Constructing A Multi Dimensional Smart Industry Scan

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ABSTRACT,
The fourth industrial revolution is on its way and had started finding it's way in daily life and across industries. Especially, manufacturing firms are actively investing in new industry 4.0 technology to stay competitive but are also confronted with many internal and external challenges. Therefore, these firms could substantially benefit from a tool that measures the extent to which industry 4.0 is implemented in different aspects within their firm. Therefore, a maturity model and quick scan measuring industry 4.0 based on multiple aspects was necessary. This paper focuses on the development of a multi-dimensional smart industry scan consisting of aspects, measurement questions and maturity levels. The goal of this paper is to construct an improved maturity model based on scientific literature. Overall the scan consists of seven aspects, 35 measurement questions and five maturity levels. The aspects "strategy & organisation", "people & organisational culture", "products and customer services", "customer interfaces", "value chain", technology & IT management" and "institutional awareness" were constructed. Afterwards, the scan was tested and validated during a workshop with the experts of Future Industries. Further recommendations to improve the scan are suggested in this thesis.

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1. INTRODUCTION

In the second part of the 18th century a massive shift took place called the first industrial revolution, which affected a lot of people. The steam engine was introduced, which let to a complete transformation of the textile industry. The factories established because of this, lead to a development of industrial cities. A century later, in the second part of the 19th century, the second industrial revolution was finding its way. During this period, the introduction of electricity lead to mass production and labour division. In the late 20th century there was a shift from mechanical and analogue electronic technology to digital electronics, which is called the third industrial revolution. The fourth industrial revolution has already started and it is in progress right now (Vale, 2016). It features a mixture of technologies in the cyber-physical, biological and digital spheres (Xu, David & Kim, 2018).

Industry 4.0 is part of this industrial revolution and is becoming increasingly important. "While in 2015, only half the manufacturing executives interviewed cited digitalization and automation of business processes as a top IT priority, in 2016 more than 90% are investing in these areas (CGI, 2017)." It is said to replace brainpower with machine intelligence (Olausson, 2016). Industry 4.0 is closely related to the term smart factory in which smart instrument are interconnected and communicate with for instance products, machines and other instruments. The outcome should entail an increase in efficiency in the business process (Vuksanovic et al, 2016). In order for firms to stay competitive, the fairly new concept of industry 4.0 should be implemented in ones business (CGI, 2017). This growing attention and importance of industry 4.0 could also lead to more firms wanting to increase digitization within their organisation. While the concept is fairly new, a lot of organisations are not up-to-date with the changes happening in this world and could benefit from a tool that offers help to some extent.

Maturity models could be helpful in order to offer some insight to organisations that try to digitize. "Maturity models are commonly used as an instrument to conceptualize and measure maturity of an organization or a process regarding some specific target state (Schumacher et al, 2016)." Next to this, a maturity model is a tool that could help people to find out the current effectiveness of an organisation and helps to figure out what should be adjusted in order to improve their performance (Fowler, 2014). The increase in digitization could result into an increasing need for a fully integrated maturity model, in other words, a multi dimensional smart industry scan.

Future Industries is a company that in the progress of making a multi dimensional smart industry scan, measuring the maturity level of adaption of industry 4.0 within an organisation. The scan should measure this by formulating measurement questions on different aspects within the organisation. The different range of aspects should give a more reliable outcome of the level of maturity in the organisation. In this research I will create such a multi dimensional smart industry scan myself based on an extensive systematic literature review. Literature on the topics industry 4.0, maturity models and the different aspects in the scan will be reviewed and selected. Next, the aspects, measurement questions and possible answers of the scan will be formulated. Future Industries supplied there scan, which they have made so far to me in order to be used as a guideline. To support and follow the process of the multi dimensional smart industry scan, meetings together with Future Industries will be scheduled. Furthermore, a workshop is scheduled in which the experts from Future Industries will validate the scan at the end of the process by checking it and giving feedback on the end result. At the end of this research, I should have created a multi dimensional smart industry scan that gives firms a complete overview of their progress in adapting industry 4.0. The scan should be an improvement on the already existing scans and will be based on scientific research.

First, a critical assessment will be done on the existing industry 4.0 maturity models. The literature will be systematically reviewed and the relevant information will be gathered. Next, the process of creating the scan, including aspects, measurement questions and possible answers will be described and further on the scan will be introduced to the reader. Furthermore, my own perceptions of the aspects are explained individually in detail. Lastly, the methodology will be described, the results of the workshop will be given and some recommendations and limitations will be provided.

2. LITERATURE REVIEW

In this part a critical assessment of existing maturity models will be done. Moreover, the process of getting to my own multi dimensional smart industry scan will be explained. Next to this, the scan that I created will be explained in detail.

2.1 Critical assessment of maturity models

A critical assessment of existing maturity models is an effective way to find out all the ins and outs of the maturity models that are available. In general the term "maturity" refers to being complete, perfect, or ready and implies some progress in the development of a system (Simpson et al, 1989). A maturity model is a tool that helps people to find out the current effectiveness of a person or group and helps to figure out what should be improved in order to improve their performance (Fowler, 2014). In this case the "person or group" is the extent to which industry 4.0 is applied in an organisation. The first step was to look up existing maturity models, which are related to industry 4.0. Multiple models, which could be of importance for this results were found. The most fitting maturity models amongst all of these models were selected in accordance with the constructed criteria.

One of the criteria (C1) that were used in order to select the models was the completeness of the model on different aspects. In order words, the model should have multiple aspects measuring industry 4.0 within the organisation. In such a way, the models can be an inspiration for my model, which is also a model that measures industry 4.0 maturity on different aspects. Next, I looked for maturity models that contained measurement questions in order to measure the maturity levels. My model will also consist of measurement levels and these can come in handy (C2). The last criteria (C3) were the maturity levels. I selected the models that all had maturity levels in order to frame the outcome. Eventually, four maturity models (partly) satisfied these criteria and were selected. An overview of the used criteria and the selected maturity models is shown in table 1.

Table 1. Selection criteria

	C1: Availability of multiple aspects	C2: availability of Measurement questions	C3: Availability of maturity levels
IMPULS (2015) – industry 4.0 readiness online self-check for businesses	Achieved	Achieved	Achieved
PWC (2016) – Industry 4.0 Self Assessment	Achieved	Achieved	Achieved
A. Schumacher et al (2016) – A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises	Achieved	Not Achieved	Achieved
Future Industries – I4 maturity tool	Achieved	Achieved	Not Achieved

As stated above, next to the scan offered by Future Industries three additional models were selected: "PWC's industry 4.0 self assessment model (2016)", "IMPULS's industry 4.0 readiness online self-check for businesses (2015)" and "a maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises" by Schumacher, Erol and Sihn (2016). For the sake of ease these will be called, chronologically: "FI model", "IMPULS model", "PWC model" and "Schumacher et al model" in the remainder of this thesis.

The PWC model and the IMPULS model were selected, because of their completeness. The models not only states aspects, which can be interesting for creating the model, but also measurement questions and maturity levels with regards to industry 4.0 maturity. These questions can help to get a better understanding of the aspects and could be useful in the creation of my own model. Next to these models, the Schumacher et al model is selected. The paper doesn't contain any measurement questions, but is still selected because of the completeness of the model. Schumacher et al already did research on different existing maturity models and created their own model. The model is already tested in several companies, and the first validations were positive. Lastly, the Future Industries scan did contain interesting aspects and measurement questions.

The models are obviously a great mixture of different aspects, measurement questions and maturity levels. When the models are looked at, the variety of them can be a great foundation and a big source of inspiration for my own model. An overview of all aspects and measurement questions of the IMPULS model,

the PWC model and the Schumacher et al model can be seen in Table 2, 3 and 4 in appendix 2, 3 and 4.

Table 5 states the most interesting information of these models. Next to these papers, the paper from Leyh et al (2016) was very useful in order to be used as inspiration for creating my own maturity levels. However, I did not use it for anything else but the levels, this is why it is not stated in table 5.

Table 5. Selected maturity models

Maturity Model Name	Aspects	Maturity levels
IMPULS (2015) – industry 4.0 readiness online self-check for businesses	**Six aspects:** strategy & organization, smart factory, smart operations, smart products, data-driven services and employees	Six maturity levels: outsider, beginner, intermediate, experienced, expert and top performer
PWC (2016) – Industry 4.0 Self Assessment	**Six aspects:** business models & product and service portfolio, market & customer access, IT architecture, value chains & processes, compliance, legal, risk, security & tax and organization & culture	Three maturity levels: digital novice, vertical integrator and horizontal collaborator
A. Schumacher et al (2016) – A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises	**Nine aspects:** strategy, leadership, customer, products, operations, culture, people, governance and technology	Five maturity levels: 1 to 5 in which 1 describes a complete lack of attributes supporting industry 4.0 and level 5 represents the state-of-the-art of required attributes
Future Industries – I4 maturity tool	**Nine aspects:** vision & direction & business model, people & organisation, marketing & customer access, product, product development, production process & production control, production automation, performance management, big data analytics	N.A
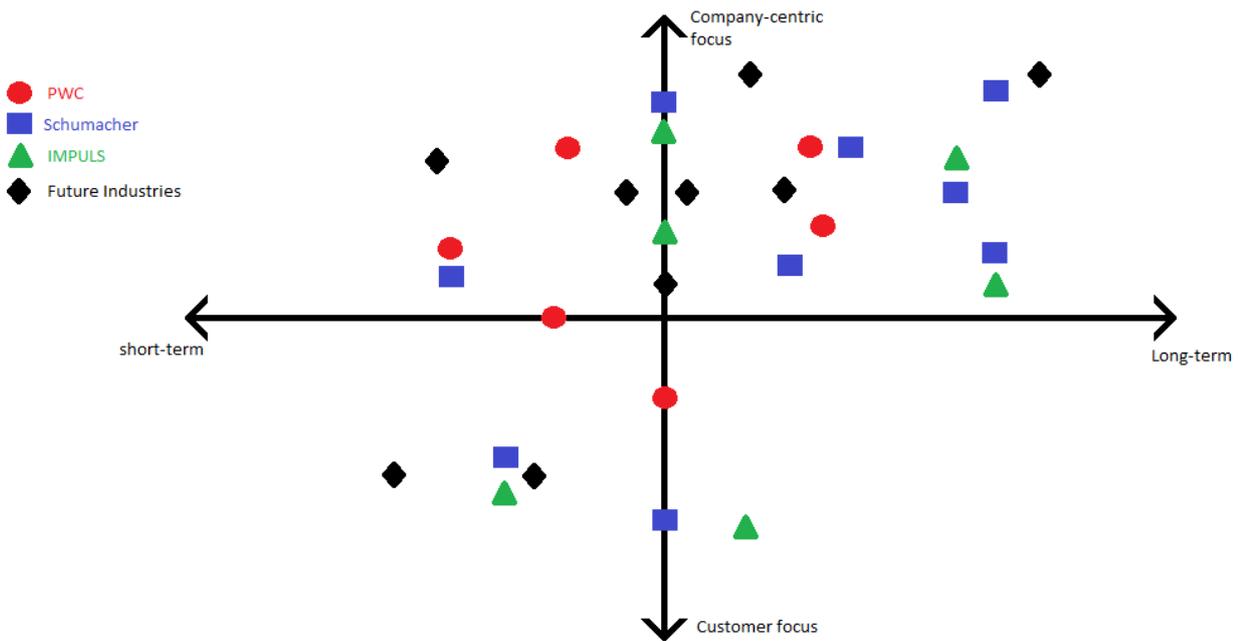
Figure 1. Positional map on all aspects

These four models have a total of 30 aspects, but some of these aspects are overlapping each other in one way or another. To get a good overview and to position the provided aspects I created a positional map with two adverse dimensions for both the horizontal axis and the vertical axis. These dimensions are short-term focus against long-term focus and company-centric focus against customer focus. On the vertical axis the aspects are plotted relating to customer focus and company-centric focus. Customer focus is really important in order to satisfy the customers. Focussing on the customer needs could lead to more satisfaction and only a satisfied customer will come back (Cottenje, 2016). The aspects that tend towards company centric focus are understood as "aspects that are directly related to creating value within the company" such as the aspect leadership from Schumacher et al (2016). Moreover, on the horizontal axis the aspects are plotted representing short-term against long-term. A long-term goal is a plan for a longer term (3 to 5 years) and should be done in steps; the steps can be seen as the short-term goals (Gleeson, 2018). The aspects stated contribute (partly) to long or short-term goals and are plotted in the positional map in this way.

This positional map is shown in figure 1. Interestingly enough the positional map shows a gap, namely the long-term customer focus. According to this research on all the aspects of the models there is a lack of aspects focussing on long-term customer focus. The aspects in my scan should cover all four dimensions of the positional map.

2.2 Creation of the multi dimensional smart industry scan

In order to assist the process of a scan that measures the level of industry 4.0 on all four dimensions as stated in figure 1, the proposed model consists of a total of 35 measurement questions divided amongst seven aspects. In my opinion these are of great value in order to test the maturity level of industry 4.0 within the organisation.

To get to these seven aspects, the 30 aspects from the four maturity models seen in figure 1 were collaborated. The overlapping aspects were removed and the scan was formed.

The complete scan created including measurement questions can be seen in table 6 in appendix 1. To give a general idea of the scan the aspects of the scan and some subjects of the industry 4.0 measurement questions are shown in table 7.

Table 7. Multi dimensional smart industry scan

Aspects	Example subjects of the measurement questions
Strategy & organisation	Implementation of industry 4.0 strategies, gathering of data, essence of innovation, …
People & organisational culture	Knowledge of employees, involvement of management, communication, …
Products & customer service	Product portfolio, gathering of customer feedback, implementation of industry 4.0 within product process, …
Customer interfaces	Interaction with customers, the use of customer data, digitization of customer journey, …
Value chain	Vertical value chain, horizontal value chain, digitization of machinery, …
Technology & IT management	Produce value through technology, focus on technology, manage the IT, …
Institutional awareness	Digital compliance policy, rules and regulations, taxes, …

2.3 Explanation of the multi dimensional smart industry scan

2.3.1 Explanation aspects

Next an explanation of the selected aspects is provided to get on one line with the reader, resulting in the following section that contains the explanations of my understanding based on literature of all seven aspects. The aspects are constructed in such a way that all dimensions within the positional maps are covered.

Strategy is understood as accomplishing an aim by setting a plan of action. The measurement questions formulated in my scan should give a general overview of the strategy and to what extent this strategy contributes to an environment within the organisation in which industry 4.0 is of great importance. The measurement questions related to the *organisation* should confirm this environment.

Moreover, "people and culture" is interpreted in the following way. *People* are all people within the organisation, so all employees including management. The people within an organisation can be of major importance in the success or failure of the attempts to digitize in an organisation, thinking of the current ability to change and adapt new knowledge for example. Next to people, *organisational culture* is also very important. Culture determines through the use of for example rituals, values, beliefs and norms the way that things are done within the organisation (O'Donnel & Boyle, 2008).

Products will for now be discussed as the offerings of an organisation, so depending on the firm this can also be a service, but for the sake of ease referred to as products. It's about the product itself, but also consists of the process of the product throughout all the phases. Closely connected to the products are customer services. "*Customer services* are the services provided to customers before, during, and after a purchase" (Baines & Fill & Page, 2013, p 390). One important subject related to products and customer services is customer feedback, which is an effective way to find out the opinions and experiences of receivers (Baines & Fill & Page, 2013, p 392).

Customer interfaces is understood as the way in which a customer interacts with the organisation and meets the customer (Gonzales, 2014). These can be for example via face-to-face talk, phone conversations or the Internet communication.

The value chain consists of all activities necessary to create, produce, market and deliver a product of service (Porter, 1985). While a value chain consists of the whole process of making and selling a product it is essential for this maturity model to measure the extent to which it is digitized.

Sazali, Raduan & Suzana (2011) state: "the term technology has been given various definitions by previous literature". *Technology* can be seen as developing for example tools and machines in order to help and solve problems of people (Reisman, 2005). *Information technology* is using these tools to create or store different kinds of electronic data (Rouse, 2015).

Institutional awareness is a collective name for a lot of subjects, which, in my opinion, are of great importance when measuring the maturity level of industry 4.0 of an organisation. It consists of compliance, laws, risks, security, taxes and rules and regulations. In this part, the organisation is tested based on their maturity on these aspect related to industry 4.0.

2.3.2 Explanation measurement questions

All seven aspects consist of five measurement questions each. The question can all be answered from (1) not at all to (5) fully. This interval way of scaling the answers can provide the researcher with more useable information to apply more powerful statistical techniques such as correlation analysis. By giving the response options on a scale with equal interval in between them the researcher could attain a higher level of measurement than it should have with ratio, ordinal or nominal scaling (Burns & Bush, 2005, p 280). The 35 measurement questions each correspond to the information provided by Burns & Bush (2005, p 306/307) on problem words in questionnaire design. These problem words were removed from the measurement questions, however in some situations they are still present, but are formulated correspondent to the allowed terms in which they may still be used.

The IMPULS model provided 19 measurement questions related to different aspects of the maturity model that they provided. The PWC provided 33 measurement questions that were also related to the aspects that they implemented into their maturity model. Next to these two models the Future Industries scan offered a large amount of measurement questions as well, which were also helpful in getting to my own model. The measurement questions were used as inspiration to make the measurement questions for the maturity model. By studying these scans and general survey questions available on the Internet about the different aspects in my maturity model, I was able to frame my own measurement questions. The measurement questions resulted from this extensive study of different maturity models is shown in table 6 appendix 2.

2.3.3 Explanation maturity levels:

As previously stated the measurement questions all have five answering options, reaching from (1) not at all to (5) fully. The measurement questions are all drawn up in such a way that "not at all" is the least preferable situation and "fully" is the most preferable situation. The scores of the results of all five questions (Q1-Q5) within one of the aspects will be displayed in a radar chart. This radar chart will be provided for all of the seven aspects individually as shown in figure 2. These scores will be added up and divided by five to get the average score of every single aspect. Next, the averaged scores for every aspect are displayed into a combined radar chart. An example is shown in figure 3. The radar chart is made up of seven corners in which all seven aspects are stated (A1-A7). The scores will reach from 1 to 5 for all aspects.

The radar chart is a good way to visualize multivariate data to the user and represents an easy visualization of the attributes, including visualization of comparisons and differences in between aspects and measurement questions in this case (Nowicki & Merenstein, 2016).
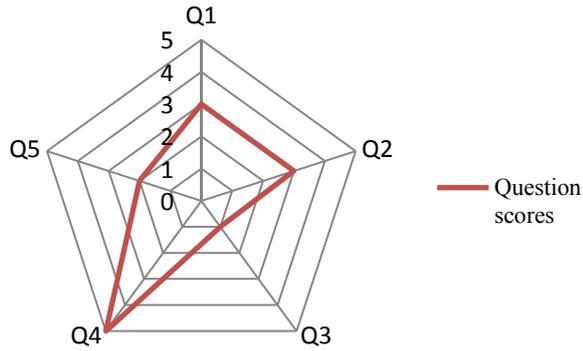
Figure 2. Radar chart aspect 1

Figure 3. Radar chart of all aspects

After answering all measurement questions the person answering the measurement questions can be put into five maturity levels. The paper of Leyh et al (2016) was used as inspiration to create these five levels. This distribution will be based on an average of the results on all measurement questions and is shown in figure 4. Level 1 indicates an average score in between (1-1,49). Level 2 indicates an average score of (1,5-2,49). Level 3 indicates an average score of (2,5-3,49). Level 4 indicates an average score of (3,5-4,49) and level 5 indicates an average score of 4,5 or higher.
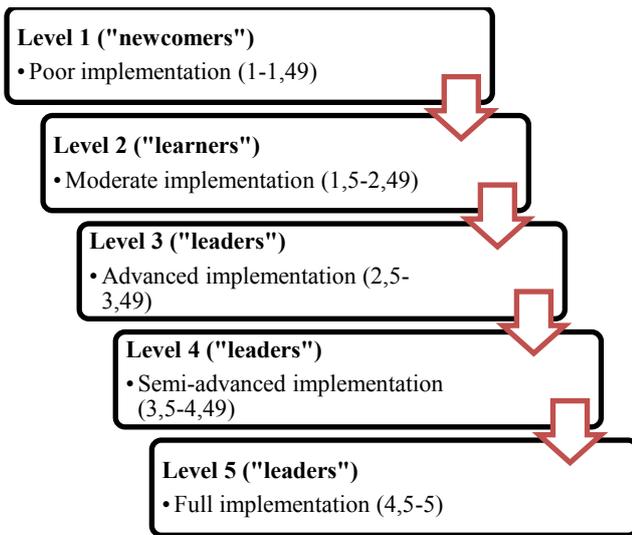
In this radar chart aspect 1 to aspect 7 (A1-A7) is provided with an average. These averages in this example are from A1 to A7: 2,8, 3.2, 4.4, 1,2, 3.6, 4 and 2.6. Together these averages count up to 21,8, which is then divided by 7. An average score of 3,11 is the results, which means that the user of the scan is in level 3 "advanced implementation" (figure 4) and is classified as a "leader".

3. METHODOLOGY

I created my own development steps in order to create the multi dimensional smart industry scan. The development steps can be seen in figure 5 and are explained in detail in the following. Step 1 and step 2 are already discussed in the previous sections, but will be quickly summarized in this section as well.

Figure 4. Maturity levels

In order to further clarify the five maturity levels the user of the scan is classified into three types. The types are from the IMPULS model and consist of "newcomers", "learners and "leaders". According to IMPULS (2015) the newcomers are defined as "companies that have never initialized first projects related to industry 4.0." The learners did initialize some first projects related to industry 4.0. The leaders are ahead of other companies in their industry 4.0 implementation. The newcomers are in level 1, the learners are in level 2 and the leaders are in level 3, 4 and 5 of the maturity levels in figure 4.

Next, using the radar chart of figure 3, the distribution of the maturity levels and the types of implementation an example is provided.
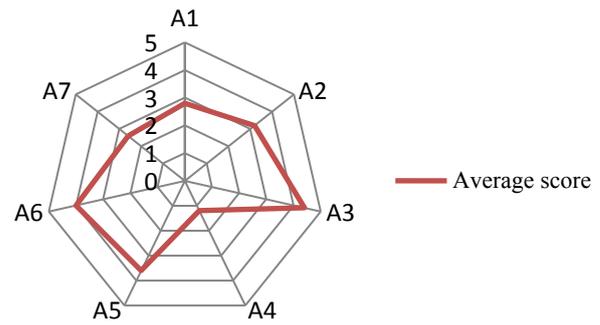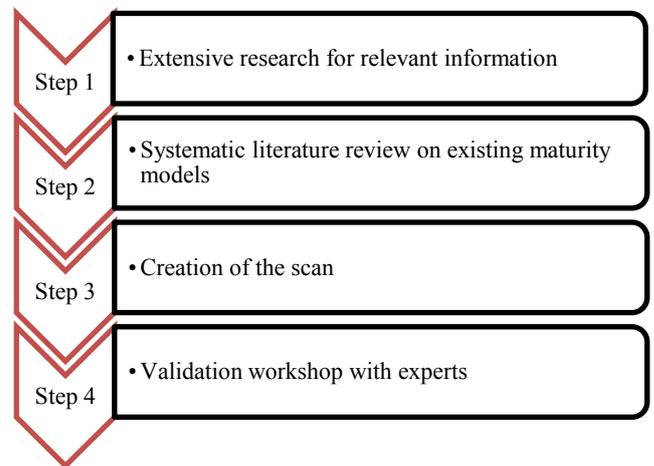

Figure 5. Development steps 1

The first step included complete understanding of industry 4.0 and industry 4.0 maturity models, which is an essential activity in the process. In this step an extensive research was done to find relevant information in the literature in order to start finding relevant maturity models and eventually creating the multi dimensional smart industry scan.

The second step consisted of a systematic literate review of the existing maturity models and selecting the appropriate maturity models for this study. "The purpose of a systematic literature review is to provide as complete a list as possible of all the published and unpublished studies relating to a particular

subject area" (Ramdhani, Ramdhani & Amin, 2014). The selected maturity models are shown in table 5, moreover the complete maturity models, including aspects; measurement questions and answers are summarized in table 2, 3 and 4 in appendix 2, 3 and 4. Furthermore, the maturity models were analysed and compared and the aspects of them were located in the positional map in figure 1. Relevant information was derived for structuring my own maturity model.

In step three, the previously mentioned information was used in order to create my own multi dimensional smart industry scan. First of all, the 30 aspects of the four maturity models selected in the systematic literature review were looked at and the overlapping aspects were removed. The remaining aspects were elaborated upon and joined together into seven aspects, which occupied all four dimensions of the positional map of figure 1. The IMPULS scan and the PWC scan also disclosed measurement questions, which could easily be adjusted to fit the aspects of the scan. Together with my own knowledge and the FI model this resulted into 35 questions divided amongst seven aspects. Lastly, the maturity levels were formulated and put into the model.

The last step is the organisation of a workshop in which the multi dimensional smart industry scan was proposed to the experts of Future Industries. In this workshop a discussion will take place in which the model is proposed to experts. The experts will provide feedback in order to improve the scan. This feedback will be analysed and implemented into the model afterwards. The experts on this field will check the scan and provide feedback in order for me to adjust the model. This validates the multi dimensional smart industry scan and the research.

4. RESULTS

In this research a multi dimensional smart industry scan that measures industry 4.0 on different aspects within a firm is created, which is shown in figure 6.

During this research I made a positional map with four dimensions. I plotted all 30 aspects from the selected maturity models in this positional map and noticed that there was a lack of aspects that were long-term customer focussed. The aspects in my scan are evenly plotted and the aspect customer interfaces covers the long-term customer focus part of the positional map.

The created multi dimensional smart industry scan was tested during a workshop with experts of Future Industries. In this workshop, the scan was explained to them. This included, the explanations of the systematic literature review I did, the process of getting to the multi dimensional smart industry scan and the aspects, measurement questions and maturity levels of the scan. In this workshop, the experts were satisfied with the results. The aspects, measurement questions and the maturity levels were clear.

However, I did change two things after the workshop with the experts. I renamed the first aspect of the multi dimensional smart industry scan. The aspects included the business model, but I removed this aspect and renamed the aspects to strategy and organization. The business model part was removed, because it did not fit in my structure of having five measurement questions per aspect. The structure limited me to only one question related to the business model and being realistic; one question is not enough to get a general overview of the extent to which industry 4.0 is implemented in the business model. Next to this, I made a small change to the maturity levels.
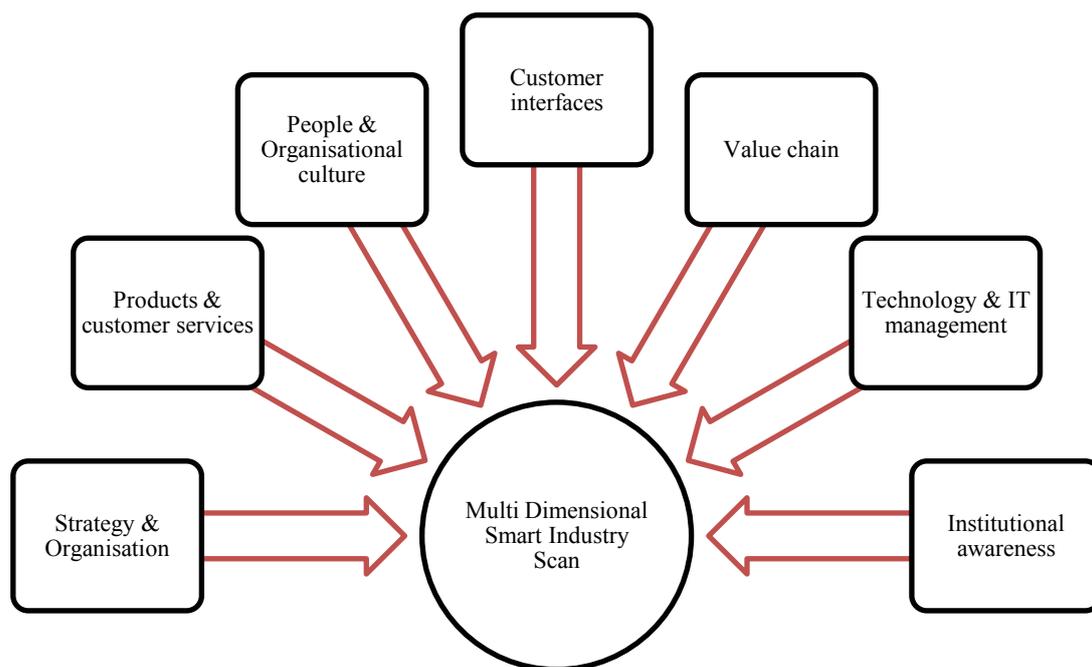

Figure 6. The aspects of the Multi Dimensional Smart Industry Scan

I renamed level 1 from "traditional implementation" to "poor implementation" and level 5 from "fully integrated" to "full implementation". In this way no confusion can result for a traditional way of implementation and all levels can be interpreted in the same way. Next to this, I added three types in which the user can be classified: "newcomer", "learner" and "leader". Figure 4 shows the renamed maturity levels.

Moreover, during the discussion in the workshop the experts of Future Industries suggested that the multi dimensional smart industry scan can be perfectly used as a quick scan on their website. A quick scan is a scan, which can be made quickly and is provided for free. It gives the user a general overview of their industry 4.0 maturity levels within their organisation by answering all measurement questions. The ultimate goal is to move these people who make this quick scan to actually ordering the long scan, which has to be paid for and gives a more in depth overview of the maturity levels of the organisation. I agreed to meeting up with Future Industries some time, to discuss the options of putting the multi dimensional smart industry scan on their website. Experts that can put the scan into a working scan on the website of Future Industries will also be attending the meeting to discuss the feasibility of my proposal.

Next to the meeting with Future Industries, a meeting with my supervisor will also be scheduled. Someone from within the University of Twente contacted my supervisor with regards to the maturity model I am making. The maturity model can be used in a minor about Industry 4.0, which she is setting up. In this way the multi dimensional smart industry scan can be used for educational purposes too. A meeting will be scheduled some time to discuss the feasibility of implementing the scan in this minor.

5. DISCUSSION

In this part, the limitations of the research will be discussed. Together with the limitations, the possibilities of future research will also be explained. Moreover, some recommendations will be mentioned for the implementation of the scan. As mentioned before, Future Industries is willing to implement the scan on their website, so these recommendations are quite useful. Lastly, a small conclusion and acknowledgement is provided.

5.1 Limitations and future research

One of the limitations is that the scan doesn't take the industry into account that the user of the scan is in. The industry of the organization of the user can be of influential importance on the weights of the aspects. In some industries, digitizing aspect X, is way more important than the digitization of aspect Y. Subsequently, the average would be measured in a different way and the results could differ. Closely connected to this and already previously mentioned are the weights of the aspects. If organisation X is in industry X, then some aspects should have a different weight and count heavier in order to get the average and subsequently the results right. In my future research I would focus on different industries and weights, so I can get a more reliable result for the user. The same applies for the size of the company, the revenue of the company and the amount of employees in the company. All three are important as well and could influence the reliability of the outcome of the scan.

Secondly, the validation of the multi dimensional smart industry scan on a large scale is missing. The workshop with the experts is the only validation that was done in the progress of making the scan. In my future research I would like to test the model at organisations and get feedback from them in order to improve the scan. Moreover, in the future research I would like to go into more detail about the maturity levels. They are named in this thesis, but in the future I would like to give a detailed explanation of the maturity levels as well. In that case the user will not only see the maturity level which they are in, but can also see a detailed explanation of the maturity level. An explanation of the maturity levels should also give the user more insight into possible improvement steps. This also belongs to the next section: recommendations.

5.2 Recommendations

As previously stated one of the recommendations is the explanation of the maturity levels. For now they are stated as: "poor implementation", "moderate implementation", "advanced implementation", "semi-advanced implementation" and "full implementation" and these are classified into "newcomers", "learners" and "leaders". These levels give a general overview of the industry 4.0 maturity, but there is no detailed explanation of these levels included. It would be great if the user will receive a short explanation of the maturity level that they are in. Next to this, it would fit if the user would receive a plan of action for possible future steps in order to improve their maturity level. Another recommendation is including general questions at the start of the scan to get an overview of the situation that the user is in. Questions related to the size of the organisation, the revenue of the organisation, the amount of employees in the organisation and the industry in which the organisation of the user is active. Subsequently, the weight of different aspects could be constructed according to this knowledge. In this way, different aspects could get different weights according to the knowledge gathered from the general questions. The weights could be constructed by using a 100-point-scale. In this way all aspects get a different amount of points based on the knowledge received from the general questions. Obviously, this will take the importance of the different aspects into account and could make the results more reliable. Lastly, I recommend the different aspects of the scan to have a small explanation in order to make sure that the reader interprets the aspect in the same way as I did. This could slightly improve reliability. The explanations should be something similar as the explanation of the aspects in section 2.3.1: "explanation aspects".

5.3 Conclusion

In this study I wanted to create a multi dimensional smart industry scan on my own. This scan should be based on existing literature on maturity models about industry 4.0 and should be evenly distributed across the positional map in figure 1. First of all, the literature on industry 4.0 and maturity models were selected in order to get a good understanding of the subject. Afterwards, all maturity models related to industry 4.0 from literature were chosen. Then I selected the maturity models based on the formulated criteria. I found four models, including the model from Future Industries. These models had a total of 30 aspects, a large number of measurement questions and different maturity levels. From this information I started to create my own maturity model, in other words: multi dimensional smart industry scan. I came up with seven aspects with five measurement questions each, so 35 questions.

Moreover, I formulated 5 maturity levels and three types of classification. The questions have five possible answers. After answering all questions, the results are shown in a radar chart for the average of all aspects and for the results of the five questions for every aspect individually. The scan was validated during a workshop with experts of Future Industries. During this meeting, the experts of Future Industries told me that they were probably going to use the scan as a quick scan on their website. Moreover, my supervisor proposed to use the scan for educational purposes in a new minor starting in November 2018 about industry 4.0.

5.4 Acknowledgement

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7. APPENDICES

7.1 Appendix 1: Multi dimensional smart industry scan:

Table 6. Multi dimensional smart industry scan

Aspects	Measurement Questions		Answers: (1) Not at all, (2) to some extent, (3) advanced, (4) semi advanced, (5) fully
1. Strategy and organisation	I.	To what extent are industry 4.0 strategies implemented within the organisation	
	II.	To what extent do digital features, products & services contribute to the overall value creation of your organisation?	
	III.	To what extent do you record and tail the implementation status of your industry 4.0 strategies?	
	IV.	To what extent do you use the data gathered for creating value within the organisation?	
	V.	To what extent is innovation essential within the strategic plans of the organisation?	
2. People and organisational culture	I.	To what extent are employees within your organisation up-to-date with the knowledge regarding industry 4.0?	
	II.	To what extent is the management focussing on implementing industry 4.0?	
	III.	To what extent is the communication between management and employees open?	
	IV.	To what extent do employees easily adapt to changes and learn to apply this new knowledge?	
	V.	To what extent is the culture within your organisation capable and willing to carry out the effort to transform the organisation in order to digitalize?	
3. Products and customer services	I.	To what extent are the products offered by your organisation digitized?	
	II.	How would you rate the current implementation of industry 4.0 related to the products in your product portfolio?	
	III.	How would you rate the current implementation of industry 4.0 throughout the phases, which your product goes through?	
	IV.	To what extent do you gather customer feedback for improvements in the future?	
	V.	To what extent does digitization within your organisation help you to satisfy your customers?	
4. Customer interfaces	I.	To what extent do clients use the Internet as a tool to interact with your organisation?	
	II.	To what extent do you use different channels for interaction with your customers?	
	III.	Customer data can be gathered in different ways. To what extent do you use customer data to boost the judgement about your customers?	

	IV.	The customer journey entails the phases, which a customer goes through when communicating with an organisation. To what extent is your customer journey digitized?	
	V.	To which extent does the digitization within your organisation enable you to work together with customers?	
5. Value chain	I.	To what extent does your organisation focus on improving digitization within the value chain?	
	II.	The horizontal value chain entails the chain from customer order, production, logistics, and marketing to service (Michael Porter, 1985). To what extent is your horizontal value chain digitized?	
	III.	To what extent are you already collecting machine data and process data during the production of a product?	
	IV.	To what extent do you experience delays in your value chain?	
	V.	Do you consider the machinery used in the value chain to be digitized?	
6. Technology and IT management	I.	To which extent do your focus on new technologies to actively contribute and empower operations within the business?	
	II.	To which extent is the department that is responsible for the information technologies capable to accomplish business requirements in the requested time, quality and cost?	
	III.	To which extent do you manage the overall requirements from digitization and Industry 4.0 of your Information technologies?	
	IV.	To which extent do you produce value through the use of available technology in your organisation?	
	V.	To what extent is your organisation focussed on technology and using technology in their processes?	
7. Institutional awareness	I.	To what extent can you ensure that your digital compliance policy is state-of-the-art and is mature?	
	II.	To which extent is your intellectual property for your products and services protected?	
	III.	Rules and regulations can be of importance in decision-making. To what extent are you up-to-date with regards to the rules and regulations of the implementation of industry 4.0?	
	IV.	Taxes can be seen as a hidden cost and can bring unforeseen costs. To what extent do you check potential tax impacts when considering new industry 4.0 driven circumstances?	
	V.	The new European privacy legislation (GDPR) gives extended rights to consumers and customers. Some of these can be summarized in Subject Access Requests, namely: the right of information, the right of modification, the right to be forgotten and the right of data portability. To what extent are you able to answer Subject Access Request in an automated way?	

7.2 Appendix 2: IMPULS (2015) – industry 4.0 readiness online self-check for businesses

Table 2. IMPULS (2015) – industry 4.0 readiness online self-check for businesses

Dimensions	Questions	Possible answers
Strategy and organization	I. How would you describe the implementation of your industry 4.0 strategies? II. Do you use indicators to track the implementation status of your industry 4.0 strategies? III. Which technologies do you use in your company? IV. In which parts of your company have you invested in the implementation of industry 4.0 in the past 2 years and what are your plans for the future (next 5 years)? V. In which areas does your company have a systematic technology and innovation management?	i. (1) No strategy exists, (2) pilot initiatives launched, (3) in development, (4) formulated, (5) in implementation and (6) implemented. ii. (1) Yes, (2) a bit and (3) no iii. (1) Sensor technology, (2) Mobile and devices, (3) RFID, (4) Real time location systems, (5) Big data to store and evaluate real-time data, (6) Cloud technologies and scalable IT infrastructure, (7) Embedded IT systems, (8) M2M communications iv. (1) large, (2) medium, (3) small, (4) no investments in named parts of the company v. (1) IT, (2) Production technology, (3) Product development, (4) Services, (5) Centralized in integrative management, (6) Do not have
Smart factory	I. How would you evaluate your equipment infrastructure when it comes to the following functionalities? II. How would you evaluate the adaptability of your equipment infrastructure when it comes to the following functionalities? III. The digitization of factories makes it possible to create a digital model of the factory. Are you already collecting machine and process data during production? IV. Which of the following systems do you use? Does the system have an interface to the leading system?	i. (1) Machines/systems can be controlled through IT, (2) M2M communications, (3) Interoperability ii. (1) M2M communications, (2) Interoperability; integration and collaboration with other machines possible iii. (1) Yes, all, (2) Yes, some, (3) No iv. (1) MES, (2) ERP, (3) PLM, (4) PDM, (5) PPS, (6) PDA, (7) MDC, (8) CAD, (9) SCM
Smart operations	I. Where have you integrated cross-departmental information sharing into your system? Distinguish between enterprise-wide (internal) and cross-enterprise (external) information sharing. II. The vision of Industry 4.0 is a work piece that guides	i. (1) R&D, (2) Production/manufacturing, (3) Purchasing, (4) Logistics, (5) Sales, (6) Finance/accounting, (7) Service, (8) IT, (9) nowhere ii. (1) Yes, cross-enterprise, (2) Yes, but only in selected areas, (3) Yes, but

		itself autonomously through production. Does your company already have use cases in which the work piece guides itself autonomously through production?		only in the test and pilot phase, (4) No
	III.	Does your company have production processes that respond autonomously/automatically in real time to changes in production conditions?	iii.	(1) Yes, cross-enterprise, (2) Yes, but only in selected areas, (3) Yes, but only in the test and pilot phase, (4) No
	IV.	How is your IT organized?	iv.	(1)No in-house IT department, (2) Central IT department, (3) Local IT departments in each area, (4) IT experts attached to each department
	V.	How far along are you with your IT security solutions?	v.	(1) Solution implemented, (2) solution in progress, (3) Solution planned, (4) Not relevant
	VI.	Are you already using cloud services?	vi.	Yes, no but we are planning to and no for (1) cloud-based software, (2) Data analysis, (3) data storage
Smart products	I.	Does your company offer products equipped with the following add-on functionalities based on information and communications technology?	i.	Yes or no for (1) product memory, (2) self-reporting, (3) Integration, (4) Localization, (5) Assistance systems, (6) Monitoring, (7) Object information, (8) automatic identification
Data driven services	I.	The process data gathered in production and in the usage phase enable new services. Do you offer such services?	i.	(1) Yes, and integrated with our customers, (2) Yes, but not integrated with our customers, (3) no
	II.	Do you analyse the data you collect from the usage phase?	ii.	(1) Yes, (2) No, we collect data but don't analyse it, (3) No
Employees	I.	How do you assess the skills of your employees when it comes to the future requirements under Industry 4.0?	i.	Not relevant, Non-existent, Existent, but inadequate and adequate for (1) IT infrastructure, (2) Automation technology, (3) Data analytics, (4) Data security/communications security, (5) Development or application of assistance systems, (6) Collaboration software, (7) Non-technical skills such as systems thinking and process understanding

7.3 Appendix 3: PWC (2016) – Industry 4.0 Self Assessment

Table 3. PWC (2016) – Industry 4.0 Self Assessment

Dimensions	Questions	Possible answers
Business models, product & service portfolio	I. How would you rate the contribution of digital features, products & services to the overall value creation of your portfolio? II. To which degree is the average product in your portfolio digitized (e.g. RFID for identification, sensors, IoT connection, smart products etc.)? III. To which degree can your customers individualize the products they order? IV. To which degree are the life cycle phases of your products digitized (digitization and integration of design, planning, engineering, production, services & recycling)? V. How important is the usage and analysis of data (customer data, product or machine generated data) for your business model? VI. How intense is your collaboration with partners, suppliers and clients for development of products and services?	For all: rate actual (1 to 5) and rate the targeted score from (1 to 5).
Market & Customer access	I. To which extent do you use multiple integrated sales channels to sell your products to your customers? II. How far do you integrate multiple channels (website, blogs, forums, social media platforms etc.) into your customer interactions for communicating news, receiving feedback, managing claims etc.? III. How advanced is the digital enablement of your sales force (mobile devices, access to all relevant system anywhere and anytime, full sales process possible at client site)? IV. How dynamic and customer-tailored is your pricing system (consideration of customer's "willingness to pay")?	For all: rate actual (1 to 5) and rate the targeted score from (1 to 5).

	V. To which extent do you analyze customer data to increase customer insight (e. g. personalized offers to customers based on their personal situation, preferences, location, credit score; consideration of usage data for design & engineering etc.)? VI. How far do you collaborate with partners regarding your approach of accessing customers (exchange of customer insights, coordination of marketing activities etc.)?	
Value chains & Processes	I. How would you rate the degree of the digitization of your vertical value chain (from product development to production)? II. To which extent do you have a real-time view on your production and can dynamically react on changes in demand? III. To which degree do you have an end-to-end IT enabled planning and steering process from sales forecasting, over production to warehouse planning and logistics? IV. How advanced is the digitization of your production equipment (sensors, IoT connection; digital monitoring, control, optimization & automation)? V. How would you rate the degree of digitization of your horizontal value chain (from customer order over supplier, production and logistic to service)?	For all: rate actual (1 to 5) and rate the targeted score from (1 to 5).
IT Architecture	I. To which extent does your IT architecture address the overall requirements from digitization and Industry 4.0? II. To which extent do you use a manufacturing execution system (MES) or similar to control your manufacturing process? III. How mature is your IT & data architecture to gather, aggregate and interpret real-time manufacturing, product and client data? IV. How important are new technologies like social media, mobility, analytics	For all: rate actual (1 to 5) and rate the targeted score from (1 to 5).

	V.	and cloud computing for enabling business operations? To which extent is your IT organization able to fulfil business requirements in the requested time, quality and cost?	
	VI.	How advanced is your IT integration with customers, suppliers and fulfilment partners?	
Compliance, Legal, Risk, Security & Tax	I.	How sophisticated is your digital compliance policy?	For all: rate actual (1 to 5) and rate the targeted score from (1 to 5).
	II.	To which extent can you ensure that intellectual property (IP) for your digital products and services is protected properly and you do not violate external IP?	
	III.	How far does your risk management consider your (digital) product portfolio and production/the factories?	
	IV.	To which extent are digital components of your value chain managed with respect to tax related topics (location of IP etc.)?	
	V.	To which extent is your production considered within your (IT) security concept?	
	VI.	To which degree do you include service partners or customers into your compliance and risk management?	
Organization & Culture	I.	How would you rate your capability to create value from data?	For all: rate actual (1 to 5) and rate the targeted score from (1 to 5).
	II.	How would you rate your capabilities and resources related to Industry 4.0 (e.g. data analytics, IoT, CPS, HMI, production security, digital PLM etc.) in your organization?	
	III.	What level of involvement, support and expertise do executive and senior management have in your organization with regards to Industry 4.0?	
	IV.	To which extent does your organization institutionalize collaboration on Industry 4.0 topics along with external partners such as academia, industry, suppliers or customers?	

7.4 Appendix 4: A. Schumacher et al (2016) – A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises

Table 4. A. Schumacher et al (2016) – A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises

Dimensions	Questions	Answers
Strategy	N.A.	N.A.
Leadership	N.A.	N.A.
Customers	N.A.	N.A.
Products	N.A.	N.A.
Operations	N.A.	N.A.
Culture	N.A.	N.A.
People	N.A.	N.A.
Governance	N.A.	N.A.
Technology	N.A.	N.A.