in practice. Lastly, the phase where the tool is implemented and maintenance is applied is shown in blue. The combination of the phases of the four articles, therefore, gives a generic procedure merged with influences of the four articles.

The generic procedure model starts with the first phase which is the exploratory study. This beholds defining the problem, target group and domain, and the problem relevance i.e. the actual demand for the maturity model. The business problem and demand is that Company X needs a domain and target group specific assessment tool (i.e. Industry 4.0 for the FMCG industry) as it lacks one at the moment. This is followed by the comparison of existing maturity models within the domain. In Table 5, an overview and comparison of the existing maturity models for Industry 4.0 is presented. The next phase includes the determination of development strategy and the initial design (iterative procedure). The most important strategies are new model design, enhancement of an existing model, combination of multiple models into a new one or the transfer of structures and content to new application domains. In this research the development strategy is based on an existing model i.e. the Industry 4.0 maturity model by Schumacher et al. (2019), since the model was thoroughly tested in practice and improved, the manufacturing domain affiliates with the FMCG industry (BCG, 2019; KPMG, 2016), and the dimensions and items used comprise the Industry 4.0 concept.

Following the generic procedure, the central phase of the procedure model is the iterative maturity model development which means it has to be an iterative design process. The validation phase is discussed following the development phase. In this phase the tool is validated through testing in practice via Alpha and Beta testing. Next, the implementation/maintenance phase makes sure the maturity model is accessible for the user group i.e. Company X, and kept up to date. This research focusses on how to design an assessment tool, the implementation and maintenance phase will therefore not be discussed.

3. Method

This section describes in detail how the research was conducted. First, the research approach and design is explained. Next, the materials that were used, the procedure followed in this research, and the participants that were involved, are described. Lastly, the validity and reliability are discussed.

3.1 Research approach and design

The research approach and design for this research is based on design science (Simon, 1996). The design science approach aims both to develop knowledge to design interventions to solve business (e.g. improvement) problems and to design innovative artifacts such as systems, constructs, models, methods and instantiations to solve construction problems (Denyer, Tranfield, & Van Aken, 2008; March & Smith, 1995). Maturity models tend to be in-between the artifact types models and methods, given that they combine state descriptions with improvement activities (Mettler & Rohner, 2009). Assessment tools or maturity models, therefore, can be understood as artifacts which serve to solve the problems of determining a company's as-it-is state of its Industry 4.0 capabilities and deriving measures for improvement (Becker et al., 2009).

In order to structure the design science approach, the regulative model cycle by Van Aken, Berends, & Van der Bij (2007) is applied. The regulative model cycle has as main goal to test whether a proposed solution is capable of solving the business problem. It consists out of five steps, i.e., (i) problem definition, (ii) diagnosis, (iii) design, (iv) intervention, and (v) evaluation. These steps are scientific controlled actions (i.e. design) to derive a working prototype as a conclusion (Van Aken et al., 2007). As the aim of this research is to find a practical solution for the business problem defined at Company X, the problem solving cycle (i.e. regulative cycle) is the right fit.

For the third step of the regulative model cycle, i.e. the design step, Denyer, Tranfield, & Van Aken (2008) and Van Aken et al. (2007) suggest to use design propositions formed by field tested and grounded theory rules following 'CIMO-logic'. Instead of applying design propositions in the design step, this research uses the design requirements of the procedure model for development of maturity models as discussed in section 2.3. According to Becker et al. (2009), the development of maturity models falls within the application area for the design science research guidelines. In order to establish this procedure model, the author used the design science research guidelines by Hevner et al. (2004) as the basis for the set of design requirements. Both the regulative model cycle and the procedure model are combined in the research design as shown in Figure 2.

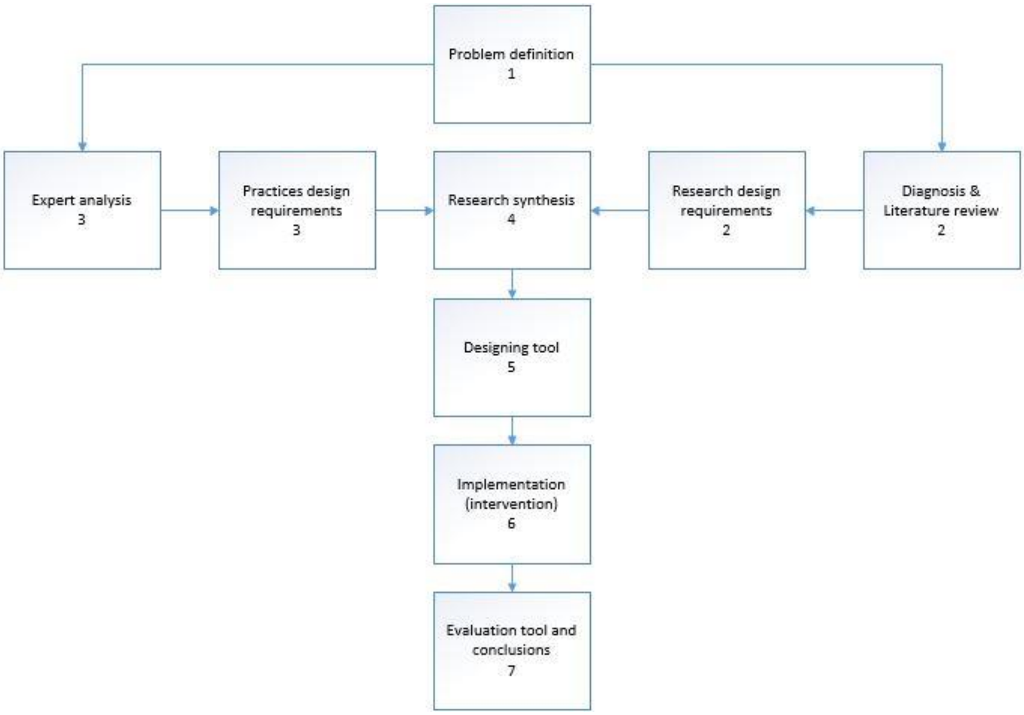

Figure 2 – Research design.

The goal of this research is to design a science and practice based framework that is used as a supportive tool for assessing the maturity of Industry 4.0 for FMCG companies. In order to facilitate that goal, academic and practice knowledge is required (steps 2 and 3 in the research design, Figure 2). Via literature review and empirical data from experts, practice and research design requirements were synthesised to form an initial design of the assessment tool (step 4 in the research design, Figure 2).

For the initial design, a procedure model based on maturity development literature as discussed in section 2.3 was used. There is an overlap with the regulative model cycle for the first step i.e. problem definition, and the evaluation steps i.e. implementation and evaluation at the end of the procedure model. Therefore the overlap steps were discarded as these steps were already executed. From there, first, the comparison of existing maturity models was followed by the determination of the design strategy. The two basic strategies are designing a new model or enhancement of an existing model. In the iterative maturity model development phase, several sub-steps follow an iterative approach. Once the maturity model is designed, the conception of transfer and evaluation was chosen.

To follow the regulative model cycle again, the initial design was tested and validated by means of alpha- and beta-testing (steps 5 and 6 in the research design, Figure 2). This testing and validating was an iterative process. The alpha-testing led to usable feedback to improve the initial design of the tool and validated partially the initial design of the tool. Next, the beta-tests were conducted in practice with two companies to gain more feedback and improve the final design of the tool.

3.2 Materials

To store articles and support referencing, the free reference manager Mendeley was used in this research. For designing the assessment tool, Microsoft Excel was used and Company X internal documentation (i.e. rating sheet tool for 'Industry 3.0'). Further, to record the interviews, the mobile phone of the author was used. Atlas.ti software was used to code and analyse the interview data, and measure intercoder reliability. The transcripts and reports from the interviews, brainstorm session, focus group, and the tests at Company Alpha and Company Delta are confidential and are available upon request with the author.

For the first two steps of the research design (Figure 2), i.e. the problem definition and diagnosis and literature review, a literature study was conducted. The scope of the literature study was set to gather sources in the literature on Industry 4.0, assessment tools and the Industry 4.0 implications for the FMCG industry. To execute the literature study, search strings were used in the databases Google Scholar, Web of Science, and Google to search for white papers and reports by consultancy firms (i.e. practice-based literature). Also the database of Company X was consulted. The following search terms were used: Industry 4.0, assessment tool, maturity model, Industry 4.0 AND FMCG, Industry 4.0 AND consumer goods industry, Industry 4.0 AND FMCG industry, Industry 4.0 AND assessment tool, Industry 4.0 AND maturity model. The results of the search commands were observed on relevance and from which journal (e.g. impact factor from Journal Citation Reports database was considered, but due to the immature research field of the topic, relevance of the article was priority). If applicable, the article was stored, coded and sorted on subject in the author' Mendeley database. In addition, the snowball method by Wohlin (2014) was used to look for citations and references of the selected articles to search for new articles.

3.3 Procedure

In order to achieve a more sound overview of the procedure, the research design distinguishes three phases, as shown in Figure 3. Phase 1 is the science- and practice-based knowledge (exploratory) phase in which the collection of qualitative data was used for the initial design. In phase 2 and 3, the tool development through alpha-testing and the validation of the tool through beta-testing were conducted.

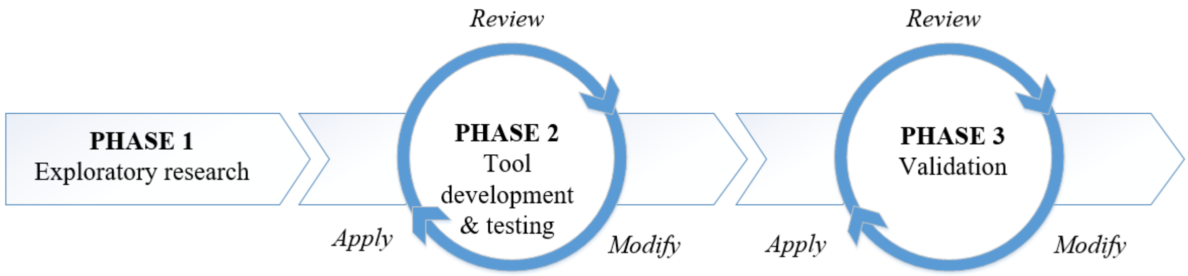

Figure 3 – Research process per phases.

In phase 1 of the research, in order to gain a better insight into the needs and requirements for an Industry 4.0 assessment tool relevant for the FMCG industry, semi-structured interviews and a brainstorm session were conducted with seven experts from Company X. The semi-structured interviews were applied as this part of the research is mostly exploratory and semi-structured interviews fit best in that situation (Sekaran & Bougie, 2016; Yin, 2015). The four interviews were conducted in the offices of Company X and via skype (two skype calls because consultants work/live in foreign country) to enhance comfort, which offers less biased responses (Sekaran & Bougie, 2016), and lasted all around 30 minutes. Answers were recorded with a mobile phone and the transcripts were anonymized. Moreover, the transcripts were sent to the interviewee for validating purposes. The interview format, as can be seen in Appendix A, follows a funnelling technique (e.g. from broad to specific questions) and focusses on minimizing biased questions (Sekaran & Bougie, 2016). This means it started with a couple of introduction questions to break the ice and to extract the relevant work experience, followed by more specific question regarding assessments, FMCG industry and Industry 4.0, in order to gradually focus on the relevant data regarding the topic.

The data collected with the interviews is analysed in the thematic analysis form based on a template approach (Miles, Huberman, & Saldaña, 2014; Sekaran & Bougie, 2016). This template approach involves analysing the data with preconceived themes (i.e. labels) gathered from the theory in Section 2, as the goal is to validate or prove the theory with the practice i.e. the qualitative data collected at Company X. With these labels the transcripts from the interviews were coded. Next, a coding scheme was constructed, see Appendix B. The second coder used this coding scheme as well. With the result from the coding it was possible to measure the intercoder reliability (Neuendorf, 2002). The non-agreement cases (x=0.288) were discussed and consensus was found for those cases. For the code scheme, every label was defined to better understand the data. In the results section the labels are used to analyse the data i.e. how often do the labels come up and what do they mean in relation to the theory.

For the brainstorm session was chosen, because the participants from different backgrounds could discuss the topic to offer more ideas and reach consensus. In the brainstorm session with three experts from Company X, observations were conducted by note-taking, and lasted approximately 30 minutes. The session was semi-structured and started with an introduction on the topic, and by the researcher and the participants that were present. Goal of this session was to discuss the Industry 4.0 topic in relation to the design of an assessment tool for the FMCG industry. After the fourth interview and the brainstorm session the researcher noticed that theoretical saturation (e.g. no new information about the subject emerges) was reached, because there were no new insights and information gained (Sekaran & Bougie, 2016).

In phase 2 of the research, the qualitative data was collected through a focus group and three semi-structured interviews. The focus group involved discussing the concept version assessment tool and rating of the maturity items by the six experts, in order to gain insight into the relevance of the FMCG industry maturity items. First, an introduction on the concept assessment tool was given, whereafter through discussion thereby reaching consensus the maturity items were rated on printed lists. The rating sheet had three options (i.e. ratings) per item: not relevant (red), doubtful (orange), relevant (green) (see Appendix C for the rating sheet used). At the end of the session, the results were evaluated. The focus group was recorded by taking notes by an observer and the researcher, and lasted approximately 45 minutes. After the focus group, three semi-structured interviews with Company X consultants were conducted. The goal of these interviews was to gain constructive feedback on the initial design of the assessment tool. Therefore, the interviews were in a semi-structured format addressing the usability, utility (i.e. functionality and usefulness) and output of the assessment tool (Maier et al., 2012; Moultrie et al., 2007).

For phase 3, one FMCG company and one manufacturing company were selected for the beta-testing of the assessment tool. In order to enhance validity of the results a case study protocol was designed (see Appendix D) for conducting the beta-testing (Yin, 2003). The selection was done on terms of availability and openness to participate, due to time constraints of this research it was not possible to involve more company cases (e.g. availability of possible companies in the test period). Both company visits lasted for two hours and involved an introduction followed by filling in of the assessment tool by a Company X consultant, the researcher and representatives of Company Alpha and Company Delta, and ended with discussing and evaluating the results generated. The recording of the tests was conducted through observations and note-taking. During both beta-tests, an observer was present for observations and note-taking. Feedback from the company representatives and the results from the assessment, were used to improve the final design of the assessment tool.

3.4 Participants

In this research a total of 15 unique experts from Company X and two companies in the manufacturing industry and FMCG industry (Company Alpha and Company Delta) participated. The Company X experts were selected internally on basis of their expertise in the FMCG industry and Industry 4.0. The FMCG companies were selected for their willingness to participate in the test case of the assessment tool, possibility to access the fabric, and categorization as a manufacturing company with the preference and priority of a company in the FMCG industry. In Table 8 an overview is given with the participants per phase, information per participant, and the type of data collection that was used. Phase 1 is the science and practice based knowledge phase in which the collection of qualitative data was used for synthesis and the initial design. In Phase 2 and 3, the alpha- and beta-testing were conducted.

Table 8 – Overview participants research

Phase 1 Participants	**Information**	**Data collection form**
FMCG Business Case Consultant	>25 year experience in FMCG industry	Semi-structured interview
Consultant digital solutions	10 year experience in FMCG industry	Semi-structured interview
Business Development Director	8 year experience in optimisation projects relating to Industry 4.0 in manufacturing industry	Semi-structured interview
Director Advisory Group	10 year experience in consultancy with focus on smart solutions for manufacturing	Semi-structured interview
IoT business consultant	<10 year experience in IoT domain	Brainstorm session
Director smart solutions	<15 year experience in smart solutions for manufacturing industry	Brainstorm session
Business development director	<20 year experience in business development for Company X	Brainstorm session
Phase 2 participants		
Business case consultant	<10 year experience in FMCG industry	Focus group – Alpha-test
FMCG business case consultant	>25 year experience in FMCG industry	Focus group – Alpha-test
FMCG business case consultant	<10 year experience in FMCG industry	Focus group – Alpha-test
FMCG consultant	<10 year experience in FMCG industry	Focus group – Alpha-test
Business case consultant	<10 year experience in FMCG industry	Focus group – Alpha-test
FMCG business case consultant	<10 year experience in FMCG industry	Focus group – Alpha-test
Business development and project management consultant	<15 year experience in business development projects and consultancy	Semi-structured interview – Alpha-test
Business model and digital business innovation consultant	<10 year experience in business development projects and consultancy	Semi-structured interview – Alpha-test
Business Development Associate director	<25 year experience in manufacturing industry and business development	Semi-structured interview – Alpha-test
Phase 3 participants		
Company Alpha	Develops and manufactures B2B and B2C products. Focus on innovation in their fabric and is market leader in their segment.	Beta-test case
Company Delta	Produces FMCG for the B2C and B2B market. Market leader and has multiple factories.	Beta-test case

3.5 Validity and reliability

To ensure the quality criteria for this research, validity and reliability methods were used. First, the reliability is described followed by the validity. Reliability refers to the consistency of the operations of a study, such that the data collection procedures can be repeated, with the same results. The goal of reliability is to minimize the errors and biases (Sekaran & Bougie, 2016; Yin, 2003). For this research multiple techniques were applied to reduce the biases and influences from the interpretation of the researcher.

First, the semi-structured interviews were applied for their exploratory approach, and the questions follow a funnel approach from general to more specific on the topic to minimize the biases (see Appendix A for the interview format) (Yin, 2015). For the coding of the transcripts from the interviews, the inter coder reliability was measured. The intercoder reliability is, according to Neuendorf (2002), important for two reasons: to provide basic validation of a coding scheme, and for the practical advantage of using multiple coders. Krippendorff (2004) stated that the acceptance level of data with reliability values below x=0.667 should not be accepted. In this research a second coder was involved with no experience in the domain, but works as a researcher, thus has the right professional skills for coding. The intercoder reliability of the four semi-structured interviews was x=0.712 and therefore the data was accepted as reliable. For the x=0.288 non agreement, the first and second coder had discussion and found agreement for those cases.

Second, in order to obtain the same results and increase the reliability, an independent observer was present for note-taking and observations during the brainstorm session, the focus group, and the beta-test cases. Afterwards, the observer and the researcher evaluated and discussed the notes and observation to reach consensus (Yin, 2015).

Validity refers to the extent to which the research results accurately represent the collected data and can be generalized to other domains (Sekaran & Bougie, 2016; Yin, 2015). The validity of the research was improved through triangulation by the use of multiple instruments i.e. documents, interviews (semi- and semi-structured), observations (focus group, brainstorm) and cases (testing in practice) (Yin, 2003). The iterative procedure that was applied with the alpha- and beta-tests enhances the validity of this research. Two company beta-test cases represent a small sample of which one case (Company Alpha) is a manufacturing company and the other case is a company acting in the FMCG industry. Although it can be seen as a weakness, it can also be a strength. Because, according to Sekaran & Bougie (2016), the deviant case adds to the validity of this research, as it provides a strong test for the theory. For the cases a case study protocol (see Appendix D) was designed to enhance the validity (Yin, 2003). Moreover, the generalizability of this research is constrained to the FMCG industry (Sekaran & Bougie, 2016; Van Aken et al., 2007).

4. Results

In this chapter the results from the data collection and the empirical analysis are discussed. First, the Company X expert data analysis is described. Then the initial design of the assessment tool is described. Through an iterative process, the initial design is alpha-tested and discussed. Next, the design is tested and evaluated through a beta-test (case study). Lastly, the final solution design of the assessment tool is presented.

4.1 Expert data analysis

In this section the qualitative data that was collected through semi-structured interviews and brainstorm session with experts from Company X will be discussed and analysed. The semi-structured interviews resulted in four conclusions that can be drawn from experts working in the field. These conclusions formed the base of necessity on building the tool, which will be discussed later.

The researcher started with establishing a common definition of Industry 4.0 between the experts and the researcher, somewhere at the beginning of the interviews and brainstorm session. It was no surprise that Industry 4.0 was defined in different ways by the experts. An interviewee (FMCG Business Case Consultant) said "well for me I think it means, creating visibility throughout your supply chain and applying intelligence to manage it". Another interviewee (Director Advisory Group) said "for me Industry 4.0 is utilizing information sources through connected devices" (i.e. cyber-physical systems). This variety in definitions is in line with the Industry 4.0 literature field in which no consensus exists on the definition of Industry 4.0. However, they almost all agreed upon what this interviewee (Consultant Digital Solutions) said "I think Industry 4.0 still is very much a buzzword, an umbrella term for so many different technologies and use cases". Thus, these definitions are similar in the core in such that it beholds an umbrella term for advanced technologies.

Assessments of factories are mostly done on basis of experience and most of the time without a standard format or tool. As most experts have their own way of working, a standard format is not always used for convenience reasons. An interviewee (FMCG Business Case Consultant) commented that "but to be honest a lot of it you just go round and it's typical sort assessment methodology. Go round and you know kind of what you're looking for without it necessarily being codified (i.e. in a tool)". Moreover, it also depends on what the client asks for in an assessment, for example the output on quality improvement or as-it-is state of factory (Business Development Director). Nevertheless, the experts agreed that not using a standard format or a tool increases subjectivity when assessing. A benefit of using an assessment tool is, according to an interviewee (Director Advisory Group), "the advantage of benchmarking is that you can compare performance of your clients and be able to structure and manage new improvements". This is agreed upon by the experts in the brainstorm session, as they found that with the collection of the data from the tool, a powerful database for benchmarking could be build. Therefore, assessment tools are useful for benchmarking and to gain structure in assessing a factory. An assessment tool can additionally improve objectivity when assessing.

The experts value the idea of a roadmap and vision for Industry 4.0 activities of a company, confirming the literature on this topic (Mettler, 2011). An interviewee (FMCG Business Case Consultant) commented about this matter "the implementation strategy (i.e. roadmap) around this is important. Don't provide something (i.e. implementation Industry 4.0 technology) unless you know how you are going to use it otherwise it won't work. Therefore you need a roadmap to tackle these kind of problems". The value of a roadmap was agreed upon by the experts in the brainstorm session, they concluded that an assessment tool is a helpful start of what can be a roadmap to a vision regarding Industry 4.0 implementation in a factory. However, not all companies lack knowledge on Industry 4.0 (FMCG Business Case Consultant), since some companies in the industry do have knowledge on Industry 4.0 and are developing vision and roadmap for Industry 4.0. In any case, the experts agree upon that an assessment tool is a first start and helpful tool for developing a roadmap and vision for Industry 4.0 regardless of the amount of knowledge already available in the company.

Following the conclusion on the necessity of a roadmap, the experts value the argument for a tailored version of an assessment tool, confirming literature (Mettler, 2011; Moultrie et al., 2015). With such an assessment tool you have to work on a more specific level to find the answer behind the client their question regarding the Industry 4.0 implementation topic (Business Development Director). When answering a specific question regarding Industry 4.0, a more tailored version of an assessment tool could be able to fully help the client in their specific industry (e.g. FMCG industry). Although, various assessment tools exist, the brainstorm session experts agree that a tailored version could be helpful in the FMCG industry to better serve the client with their question on the topic. Moreover, the Industry 4.0 implications for FMCG industry are that some of these FMCG companies lack behind in technological advancements of their value chain, due to the low pressure from the market to innovate (FMCG Business Case Consultant). It results in a wakeup call followed by a lot of questions regarding Industry 4.0 and action to develop a roadmap.

With these results it is confirmed that in practice the value for a tailored assessment tool i.e. for a certain application domain as the FMCG Industry, is necessary. Moreover, this assessment tool could contribute to be part of a roadmap or vision on Industry 4.0 action plans.

4.2 Initial design

In this section the initial design is discussed. First, the design requirements are presented in section 4.2.1. These design requirements are derived and synthesised from the theoretical analysis and expert analysis as discussed above. The design requirements consist out of functional requirements, user requirements, boundary conditions, and design restrictions. To conclude this section, the initial design of the Industry 4.0 assessment tool will be described.

4.2.1 Design requirements

To transform the maturity model into an assessment tool, a programme of design requirements was constructed (Van Aken et al., 2007). This programme of design requirements is part of the development phase of the maturity model procedure. The functional requirements, user requirements, boundary conditions, and design restrictions are formed to structure the initial design.

Functional requirements

1. The tool should support Company X in assessing the Industry 4.0 maturity of manufacturing companies with the focus on FMCG companies.
2. The tool should provide output, which is a maturity score with a current and target score per dimension and visualized scores in a chart.
3. The tool should provide information on the current and target state regarding Industry 4.0 maturity of the company to be assessed.

User requirements

4. The tool should be easy to use. This means that it is simple to navigate through the tabs, simple to fill in the scores, and simple to obtain and read the maturity scores i.e. the output.
5. The tool should be easy to understand. This means that there should be information on how to use and operate the tool.
6. The tool should be clear on what the purpose is. The user i.e. the Company X expert and the client have to understand the purpose of the tool.

Boundary conditions

7. The tool should be applicable and relevant for the manufacturing industry focussing on the FMCG industry.

8. The maturity grid of the tool should be descriptive to minimize the subjectivity when scoring.
9. The tool should be available for Company X internal use only.
10. The tool should be informative on the Industry 4.0 concept.
11. The maturity dimensions and items should cover the whole Industry 4.0 spectrum.
12. The tool should contain assessment questions and descriptions to guide the assessment of a company.

Design restrictions

13. The tool should be constructed in Word Excel.

4.2.2. Design Industry 4.0 assessment tool

In this section the initial design of the assessment tool is described. First, general information about the design is given. Followed by a more in-depth explanation of the parts (i.e. tab titles in the tool) that structure the assessment tool i.e. List (overview dimensions and maturity items), Weighted factor, Assessment and Scoring.

In line with the design requirements an initial design of the Industry 4.0 assessment tool for FMCG industry is developed. For the design of the assessment tool, the initial design builds on existing maturity models, as can be seen in section 2.3.1, several maturity models were compared. The maturity model by Schumacher et al. (2019) was selected as useful for the basis of the initial design. Dimensions and maturity items (i.e. capabilities) were adopted from several articles to build an assessment tool for FMCG industry. With the assessment questions and maturity grid/levels a current and target score per item can be obtained which is visualized in a output chart. With the assessment tool it is possible to assess the Industry 4.0 maturity (current and target state) of a FMCG company, which helps to form strategic action plans and a vision regarding Industry 4.0.

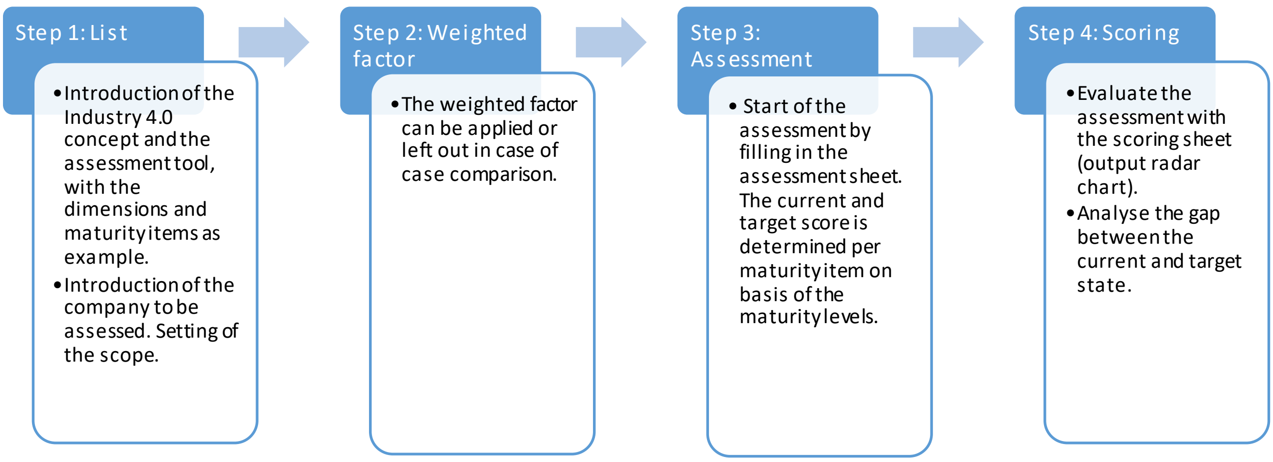

Figure 4 – Roadmap process Industry 4.0 assessment tool.

The Industry 4.0 assessment tool is a collection of Industry 4.0 maturity dimensions, items (i.e. capabilities), assessment descriptions/questions, maturity grid/levels, and output visuals regarding assessment of Industry 4.0 maturity of a FMCG company. It supports assessments of FMCG companies regarding the Industry 4.0 current and target state. The initial design of the Industry 4.0 assessment tool is a four page (i.e. four worksheets) Excel workbook that is structured with four tabs. As can be seen, in Figure 4 a roadmap of the process of the assessment tool with the four tabs is shown. This roadmap shows process of the assessment tool. In Appendix E the initial design of the assessment tool is presented.

Dimension	Technology	
	No.	Maturity items
	1	Technology for information exchange
	2	Utilization of cloud technology
	3	Mobile devices on shop floor
	4	Decentral information storage
	5	Sensors for data collection
	6	Integrated computers in machines
	7	Integrated computers in tools
	8	Additive manufacturing
	9	Utilization of robots

Products	
No.	Maturity items
1	Product individualization
2	Flexibility of product characteristics
3	Collection of product-use-information
4	Data processing components in products
5	Internet connection of products
6	Digital compatibility and interoperability of products
7	IT-services related to physical products

Customers & Suppliers	
No.	Maturity items
1	Openness to new technology
2	Competence with modern ICT
3	Digitalization of customer contact
4	Customer integration in product development
5	Utilization of customer related data
6	IT-collaboration for product development
7	Digital contact with company suppliers
8	Company suppliers degree of digitalization dimension

Dimension	Value creation processes	
	No.	Maturity items
	1	Process automation
	2	Autonomy of machine park
	3	Information exchange between machines
	4	Remote control of machine park
	5	Automated quality control
	6	Databased machine maintenance
	7	Automation object handling
	8	Collaboration of humans and robots

Data & Information	
No.	Maturity items
1	Digital information processes
2	Automated data collection
3	Analysis of collected data
4	Databased decision making
5	Automated information provision
6	Individualization of provided information
7	Digital process visualization
8	Data-driven software-simulation of future scenarios

Corporate standards	
No.	Maturity items
1	Monitoring of Industry 4.0 realization
2	Recruitment for Industry 4.0
3	Adjustments of works arrangements
4	Employee trainings for digital competences
5	Legal protection for digital products and services
6	Increased cyber security
7	Rules for employees in digital work environment
8	Technological standards

Figure 5 – List page (Snippet).

List (dimensions and maturity items) tab

The first page of the initial design of the assessment tool, as shown in Figure 5, contains the list with Industry 4.0 dimensions and maturity items (capabilities). These eight dimensions and sixty-five maturity items form the backbone of this assessment tool. This List page gives the user an overview of Industry 4.0 dimensions and maturity items. In this way the user can inform the client on the broad application of the Industry 4.0 concept translated in dimensions and maturity items.

Weighted factor tab

In Figure 6 the weighted factor page is shown which is the second page of the assessment tool. The weighted factor page contains all the dimensions and maturity items as seen in Figure 5, but with an option to include a weighted factor between 1 – 5 per maturity item. The importance is measured on a Likert-scale reaching from 1='not important' to 5=very important. With a drop-down menu in excel the score range is set between 1-5. This weighted factor option provides the user with the possibility to tweak the maturity items as some might contribute more to a specific company. However, when this option is used benchmarking is no longer valid, as it provides a unique scale to the maturity score of the specific company. This argument should be considered in the testing phase.

Dimension	Technology		
	No.	Maturity items	Weighted factor
	1	Technology for information exchange	
	2	Utilization of cloud technology	
	3	Mobile devices on shop floor	
	4	Decentral information storage	
	5	Sensors for data collection	
	6	Integrated computers in machines	
	7	Integrated computers in tools	
	8	Additive manufacturing	
	9	Utilization of robots	

Products		
No.	Maturity items	Weighted factor
1	Product individualization	
2	Flexibility of product characteristics	
3	Collection of product-use-information	
4	Data processing components in products	
5	Internet connection of products	
6	Digital compatibility and interoperability of products	
7	IT-services related to physical products	

Customers & Suppliers		
No.	Maturity items	Weighted factor
1	Openness to new technology	
2	Competence with modern ICT	
3	Digitalization of customer contact	
4	Customer integration in product development	
5	Utilization of customer related data	
6	IT-collaboration for product development	
7	Digital contact with company partners	
8	Company partner's degree of digitalization dimension	

Dimension	Value creation processes		
	No.	Maturity items	Weighted factor
	1	VC-Process automation	
	2	Autonomy of machine park	
	3	Information exchange between machines	
	4	Remote control of machine park	
	5	Automated quality control	
	6	Databased machine maintenance	
	7	Automation object handling	
	8	Collaboration of humans and robots	

Data & Information		
No.	Maturity items	Weighted factor
1	Digital information processes	
2	Automated data collection	
3	Analysis of collected data	
4	Databased decision making	
5	Automated information provision	
6	Individualization of provided information	
7	Digital process visualization	
8	Data-driven software-simulation of future scenarios	

Corporate standards		
No.	Maturity items	Weighted factor
1	Monitoring of Industry 4.0 realization	
2	Recruitment for Industry 4.0	
3	Adjustments of works arrangements	
4	Employee trainings for digital competences	
5	Legal protection for digital products and services	
6	Increased cyber security	
7	Rules for employees in digital work environment	
8	Technological standards	

Figure 6 – Weighted factor page (Snippet).

No	Dimension - Technology			Maturity level							Explanation/comments?
	Maturity item	Description	Assessment question	1	2	3	4	No answer	Current score	Target score	
1.1	Technology for information exchange	Wireless technology systems integrated in the process (Radio-frequency identification (RFID), 5G).	To what extend are wireless technology systems integrated in the supply chain processess?	No wireless technology systems in use	Initial projects for wireless technology systems are plannend. Supply chain has basic wireless systems	Multiple projects for wireless technolgy are plannend. Some wireless technology systems are	Fully integrated wireless technologies are integrated in the process				
1.2	Utilization of cloud technology	Software and hardware are available and integrated in the cloud	To what extend do you use cloud technology?	Cloud solutions not in use	Initial solutions planned for cloud-based software, data storage and	Pilot solutions implemented in some areas of the business	Multiple solutions implemented across the business				
1.3	Mobile devices on shop floor	Mobile devices increase efficiency on the shop floor due to the connectivity	Do you have mobile devices on the shop floor or in the supply chain?	No mobile devices on the shop floor	Pilot project initiated for mobile devices on the shop floor	Some processes have mobile devices integrated	Whole shop floor has mobile devices integrated				

Figure 7 – Assessment page (Snippet).

Assessment tab

The assessment page, as partly shown in Figure 7, forms the main part of the assessment tool. On this page the maturity items (per dimensions) are described (description), guided with an assessment question, measured according a maturity grid with four levels with descriptions for maximum objectivity, and scored with a current and target score. The Company X expert and the company representative together discuss the current (as-it-is) and target (as-to-be) state score regarding the maturity items. Since the maturity items are supported by descriptive examples, scoring the maturity levels is made less subjective (Moultrie et al., 2007). When all the maturity items are scored, the output page (i.e. the scoring page) shows the overall maturity score per dimension between the current and target state.

Formula		
M	Maturity	Ma = (∑n, i=1 MDIi * GDIi) / ∑n, i=1 GDIi
D	Dimension	
I	Item	
G	Weighted factor	
n	Number of maturity item	

Overview

Current maturity	
No	Item score
M1	4
M2	2
M3	3
M4	3
M5	3
M6	4
M7	5
M8	2
M9	3

Target maturity	
No	Item score
M1	5
M2	3
M3	3
M4	4
M5	4
M6	4
M7	5
M8	3
M9	3

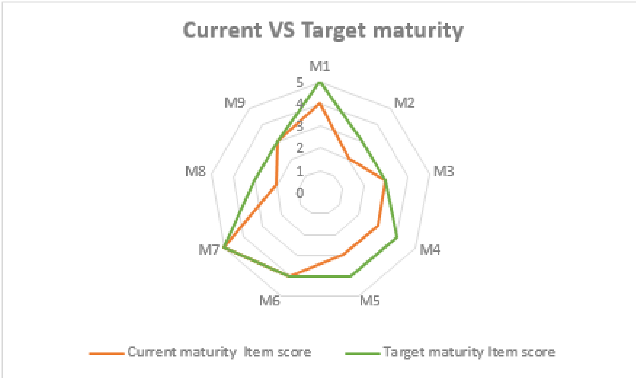

Figure 8 – Scoring page (Snippet).

Scoring tab

In Figure 8 the scoring page with the output of the assessment page i.e. the maturity score, is shown. When the current score and target score per maturity item is given via the guidance of an assessment question, the scoring page presents the score per dimension. In the radar chart the eight dimensions are presented, the differences between the dimensions become more visible. It helps the Company X expert to give a better view of the outcome of the maturity score. With the current and target maturity score, gaps per dimension can be visualized. This shows the difference between the current and target maturity state, enabling the possibility to start with strategic action plans for Industry 4.0 implementation.

4.3 Results and analysis of the Alpha-testing

In this section the four Alpha test iterations of the assessment tool are discussed. The first iteration was a focus group with Company X experts with relevant experience in the FMCG industry. Next, the second iteration was conducted by discussion (i.e. semi-structured interview) with Company X experts. Hereafter, the results and analysis of these iterations will be discussed.

First iteration: Focus group

In the focus group session six Company X experts with relevant experience in the FMCG industry participated. The structure was as follows: introduction, review of the assessment tools initial design, evaluation/end. The author of this research was session leader and made notes. An observer was also present for note-taking and observations. Goal of the session was to review the initial design according to the rating sheet (see Appendix C), and to evaluate the initial design. The review was guided by the assessing functions for usability, utility (i.e. functionality and usefulness) and on output from using the tool (Maier et al., 2012; Mettler, 2011; Moultrie et al., 2007).

The rating sheet of the maturity items involved three options: not relevant (red), doubtful (orange) and relevant (green). When the session was done, it was clear how many times the participants rated relevancy of the items. In the case of 17 out of 65 maturity items, at least one of the experts rated the item as 'not relevant' (red) or a maturity of the experts labelled the item as 'doubtful' (orange). When reviewing and rating, the experts were not unanimously about the relevancy of the items, as seen in Table 9 below. There was no item which was rated 'not relevant' by all six of the experts. The 17 items that had at least one 'not relevant' or a maturity of 'doubtful' rating are therefore discussed in Table 9 below, since disagreement about relevancy is interesting for forming the final set of maturity items for the assessment tool. A discussion about the ratings was initiated to reach consensus regarding the relevancy of the maturity items in Table 9 i.e. the items with a 'doubtful' or 'not relevant' rating. It is important to consider that the remaining 47 maturity items were not included in Table 9, since a maturity of the experts labelled these items as 'relevant' (green). It can be concluded that these 47 maturity items can be considered relevant.

When discussing the maturity items with a 'not relevant' or 'doubtful' rating, it became clear that some of the experts rated the maturity item considering their own experiences and views/knowledge based on Industry 4.0. The researcher issued a discussion on why one or more experts rated the item as 'not relevant' of 'doubtful'. It became clear that when provided more information and/or an example of that specific maturity item (e.g. capability) in a FMCG industry, the experts would rate the item as more relevant. It became clear that seeing the 'potential' for a company was somewhat challenging. The experts could not always imagine some of the items being relevant to measure, since these maturity items were not yet being used in the FMCG industry. For example, one of the experts mentioned "the FMCG industry is not that advanced yet (i.e. lacking behind), it is not yet being used and therefore this maturity item is not relevant".

Table 9 – Overview data focus group.

Maturity item	Rating			Discussion	Conclusion
Decentral information storage	2	2	2	It was discussed that some factories don't work in an online environment such as a "cloud". Since they don't work in a shared working space environment, decentral information storage is not considered very relevant. The experts mentioned that not working in an online working environment itself is "lacking behind" in innovative progress itself. When that hurdle would be taken, decentral information storage would be considered very relevant.	Relevant
Additive manufacturing	1	5	0	All experts agreed upon this item not being relevant, because "3D printing would not add to the FMCG supply chain characteristics as in case of an automobile manufacturer".	Not relevant
Openness to new technology	1	1	4	For this item consensus was reached very fast because they all agreed when one expert said that this item is a sort of basis for Industry 4.0 in every industry, and therefore relevant.	Relevant
Competence with modern ICT	1	1	4	This item had the same conclusion as 'openness to new technology', therefore it was considered relevant.	Relevant
Process automation	1	0	5	When an example was given, the one who rated not relevant agreed upon being very relevant.	Relevant
Autonomy of machine park	2	1	2	The machine park has to be autonomous at one point, this also affects the FMCG machine park, as said by one expert. The two experts that rated the item as not relevant thought this was a leap too far for the FMCG industry. In the end they agreed upon it being a necessity for Industry 4.0.	Relevant
Remote control of machine park	1	2	2	Was discussed with the item above.	Relevant
Automation object handling	2	2	2	The experts argued that this could be helpful in other segments, such as aviation of more advanced segments that rely on advanced technologies. For the FMCG industry, this advanced technical item "is not applicable to the FMCG industry".	Not relevant
Data-driven software-simulation of future scenarios	1	0	5	When asking why one expert found it not relevant, the expert said "FMCG is not this far yet, thus not relevant". But with an example and information the relevance of the item for FMCG became clear.	Relevant
Willingness to flexibilize work arrangements	2	0	4	After discussing this item, it was concluded that this item on itself is relevant, even though it is yet quite ordinary that employees work this way, but it does not contribute to the tool since there are enough items that cover "employee work ethics".	Not relevant
Autonomy of shop floor workers	1	0	5	Why should autonomy of shop floor workers fit Industry 4.0 as it is something for the current period of time? They all agreed upon that it fits with the total package for Industry 4.0 and for FMCG supply chain operations.	Relevant
Financial resources to realize Industry 4.0	0	4	2	This is a necessary part of the organization wide instruments to facilitate Industry 4.0, which became clear during the discussion.	Relevant
Product individualization	0	4	2	Innovative products are in the lift and this capability is necessary to facilitate that, was given as an example. Consensus was reached after this.	Relevant
Data processing components in products	1	2	3	This item is taken together with 'internet connection of products' and 'IT services related to physical products' to explain that these items form an essential element to reach the goal of innovative products.	Relevant
Internet connection of products	2	2	2	See data processing components in products.	Relevant
IT-services related to physical products	0	4	2	See data processing components in products	Relevant
Legal protection for digital products and services	1	1	4	It becomes more relevant for the FMCG industry to act upon legal protection as the industry sometimes lacks a little behind as mentioned by one expert. After this all the others agreed upon the relevance.	Relevant

Three maturity items were eventually excluded from the tool. ‘Additive manufacturing’, ‘automatic object handling’ and ‘willingness to flexibilize work arrangements’, were considered to be irrelevant. This finding is contrary to literature, since all maturity items which were discussed in Table 4 (section 2.2) were considered relevant for the FMCG industry. Nevertheless, the experts in the focus group could not find consensus agreeing about the relevance of these items. On the maturity items that were rated ‘doubtful’ of ‘not relevant’ beforehand (i.e. before the discussion), consensus on relevance was reached. Therefore, these maturity items were not excluded from the assessment tool.

During the evaluation, one of the experts gave feedback that the descriptions of the maturity items could be clearer when more examples were given. The rest of the experts agreed, since proposing more examples generates less discussion on the meaning of the item when assessing. All the experts agreed on the added value of such a researched assessment tool.

Second iteration: semi-structured interviews

In this section the three semi-structured interviews with their main message are discussed. In Table 10 the data from the interviews on basis of the three criteria is shown. It was not conducted as a group interview, the interviews were conducted separately. In this way, the interviewees could not affect each other’s opinion during the interview and the relevance of their conclusions are independent and endorsed by each other. The discussion with three Company X experts was mainly focussed on the process of assessing using the assessment tool, not so much about the content of the assessment tool. The lay out, content and process of assessing was evaluated by the Company X experts. When the ‘pilot’ of assessing the assessment tool with the Company X experts was conducted, it became clear that the tool was ready for the Beta-testing in practice with the clients. Some minor adjustments were made to the lay out and some assessment questions were rephrased.

Table 10 – Data interviews.

Interview	Usability	Utility	Output
Interview 1	The interviewee mentioned that the tool is clear and can be used without further clarification. One should have basic knowledge of the segment (FMCG and Industry 4.0).	The interviewee mentioned that when you use weighted factors, you lose objectivity when you want to use the tool for benchmarking purposes. It was suggested to exclude weighted factors.	The interviewee suggested that, for future use of the tool, a detailed action plan would be helpful as output of the tool.
Interview 2	The interviewee mentioned that you could consider using altered colours for people who are colour-blind.	The interviewee suggested that weighted factors contribute to the tool, but it would be necessary to set a standard weighted factor for the tool, instead of the possibility to alter the weighted factor for every company.	The interviewee mentioned that the output score are considered very clear. The radar chart really adds to the tool.
Interview 3	The interviewee commented that the tool is considered easy to use and clear in overview. It was considered very helpful that a drop down menu in Excel cell is used, to prevent wrong scores.	The interviewee mentioned that the descriptions for the maturity items should be more specific to prevent subjectivity in assessing. More elaborate descriptions would improve objectivity.	The interviewee found that the process of going through the assessment tool went smooth.

Overall, all experts concluded that the tool was sufficient for the next phase, which would be Beta-testing with clients. Additionally, the experts mentioned the following adjustments. The weighted factor is seen as valuable, but should not be used when you are using the assessment tool to build a database for benchmarking purposes. The descriptions should be more specific to improve objectivity. One expert mentioned using different colours for the tool.

On basis of this feedback, the following alterations were made. The weighted factor is still a part of the tool, but could be “hidden”. This feature was added to the tool, so that company X could use it, but it is not a standard option anymore. The descriptions were altered in a way that they are more specific to improve objectivity. Such as “Integrated computer tools that allow a decision maker to interact directly with computers in order to retrieve information useful for semi-structured and unstructured decisions.” was rephrased into “Integrated computer tools … and unstructured decisions. (Programmable logic controllers (PLC), Computer numerical controlled machine tools (CNC)). For example: 3D printer with computer software.”. The note about changing colours was taken into account and contrasted colours were used in the final design of the tool to enhance readability.

Even though the interview mainly focussed on the process of assessing, not so much about the content of the assessment tool, some content wise suggestions were mentioned. Specifically, all three interviewees found that none of the remaining 62 maturity items were seen as irrelevant, suggesting that the remaining maturity items are relevant.

4.4 Results and analysis of the Beta-testing

In this section the Beta-test results and analysis are discussed. This Beta-test was conducted at two companies, one FMCG company and one manufacturing company. The goal was to validate the assessment tool in practice and to evaluate the outcome of the assessment tool. In Table 11 the both company cases are introduced.

Table 11 – Company case introduction.

Case Company	Introduction	Sector	Staff
Company Delta	Company Delta is globally market leader in the production of synthetic turf fibres and components i.e. artificial grass surfaces for sports, leisure or landscaping.	Manufacturing industry	<1000
Company Echo	Company Echo main target is processing potatoes into frozen potato products and is now one of the world leading companies in frozen potato products.	FMCG industry	+/- 1500

The beta tests were structured and conducted according a case study protocol (see Appendix D) adapted and constructed from Sekaran & Bougie (2016) and Yin (2003). This case study protocol beholds in short: an observer is present in each case to provide independent feedback on the session, its content, and procedures to follow. Moreover, the assessment tool is tested and validated for three criteria.

- Outputs: Explicit and implicit outputs from using the tool, including completed worksheet and action plans, and improved awareness (Moultrie et al., 2007).
- Usability: The assessment tool is clear, unambiguous, and can be followed as described without clarification. This included establishing errors of omission or commission, as well as ensuring that the tool was appropriately structured and presented. In addition, the influence of the facilitator was evaluated through feedback from both participants and independent observation (Moultrie et al., 2007).
- Utility: To establish whether the assessment tool approach achieved the intended objectives, from both the company's and the researcher's perspective, and that the outputs were as a result of using the assessment tool (Moultrie et al., 2007).

The results of the two Beta-test were positive in the sense that both representatives of the companies were enthusiastic about the maturity score that was generated: "I must say, the score as output matches the actual maturity as I see it. Therefore, the tool is very accurate I think"

(Company Delta representative). Moreover, the representative of Company Echo mentioned something in the same direction, stating that: "the maturity score matches our current level on Industry 4.0, thus the tool is working and the assessment questions are accurate and the overview is okay". In Figure 9 two output scores after assessment of the two company cases (company Alpha and company Delta) during the beta-tests are shown. As can be seen in Figure 9, the output visualises gaps per dimension which is found to be very helpful for constructing strategic action plans and vision for reaching the intended target state. Both representatives were positively surprised by the way the gap between the current (as-it-is) and target (as-to-be) state was illustrated in the tool, since the opportunity gaps are made clear. This gives clear directions in what ways a company can alter their business operations to reach the target state.

Based on the results from testing the assessment tool and observations from the researcher and the observers, several observations were made. During the evaluation (after fulfilling the assessment), these observations were discussed. They are stated below.

- Extra examples per maturity items would be useful.
- When scoring the maturity levels, the guiding descriptive are sometimes too leading when filling in a score. This absolute level is a concern, since the guiding descriptions should be used as direction, not as a solid state. The Company X expert should emphasise this during filling in the assessment tool.
- Some adjustments on spelling and lay out are given such as the numbering of the dimensions in the assessment work sheet.
- The order of the dimensions in the radar chart is discussed and it is argued that the strategy and organisation dimension should be on top in the radar chart.
- The results from filling in the assessment tool are seen as accurate and as a good assessment on Industry 4.0 capabilities. With the output scores, it is easier to give advice on the roadmap and action plans for Industry 4.0 to clients.
- Maturity grid level 1 – 4 works well, since it gives discussion on the choice between the levels 2 and 3. This discussion enables to get as close as possible to the right fit of the maturity level.
- Add a dashboard worksheet to the tool with information such as time span, 'game rules' for setting boundaries when filling in the scores, standard information on the sheets and tabs in the tool.

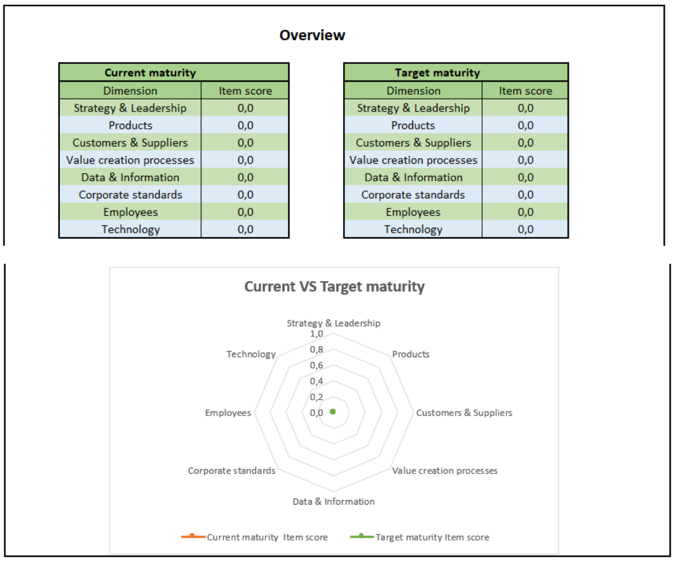

Figure 9 – Scoring page.

4.5 Final solution design

The final design of the assessment tool is discussed in this section. In Appendix F the final design of the assessment tool is presented. In Table 12 an overview of the adjustments is given. The biggest changes from the initial design are the exclusion of three maturity items, the add-in of the dashboard worksheet, changing the order of the dimensions in the scoring and the perspective of the organization when filling in the assessment tool. With the final solution design, the assessment tool is ready for usage.

Table 12 – Overview adjustments of the assessment tool pages per iteration.

Pages assessment tool → Iterations ↓	**Dashboard**	**List**	**Weighted factor**	**Assessment**	**Scoring**
Alpha test: First iteration (focus group)	X	Three maturity items are excluded from the tool.	X	X	X
Alpha test: Second iteration	X	Contrasting colours are proposed and altered on all the pages of the tool.	Weighted factor was considered useful, but could affect objectivity. Therefore it is proposed to be a hidden feature.	A more specific description of the maturity items is proposed to increase objectivity on the items.	X
Beta test: Company cases	A dashboard is added to the final assessment tool.	X	X	Adjustments on spelling and lay-out are made and changed.	The order of the dimensions in the radar chart was altered.

Table 12 shows the most important changes from the initial design. Most of the changes are already discussed in previous subchapters. One alteration that was proposed during the Beta-testing, will be discussed at this stage. Figure 10 shows the dashboard page that was introduced as part of the final design of the Industry 4.0 assessment tool. This dashboard was suggested as addition during the Beta-test, to set the scope and discuss the 'game rules' with the expert and the company representatives of the assessment tool.

For confidentiality reasons, not available here but in separate attachment.
Figure 10 – Dashboard page.

5. Conclusion and discussion

In this section the conclusions and discussion are described. First, in the conclusion section the answer on the main research question is presented. Next, the discussion of the theoretical and practical implications of this research are described. Lastly, the limitations and future research directions are presented.

5.1 Conclusion

In this section the conclusion of this research is presented. The answer on the main research question is given and explained. Further, the aim of this research was to design an Industry 4.0 assessment tool for the FMCG industry, which contains Industry 4.0 capabilities that are relevant for the FMCG industry. The result is a tangible Industry 4.0 assessment tool for the FMCG industry available in Microsoft Excel for internal use by Company X. This provides an answer to the main research question:

How can an assessment tool be designed to assess the FMCG industry on their Industry 4.0 capabilities?

The maturity of Industry 4.0 capabilities (i.e. the as-it-is state and target state) of companies in the manufacturing industry and FMCG industry can be assessed by Company X when a factory visit is conducted by means of a supportive assessment tool. With the Industry 4.0 assessment tool developed in this research Company X is able to conduct such an assessment in practice at their client factories. The attributes of the assessment tool exist out of a dashboard, a list with the dimensions and capabilities, the assessment model and scoring charts. In the assessment tool, Industry 4.0 relevant FCMG capabilities are categorized over eight dimensions: technology, products, customers & suppliers, data & information, corporate standards, employees, strategy & leadership.

The assessment tool will generate a score which can be used to fill in a report regarding the maturity score on Industry 4.0 capabilities of a company. The maturity grids with descriptions exist out of four levels designed per assessment item (i.e. capability). In this way the progress of maturity is best observed and most objective. For the scoring of maturity i.e. the current and target state, a radar chart is used for the best visualization. Consultants from Company X can use this supportive tool to give advice on a strategic roadmap and action plans for Industry 4.0 investments. The goal of this supportive tool is to be able to help clients of Company X with their questions regarding Industry 4.0 and in their search for Industry 4.0

strategic solutions. Moreover, the assessment tool makes it easier to build a database for benchmarking purposes. With such a database Company X will be able to compare results in the sector and advice their clients with more precision.

5.2 Theoretical implications

In this section the theoretical implications are described. Since this research analyses and compares various theories and fields i.e. maturity models, Industry 4.0 and FMCG implications, it contributes to literature. This research offers a contribution from a theoretical point of view to the literature of maturity models in general and specifically in relation to the FMCG industry and Industry 4.0.

First, this research adds to the literature by integrating the theory of Industry 4.0 capabilities and the literature field of maturity models applied to a specific industry (i.e. FMCG industry) which has not been researched yet. Both literature streams i.e. maturity models and Industry 4.0 capabilities are independent and not applied to FMCG industry in a combined matter. This combination and application is interesting and relevant due to the specific context the FMCG industry operates in, and hence follow different routes than other application domains. The maturity models theory focusses mainly on development procedures and on application domains such as (advanced) manufacturing, small and medium enterprises (SME) and new product development (NPD) (Frank et al., 2019; Moultrie et al., 2007). For the Industry 4.0 capabilities theory no specific application to FMCG industry is researched. In the current study, to create Industry 4.0 capabilities for the FMCG, these capabilities were checked on relevance for the FMCG industry. This resulted in Industry 4.0 capabilities which are relevant and suitable for the FMCG industry. In addition, the maturity models literature has been analysed to determine how it can be applied to a specific industry (i.e. FMCG industry), as an outcome a FMCG industry maturity model (i.e. assessment tool) was constructed. Various insights and perspectives of existing theories on maturity model development were analysed by discussing the similarities and differences between the existing maturity models and assessment tools. Since a FMCG industry assessment tool (i.e. maturity model) was not researched and developed yet, this assessment tool contributes to fitting the existing research gap. Additionally, it contributes to research directions suggested by academia to research and develop domain specific (i.e. customized) assessment tools (Becker et al., 2009; Mittal, Khan, et al., 2018; Schumacher et al., 2019).

Second, this research identified capabilities from the Industry 4.0 and FMCG implications literature that were translated into maturity items. These maturity items were incorporated in the maturity model with descriptions and guiding questions based on the research by Moultrie et al. (2007). The multi-methodological approach consisting of literature review, collection of qualitative data (i.e. expert analysis) and testing for validation, led to an integrated model based on different perspectives. Therefore, it adds to the existing literature as comprehensive overview on the Industry 4.0 maturity items relevant for the FMCG industry.

5.3 Managerial implications

In this section the managerial implications are discussed. This research offers a contribution from a managerial point of view, since this Industry 4.0 assessment tool which is fit for the FMCG industry, was applied and tested in practice. With this result Company X has a tangible assessment tool ready for usage, although some managerial implications must be considered.

First, the assessment tool generates a maturity report in which the maturity score is shown per dimension. With this maturity score the Company X experts are able to advise their FMCG clients on strategic action plans for Industry 4.0 investments in both the long term and the short term. Moreover, with the results of these assessments, Company X is able to generate data of all the assessments in one database for benchmarking purposes. Since the data from the assessments become more meaningful when the database is expanding, the value of benchmarking could be very high for Company X. In addition, the improvement of the maturity items (e.g. the descriptions and questions) on efficiency and relevance will be crucial to keep the assessment tool up-to-date.

Second, the goal of this research was to develop an Industry 4.0 assessment tool for the FMCG industry. Hence, there was no goal to develop an implementation plan for the assessment tool. For now the assessment tool has to be accepted by Company X and included in their process when assessing a production plant. Therefore, to ensure that the assessment tool has an impact, Company X should set up a detailed plan for implementing the assessment tool in the procedure when assessing factory plants. Such a component of a detailed plan could be to develop the tool in a software program such as Qualtrics to facilitate the expert when working with the assessment tool. It additionally enables the possibility to connect the tool with a database for benchmarking purposes in real time. It would enhance the collection, storage and analysis of the assessment tool data. Moreover, it raises the value of the assessment tool for Company X, as the data can be used to compare between companies in the industry.

Lastly, Company X consultants who want to use the assessment tool should be experienced in the FMCG industry and should have considerable knowledge on Industry 4.0.

When assessing a FMCG production plant with the assessment tool, the current score and the target score are subjective to the perspective of the expert who fills in the tool. Therefore, an introduction on how to use the assessment tool in addition to expanding relevant background information on Industry 4.0 is necessary to fully capitalize this tool. It is considered important that colleagues use the information when using the tool. A team wise introduction could help one to get familiar with Industry 4.0. Studying actual cases can improve the validity and (inter-rater) reliability.

5.4 Limitations and future research directions

In this section the limitations and future research directions are described. In the current research qualitative data was used. Despite the fact that validity and reliability are maximized, there may be some potential limitations. These limitations will be discussed and form the base for future research directions.

First, the research mainly focussed on the Industry 4.0 topic which is an immature research domain (Muhuri et al., 2019). Kagermann et al. (2011) coined the term at the Hannover Messe. In 2012 the first article on the topic was published. Moreover, the practitioners (e.g. consultancy) contributed in creating a hype around Industry 4.0 (Alcácer & Cruz-Machado, 2019; McKinsey & Company, 2011). The topic became more popular resulting in exponential increase in papers in the last eight years. However, there is still no consensus on the definition and characteristics of Industry 4.0. There are several perspectives (e.g. operational, technical, management and strategy) or domains (e.g. automotive manufacturing) with their own sort of definition, but it still lacks a general definition. As a result, the impact could be that the assessment tool and its maturity items change over time when reaching consensus on the definition and characteristics of Industry 4.0. For future research, Industry 4.0 in general and specifically in the FMCG domain could be researched to fill the gap and reach consensus on the definition and characteristics.

Secondly, while this research aimed at reaching a valid Industry 4.0 assessment tool for the FMCG industry, only two company cases were used in this research to test the assessment tool due to time constraints of the researcher' thesis period and availability of the selected companies. Therefore, the generalizability of the assessment tool may be lacking due to the small test sample of manufacturing and FMCG industry company cases. To overcome this validity limitation, future research should include more companies as test cases for the assessment tool to increase the generalizability and validity.

Thirdly, the frame of reference of the respondents (i.e. participants of the interviews and focus group) is limited to boundaries of their knowledge on Industry 4.0 and of that in relation to the FMCG industry. A certain amount of knowledge and experience on the Industry 4.0 topic is needed to avoid a barrier to critical thinking. Moreover, it could be that criteria such as daily routine tasks thinking are taken into account while assessing the tool, which are not necessary. For future research one must take into account, to instruct the respondents to think outside the box and try to think beyond their familiar frame of reference, and the research benefits to select other respondents.

Future research directions. For future research, it would be interesting to focus on researching if insight in the performance (i.e. maturity score) makes a difference in attaining Industry 4.0 readiness. Additionally, how could a company increase the success rate (i.e. maturity score), since a company probably wants to know what the best way is in increasing the performance i.e. to move to higher maturity levels.

Secondly, a roadmap for determining strategic plans to attain Industry 4.0 maturity could be researched. This roadmap is a natural follow up, because the assessment of the current state is the first step to a roadmap. The research could focus on specific dimensions from the assessment tool to develop these dimensions in strategic action plans.

Lastly, a rather straightforward research direction would be to replicate this research and apply it to other markets or industries such as retail or logistics. In the case for Company X it could be interesting to look at other markets that Company X serves such as aviation, buildings, and mining.

References

Accenture. (2014). *The Future Of Consumer Goods: Moving From Analog To Digital.*

Akdil, K. Y., Ustundag, A., & Cevikcan, E. (2018). Maturity and Readiness Model for Industry 4.0 strategy. In *Industry 4.0: Managing The Digital Transformation, Springer Series in Advanced Manufacturing* (pp. 61–94). https://doi.org/10.1007/978-3-319-57870-5_4

Alcácer, V., & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. *Engineering Science and Technology, an International Journal*, *22*(3), 899–919. https://doi.org/10.1016/j.jestch.2019.01.006

Aljunaidi, A., & Ankrak, S. (2014). The Application of Lean Principles in the Fast Moving Consumer Goods (FMCG). *Journal of Operations and Supply Chain Management*, *7*(2), 25. https://doi.org/10.12660/joscmv7n2p1-25

Bauer, W., Hämmerle, M., Schlund, S., & Vocke, C. (2015). Transforming to a Hyper-connected Society and Economy – Towards an "Industry 4.0." *Procedia Manufacturing*, *3*, 417–424. https://doi.org/10.1016/j.promfg.2015.07.200

BCG. (2015). *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries*. Retrieved from https://www.bcgperspectives.com/Images/Industry_40_Future_of_Productivity_April_2015_tcm80-185183.pdf

BCG. (2019). *UNDER PRESSURE, CPG COMPANIES LOOK TO DIGITAL*.

Becker, J., Knackstedt, R., & Pöppelbuß, J. (2009). Developing Maturity Models for IT Management. *Business & Information Systems Engineering*, *1*(3), 213–222. https://doi.org/10.1007/s12599-009-0044-5

Capgemini. (2014). *Industry 4.0 - The Capgemini Consulting View*. Retrieved from https://www.capgemini.com/consulting/wp-content/uploads/sites/30/2017/07/capgemini-consulting-industrie-4.0_0_0.pdf

Capgemini. (2017). *Smart Factories: How can manufacturers realize the potential*. Retrieved from https://www.capgemini.com/wp-content/uploads/2017/05/dti-smart-factories-full-report-rebranded-web-version_16032018.pdf

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, *204*, 383–394. https://doi.org/10.1016/j.ijpe.2018.08.019

De Bruin, T., Freeze, R., Kaulkarni, U., & Rosemann, M. (2005). Understanding the Main

Phases of Developing a Maturity Assessment Model. *Australasian Conference on Information Systems (ACIS)*.

Deloitte. (2019). *2019 consumer products outlook*.

Denyer, D., Tranfield, D., & Van Aken, J. E. (2008). Developing design propositions through research synthesis. *Organization Studies*, *29*(3), 393–413. https://doi.org/10.1177/0170840607088020

Felch, V., Asdecker, B., & Sucky, E. (2019). Maturity Models in the Age of Industry 4.0 – Do the Available Models Correspond to the Needs of Business Practice? *Proceedings of the 52nd Hawaii International Conference on System Sciences*, *6*, 5165–5174. https://doi.org/10.24251/hicss.2019.620

Francis, M., Dorrington, P., & Hines, P. (2008). Supplier led new product development in the UK fast moving consumer goods industry. *International Journal of Innovation Management*, *12*(2), 195–222. https://doi.org/10.1142/S1363919608001959

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15–26. https://doi.org/10.1016/j.ijpe.2019.01.004

Fraser, P., Moultrie, J., & Gregory, M. (2002). The use of maturity models / grids as a tool in assessing product development capability. *IEEE International Engineering Management Conference*, *1*, 244–249.

Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*, *29*(6), 910–936. https://doi.org/10.1108/JMTM-02-2018-0057

Gilchrist, A. (2016). Introducing Industry 4.0. In *Industry 4.0: The industrial internet of things* (p. 20). https://doi.org/10.1007/978-1-4842-2047-4

Gokalp, E., Sener, U., & Eren, E. (2017). Development of an Assessment Model for Industry 4.0: Industry 4.0-MM. *International Conference on Software Process Improvement and Capability Determination*, 128–142. https://doi.org/10.1007/978-3-319-67383-7

Harris, J. S. (1961). New Product Profile Chart. *Chemical and Engineering News*, *39*(16), 110–118.

Hermann, M., Pentek, T., & Otto, B. (2016). Design principles for industrie 4.0 scenarios. *Proceedings of the Annual Hawaii International Conference on System Sciences*, *2016-March*, 3928–3937. https://doi.org/10.1109/HICSS.2016.488

Hevner, A. R., March, S. T., Park, J., & Ram, S. (2004). Design Science in IS research. *MIS Quarterly*, *28*(1), 75–105. https://doi.org/10.2307/25148625

Hjørland, B., & Christensen, F. S. (2002). Work tasks and socio-cognitive relevance: A specific example. *Journal of the American Society for Information Science and Technology*, *53*(11), 960–965. https://doi.org/10.1002/asi.10132

Hofmann, E., & Rüsch, M. (2017). Industry 4.0 and the current status as well as future prospects on logistics. *Computers in Industry*, *89*, 22–34. https://doi.org/10.1016/j.compind.2017.04.002

Jardim-Goncalves, R., Romero, D., & Grilo, A. (2017). Factories of the future: challenges and leading innovations in intelligent manufacturing. *International Journal of Computer Integrated Manufacturing*, *30*(1), 4–14. https://doi.org/10.1080/0951192X.2016.1258120

Kagermann, H., Lukas, W.-D., & Wahlster, W. (2011). Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. *VDI Nachrichten*. Retrieved from http://www.wolfgang-wahlster.de/wordpress/wp-content/uploads/Industrie_4_0_Mit_dem_Internet_der_Dinge_auf_dem_Weg_zur_vierten_industriellen_Revolution_2.pdf

Kang, H. S., Lee, J. Y., Choi, S., Kim, H., Park, J. H., Son, J. Y., … Noh, S. Do. (2016). Smart manufacturing: Past research, present findings, and future directions. *International Journal of Precision Engineering and Manufacturing - Green Technology*, *3*(1), 111–128. https://doi.org/10.1007/s40684-016-0015-5

KPMG. (2016). *Is it zero hour for consumer packaged goods companies ?*

KPMG. (2018). *A reality check for today's C-suite on Industry 4.0*. Retrieved from https://home.kpmg/content/dam/kpmg/xx/pdf/2018/11/a-reality-check-for-todays-c-suite-on-industry-4-0.pdf

Lasi, H. (2014). Industry 4.0. *Business & Information Systems Engineering*, *132*, 205–215. https://doi.org/10.1007/978-981-13-3384-2_13

Leyh, C., Bley, K., Schaffer, T., & Forstenhausler, S. (2016). SIMMI 4.0-a maturity model for classifying the enterprise-wide it and software landscape focusing on Industry 4.0. *Proceedings of the 2016 Federated Conference on Computer Science and Information Systems, FedCSIS 2016*, *8*, 1297–1302. https://doi.org/10.15439/2016F478

Liao, Y., Deschamps, F., Loures, E. de F. R., & Ramos, L. F. P. (2017). Past, present and future of Industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research*, *55*(12), 3609–3629. https://doi.org/10.1080/00207543.2017.1308576

Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., … Schröter, M. (2015). IMPULS - INDUSTRIE 4.0 READINESS. *Impuls-Stiftung Des VDMA*.

https://doi.org/10.3969/j.issn.1002-6819.2010.02.038

Lu, Y. (2017). Industry 4.0: A survey on technologies, applications and open research issues. *Journal of Industrial Information Integration*, *6*, 1–10. https://doi.org/10.1016/j.jii.2017.04.005

Maier, Moultrie, J., & Clarkson, P. J. (2012). Assessing organizational capabilities: Reviewing and guiding the development of maturity grids. *IEEE Transactions on Engineering Management*, *59*(1), 138–159. https://doi.org/10.1109/TEM.2010.2077289

March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. *Decision Support Systems*, *15*, 251–266.

McKinsey & Company. (2011). The decade ahead : Trends that will shape the consumer goods industry. In *Consumer and Shopper Insights: McKinsey & Company*. Retrieved from http://csi.mckinsey.com/knowledge_by_topic/consumer_and_shopper_insights/decadeahead

McKinsey & Company. (2016a). Digital innovation in consumer- goods manufacturing. In *McKinsey & Company*. Retrieved from https://www.mckinsey.com/industries/consumer-packaged-goods/our-insights/digital-innovation-in-consumer-goods-manufacturing

McKinsey & Company. (2016b). Western Europe's Consumer-Goods Industry in 2030. *Perspectives on Retail and Consumer Goods*, (5), 4–9. Retrieved from https://www.mckinsey.com/~/media/McKinsey/Industries/Retail/Our Insights/Perspectives on retail and consumer goods Number 5/Perspectives-on-retail-and-consumer-goods-Issue-5-December-2016.ashx

Mettler, T. (2011). Maturity assessment models: a design science research approach. *International Journal of Society Systems Science*, *3*(1/2), 81. https://doi.org/10.1504/ijsss.2011.038934

Mettler, T., & Rohner, P. (2009). Situational maturity models as instrumental artifacts for organizational design. *Proceedings of the 4th International Conference on Design Science Research in Information Systems and Technology, DESRIST '09*. https://doi.org/10.1145/1555619.1555649

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). Qualitative data analysis: a methods sourcebook. In *SAGE* (Vol. 3). https://doi.org/10.7748/ns.30.25.33.s40

Mittal, S., Khan, M. A., Romero, D., & Wuest, T. (2018). A critical review of smart manufacturing & Industry 4.0 maturity models: Implications for small and medium-sized enterprises (SMEs). *Journal of Manufacturing Systems*, *49*, 194–214.

https://doi.org/10.1016/j.jmsy.2018.10.005

Mittal, S., Romero, D., & Wuest, T. (2018). Towards a Smart Manufacturing Maturity Model for SMEs (SM3E). In *Product Lifecycle Management to Support Industry 4.0* (Vol. 536, pp. 155–163). https://doi.org/10.1007/978-3-319-99707-0

Moeuf, A., Pellerin, R., Lamouri, S., Tamayo-Giraldo, S., & Barbaray, R. (2018). The industrial management of SMEs in the era of Industry 4.0. *International Journal of Production Research*, *56*(3), 1118–1136. https://doi.org/10.1080/00207543.2017.1372647

Monostori, L. (2014). Cyber-physical production systems: Roots, expectations and R&D challenges. *Procedia CIRP*, 5. https://doi.org/10.1016/j.procir.2014.03.115

Moultrie, J., Clarkson, P. J., & Probert, D. R. (2007). Development of design audit tool for SMEs. *Journal of PRODduct INNOVation MANAGement*, (24), 335–368. https://doi.org/10.1243/09544054JEM452

Moultrie, J., Sutcliffe, L., & Maier, A. (2015). A maturity grid assessment tool for environmentally conscious design in the medical device industry. *Journal of Cleaner Production*, *122*, 252–265. https://doi.org/10.1016/j.jclepro.2015.10.108

Muhuri, P. K., Shukla, A. K., & Abraham, A. (2019). Industry 4.0: A bibliometric analysis and detailed overview. *Engineering Applications of Artificial Intelligence*, *78*, 218–235. https://doi.org/10.1016/j.engappai.2018.11.007

Neuendorf, K. A. (2002). *The Content Analysis Handbook*.

Oraman, Y., Azabagaoglu, M. O., & Inan, I. H. (2011). The firms' survival and competition through global expansion: A case study from food industry in FMCG sector. *Procedia - Social and Behavioral Sciences*, 188–197. https://doi.org/10.1016/j.sbspro.2011.09.021

Oztemel, E., & Gursev, S. (2018). Literature review of Industry 4.0 and related technologies. *Journal of Intelligent Manufacturing*, (January). https://doi.org/10.1007/s10845-018-1433-8

Panetto, H., Iung, B., Ivanov, D., Weichhart, G., & Wang, X. (2019). Challenges for the cyber-physical manufacturing enterprises of the future. *Annual Reviews in Control*, *47*, 200–213. https://doi.org/10.1016/j.arcontrol.2019.02.002

Pereira, A. C., & Romero, F. (2017). A review of the meanings and the implications of the Industry 4.0 concept. *Procedia Manufacturing*, *13*, 1206–1214. https://doi.org/10.1016/j.promfg.2017.09.032

Piccarozzi, M., Aquilani, B., & Gatti, C. (2018). Industry 4.0 in management studies: A systematic literature review. *Sustainability*, *10*(10), 1–24.

https://doi.org/10.3390/su10103821

Pisano, G. P. (2015). A Normative Theory of Dynamic Capabilities: Connecting Strategy, Know-How, and Competition. In *Harvard Business School Technology & Operations Mgt. Unit*. https://doi.org/10.2139/ssrn.2667018

Pöppelbuß, J., & Röglinger, M. (2011). What makes a useful maturity model? A framework of general design principles for maturity models and its demonstration in business process management. *19th European Conference on Information Systems, ECIS 2011*.

PwC. (2017a). Digital Factories 2020. In *PricewaterhouseCoopers GmbH*. Retrieved from https://www.pwc.de/de/digitale-transformation/digital-factories-2020-shaping-the-future-of-manufacturing.pdf

PwC. (2017b). *Global Digital Operations Study 2018 Digital Champions*. Retrieved from http://www.pwc.com/m1/en/about-us.html

Schuh, G., Anderl, R., Gausemeier, J., ten Hompel, M., & Wahlster, W. (Hrsg). (2017). Industrie 4.0 Maturity Index. In *Acatech Study*. https://doi.org/ISSN 2192-6174

Schumacher, A., Erol, S., & Sihn, W. (2016). A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. *Procedia CIRP*, *52*, 161–166. https://doi.org/10.1016/j.procir.2016.07.040

Schumacher, A., Nemeth, T., & Sihn, W. (2019). Roadmapping towards industrial digitalization based on an Industry 4.0 maturity model for manufacturing enterprises. *Procedia CIRP*, 409–414. https://doi.org/10.1016/j.procir.2019.02.110

Sekaran, U., & Bougie, R. (2016). *Research Methods for Bussiness A Skill-Bulding Approach* (Seventh ed). Retrieved from www.wiley.com

Simon, H. A. (1996). The Sciences of the Artificial. In *Technology and Culture* (Third edit, Vol. 11). https://doi.org/10.2307/3102825

Sony, M., & Naik, S. (2019). Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review. *Benchmarking: An International Journal*, 20. https://doi.org/10.1108/BIJ-09-2018-0284

Teece, D. J. (2017). Towards a capability theory of (innovating) firms: Implications for management and policy. *Cambridge Journal of Economics*, *41*(3), 693–720. https://doi.org/10.1093/cje/bew063

Teece, D. J., Pisano, G., & Shuen, A. M. Y. (1997). Dynamic Capabilities and Strategic Management. *Strategic Management Journal*, *18*(7), 509–533.

Thoben, K. D., Wiesner, S. A., & Wuest, T. (2017). "Industrie 4.0" and smart manufacturing-a review of research issues and application examples. *International Journal of*

Automation Technology, *11*(1), 4–16. https://doi.org/10.20965/ijat.2017.p0004

Ulrich, D., & Smallwood, N. (2004). Capitalizing on capabilities. *Harvard Business Review*, 119–127.

Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0 - A Glimpse. *Procedia Manufacturing*, 233–238. https://doi.org/10.1016/j.promfg.2018.02.034

Van Aken, J. E., Berends, H., & Van der Bij, H. (2007). *Problem-solving in Organizations*. cambridge university press.

Wang, Y., Ma, H. S., Yang, J. H., & Wang, K. S. (2017). Industry 4.0: a way from mass customization to mass personalization production. *Advances in Manufacturing*, *5*(4), 311–320. https://doi.org/10.1007/s40436-017-0204-7

WNG. (2017). *An Industry 4 readiness assessment tool*. Retrieved from www.warwick.ac.uk/scip1

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. *ACM International Conference Proceeding Series*. https://doi.org/10.1145/2601248.2601268

World Economic Forum. (2016). *Digital Transformation of Industries: Consumer Industries*. Retrieved from http://reports.weforum.org/digital-transformation/wp-content/blogs.dir/94/mp/files/pages/files/dti-logistics-industry-white-paper.pdf

Xu, L. Da, Xu, E. L., & Li, L. (2018). Industry 4.0: State of the art and future trends. *International Journal of Production Research*, *56*(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806

Yao, X., & Lin, Y. (2016). Emerging manufacturing paradigm shifts for the incoming industrial revolution. *International Journal of Advanced Manufacturing Technology*, *85*, 1665–1676. https://doi.org/10.1007/s00170-015-8076-0

Yin, R. K. (2003). Case study research: Design and methods. *Applied Social Research Methods Series.*, *5*, 80–91. https://doi.org/10.4324/9780429059056-6

Yin, R. K. (2015). Qualitative research from start to finish. In *THE GUILFORD PRESS* (second edi). The Guilford Press.

Yin, Stecke, K. E., & Li, D. (2018). The evolution of production systems from Industry 2.0 through Industry 4.0. *International Journal of Production Research*, *56*(1–2), 848–861. https://doi.org/10.1080/00207543.2017.1403664

Zou, C. (2016). Study on Efficiency of FMCG Industry. *International Conference on Applied Social Science Research (ICASSR 2015)*, 183–185. https://doi.org/10.2991/icassr-15.2016.52

Appendix A – Interview format

Interview draft

Heading
Date:
Place:
Interviewer:
Interviewee (A/B/C etc.):

Information

- Introduction: FMCG companies show interest to invest in the transformation to smart factories following the Industry 4.0 trend, but they lack knowledge on their current state in Industry 4.0.
- Usage of the data during research: Interview will be anonymized. Transcript of interview will be sent via mail to the interviewee. Data will be used in the study.
- Recording: Ask for permission to record the interview.
- Semi-structured interview style: I am specifically interested in your opinion on Industry 4.0 in relation to the FMCG Industry. I am not looking for the 'correct answer', I am looking for you opinion. That is why I will sometimes ask for a elaborated comment.
- Interview time: Approx. 30 min.

Questions

Intro question

1. Could you give a short introduction about yourself regarding you current/previous functions?

2. What is your work experience?

Question regarding assessment FMCG companies

3. Are you familiar with the assessment of FMCG factories? If so, do you have a role in these assessment? What is your role?

4. Could you describe the process of an assessment on a FMCG factory?

5. What is the main purpose of an assessment on a FMCG factory?

6. What are important factors to consider when assessing a FMCG factory?

7. How do you benchmark the results of the assessments?

8. To what extent is the expert's insight sufficient to complete an assessment of a FMCG factory? In other words, do you think the results differ, when different co-workers do the assessment.

9. Are you familiar with the Company X Rapid Plant Assessment Rating tool (show tool)? What do you think of it? Could you name three useful elements that come to mind? Could you name three elements that you would like to see differently?

Questions regarding Industry 4.0

10. Are you familiar with Industry 4.0? If so, to what matter? Do you get involved with Industry 4.0?

11. Could you describe what Industry 4.0 means?

12. Which technologies do you relate to Industry 4.0?

13. Which Industry 4.0 technologies are relevant for the FMCG industry?

14. Could you explain why FMCG companies lack knowledge on their current state on Industry 4.0?

15. On a scale from 0 - 10, with 0 meaning no knowledge at all and 10 meaning perfect knowledge, to what extent do you think FMCG companies have current knowledge regarding Industry 4.0?

16. Could you explain what kind of implication(s) Industry 4.0 has on the FMCG industry?

    a. Problems when implementing I4.0? financial, no knowledge?
    b. What should the role of Company X be in this industry 4.0?

Questions regarding Industry 4.0 assessment tool

17. Why should an Industry 4.0 assessment be conducted?

18. What could an Industry 4.0 assessment tool add to the assessment of the FMCG industry? Why?

19. What kind of output do you expect from the Industry 4.0 assessment tool? For example: charts (spider), table with scores? Why?

20. What kind of scoring method for the assessment tool would you advise? Why?

21. Do you think that guiding questions could be helpful for the Industry 4.0 assessment tool? Why?

22. What kind of program/software for the tool would be workable for you? For example: Excel, Quantrix, other suggestions? And why?

Closing

Is there anything more you like to share?
Thank you for participating.

Appendix B – Coding scheme interviews

Coding scheme

Codes	Description
Conducting assessment based on experience	An assessment conducted on basis of past experiences so without a supportive tool
Definition I4.0	Definition Industry 4.0
Experience with assessments	Interviewee has experience with conducting assessments of factories
I4.0 implications for FMCG	Make the Supply Chain more efficient
Organization knowledge on I4.0	There is knowledge on Industry 4.0 in the FMCG industry companies
Suggested factor assessment tool	Factor (i.e. capability or criteria) for in the assessment tool
Value assessment tool	Assessed value of an assessment tool when assessing a plant to gain standardized results for benchmarking purposes
Value benchmarking in assessment	Benchmarking of assessment scores is handy for cross referencing and comparing
Value roadmap/vision on I4.0	Companies need a roadmap on Industry 4.0 otherwise it will not work
Value tailored version of assessment tool	A tailored version of an assessment tool instead of a generic version

Appendix C – Focus group rating sheet

For confidentiality reasons, not available here but in separate attachment.

Appendix D – Case study protocol

Case study protocol

Category	Content	
Preface	*Confidentially and data storage*	Concerning confidentiality, the names of the companies and experts are anonymized. Moreover, the data collected will also be anonymized. The data will be stored with the researcher and Company X.
	Publication	The assessment will be used for research and development purposes of the assessment tool. The raw will not be published without confidentially taken into account.
	Documentation	The data will be documented in Excel and Word.
General	*Overview research*	The goal of this research is to design an Industry 4.0 assessment tool. With this tool the goal is to assess the Industry 4.0 maturity of a company. This is obtained through score the Industry 4.0 maturity items of the company on basis of a four level maturity grid. With the output the current and target maturity score can be observed in a chart to determine further strategic action plans for Industry 4.0 implementation.
Procedures	*Selection & number of cases*	Two company cases active in the manufacturing and FMCG industry.
	Planning case visits	Company Alpha – 29 November 2019 Company Delta – 2 December 2019
	Duration case visits	Approximately 3 hours (one session)
	Equipment	Laptop and notebook
	Programme	1. Introduction 2. Assessment tool testing 3. Evaluation
Research instruments	*Type of data*	Qualitative data collection. Focus on three assessment criteria for collecting feedback: Outputs, Usability, Utility (Moultrie et al., 2007).
Validation	*Principles of measurement*	Validity regarding observers: Researcher, Lead-consultant Company X, and extra observer Company X.

Appendix E – Initial design tool

For confidentiality reasons, not available here but in separate attachment.

Appendix F – Final design tool

For confidentiality reasons, not available here but in separate attachment.